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Revisiting employment density as a way to detect metropolitan subcentres: an analysis for Barcelona & Madrid.

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Abstract

The changes on metropolitan areas characterized by the dispersion and concentrated decentralization of both employment and population has lead to a specialized research line addressed to analyze polycentrism. In this line there are two families of subcentre identification: the first based on the analysis of density, and other based on the analysis of mobility flows. Huge efforts have been paid, in the first family, to get robust models in statistical terms. Nevertheless, very little attention has been paid to the very object of analysis: employment density. In this paper a different approach to density calculus is proposed, it allows for prioritize, as subcentres, those municipalities that have features close to the urban paradigm of central cities in Southern Europe: have residents, are attractive in labor terms because retain resident employed population, and at the same time, attract commuters; and impact on the overall density function and have functional relations with other municipalities. The efficacy of the proposed density is tested in the metropolitan areas of Barcelona and Madrid. The analysis suggest that the municipalities prioritized as subcentres using this “compound density” excels in modifying both the employment and demographic metropolitan density functions, and are more diverse, concentrate more central activities, and strengthen functional relations with other municipalities in comparison to the results of standard density.

Keywords

Policentrism, new urban economy, metropolitan structure.

1. Polycentrism and methodologies to detect subcentres.

The changes on metropolitan areas characterized by the dispersion and concentrated decentralization (Dematteis, 1998) of both employment and population has lead to a specialized research line addressed to analyze polycentric urban systems. The interest of this topic is obvious because a

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perfect polycentric system would put together two positive aspects of urban systems in the economic arena: the presence of agglomeration economies, and consequently increasing returns for firms; and a potential reduction of transport costs (including time), and consequently a reduction of both salaries and land rent (McMillen y Smith, 2003; McMillen 2003, McDonald, 2009). On the other hand this urban model would have social and environmental benefits produced by an improvement on the transport planning (McMillen, 2001) and a reduction on commuting (Gordon *et al.* 1986) in case of having networks connecting subcentres (McMillen, *Op. Cit.*). Polycentric system put together the benefits of big and medium cities (McMillen y Smith, *Op. Cit.*) by joining the advantages of traditional centralized cities with a decentralized spatial configuration (McMillen, 2003).

Some theoretical approaches have suggested that the emergence of a polycentric structure is produced by a population growth and mobility costs typical of big conurbations. In this way firms gain benefits when decentralize from CBD and relocate in subcentres, such a movement, allow them to get agglomeration economies, and at the same time, reduce mobility costs, salaries and real estate expenditures. McMillen (2003) and McMillen & Smith (2003) have found that in USA the number of subcentres is explained by the population size and transport costs.

One research line in this topic is the subcentre detection, and mainly, the measurement of polycentrism level (Yiu y Tam, 2006). Most of the methodologies have focussed in the subcentres identification, as well as in the analysis and impact of them on the metropolitan function of both population and employment. In the literature there are two families of subcentre identification: the first based on the analysis of density, and other based on the analysis of mobility flows (i.e. residence-to-work place).

1.1 Methods based on the density analysis

The first family based on the analysis of density is fairly the most used, according to McMillen (2001) “a reasonable working definition of a sub-centre is a site (1) with significantly larger employment density than nearby locations that has (2) a significant effect on the overall employment density function”. In this family there are four major methodologies: **1)** The first criterion suggested by McDonald (1987) is based on the identification of employment density “peaks”, McDonald considers that a subcentre is a second crest beyond CBD. This criterion consist in analyze density employment with GIS aid to detect local disruptions; alternatively the ratio employment/population can be used to detect zones that outstands as relative concentrations of economical activity. Gordon, Richardson & Wong (1986) have restricted the number of subcentres only to those zones with high *t-values*; this line has been continued by McDonald & McMillen (1990) and Craig & Ng (2001). **2)** The second approach consists in the use of inferior and superior cutoffs; this line was originally proposed by Giuliano

& Small (1991) who considered as subcentres those contiguous census tracts whose density is above 10 employees per acre, having a total critical mass of 10,000 or more working places. According to McMillen (2001) this latter methodology is interesting since thresholds are supported by the “local knowledge” of researchers (some times it is also a disadvantage), and it allows to make a historical analysis of the subcentre structure. The referents of this method are: Song (1994); Cervero & Wu (1997); McMillen & McDonald (1997); Bogart & Ferry (1999); Anderson & Bogart (2001); Shearmur & Coffey (2002); and Giuliano & Readfearn (2007). In this line Muñiz & García-López (2003) and García-López (2007) has proposed as subcentres those zones having a density above the metropolitan average, and at the same time, at least 1% of metropolitan employment. **3)** From an econometric perspective there is a third methodology which identify as potential subcentres to those zones that have significant residuals in a exponential negative density model. McDonald & Prather (1994) has suggested several models to detect subcentres based on the identification of zones with positive residuals significant at 95% confidence level. **4)** The fourth approximation is based on non-parametric models (e.g.: locally or geographically weighted regression), in order to detect “peaks” adjusting locally (prioritizing the effect of neighboring municipalities on the adjust process) the density function McMillen (2001 y 2002), Craig & Ng, (2001); Readfearn (2006); and Readfearn (2007). The main advantage of this method is that allows for determining local gradients of density reduction across the metropolitan area.

1.2 Methods based on the analysis of functional relations

The second family of methods is based on the understanding that subcentres, not only are zones “abnormally” dense in the metropolitan space, but also structural nodes able to strength the functional relation with their surrounding municipalities. In general the methods based on the analysis of functional interactions have been designed to delimit territorial systems (Nel-lo, 1998), like the Travel To Work Areas in England, the Statistical Metropolitan Areas in USA or the Functional Urban Areas, in particular some of them, have gone in the detection of subcentres that structure such territorial systems. Some referents in this line are in Bourne (1989); Gordon & Richardson (1996); Burns, Moix & Roca (2001); Roca & Moix (2005) and Roca; Marmolejo & Moix (2010).

According to this latter authors, by analyzing the interaction among the municipalities in a metropolitan system, and namely, using the interaction value (originally proposed by Coombes & Openshaw in 1982) it is possible to delimit the most interlinked areas forming a subsystem (in their terminology called proto systems), and it is easy to find the biggest municipality inside which has the most intense relation with the remaining municipalities, finding in this way the subsystem’s subcentre. In this way, the method proposed is a bottom-up

procedure, where firstly the influence area is delimited, and secondly, the point with maximum interaction is detected (i.e. the centre attracting and emitting the biggest proportional residence-work flows).

1.3 Objective, case study and data.

The aim of this research is to propose and evaluate an alternative way to compute employment density, in order to prioritize subcentres that, being employment concentrations with influence on the overall labor and demographic functions, do retain their own resident population; also, these subcentres should have a diversified economical structure. It is to say prioritize municipalities with the paradigmatic characteristics of Mediterranean urban centres, beyond the traditional (north) American² concept of employment subcentre. The rest of the paper is organized as follows: 1) first it is discussed the nature of employment density used in the literature, 2) second an alternative way to compute such a density is proposed, the efficiency of this new approach is tested in two Spanish metropolitan areas; and finally 3) the results and findings are discussed in perspective in the final remarks.

The efficiency of the proposed density is tested, at a municipal level, at the Metropolitan Region of Barcelona³ (MRB). As a proxy of the location of economical activity the working places derived from 2001 Census mobility matrix are used. This data is classified according to 2 digits Spanish Standard Industrial Classification and 1 digit Occupation Classification. Effective (net) urban land is derived from a semi-automatic process of remote sensing using Spot Imagery (see Alhaddad, *et al.* 2006) from year 2000. Distance between municipalities derives from a GIS analysis using effective road networks. Only to validate the conclusions, the analysis is repeated in Metropolitan Madrid (a structurally different metropolitan region). Madrid is basically a monocentric urban system, and Barcelona is slightly more policentric (MMAMB, 1995; ATM 1998; Burns *et al.* 2001 & CPSV, 2001).

² With few exceptions (e.g. Applied Economics Department of the Universitat Autònoma de Barcelona, the Laboratoire d'Analyse et des Techniques Economiques de la Université de Bourgogne and the Centre of Land Policy and Valuations of the Universitat Politècnica de Catalunya, the huge contributions to the subcentre literature come from USA. For that reason the subcentre concept is quite different of the (still) predominant paradigm in Southern Europe.

³ MRB has 164 municipalities in 3,100 Sq.Km, in 2001 had 4.39 million inhabitants and 1.96 million localized work places. For a description of MRB see García-López (2007) for an excellent description of economical structure; Muñiz *et al.* (2003) and Sánchez (1998) for an historical evolution analysis and Marmolejo & Stallbohm, (2008) for an analysis of urban land patterns.

2. Employment density revisited in the paradigm of Mediterranean metropolitan subcentres

As it has been said in the first part, in the field of methods based on density huge efforts have been invested to develop econometric models that progressively have gained robustness. In this context outstands the use of spatial models which allows for considering the geographical interdependencies. From the perspective of thresholds the development has not been quite different, since cutoffs have been modified in order to get results coherent with aprioristic hypothesis of subcentres. Nevertheless the very object of analysis (i.e. employment density) has received little attention, main criticism arises on the “aggregated treatment” of density: this simplification do not allow to distinguish the density generated by the workers that arrive from other zones (in commuters), from that density that is endogenously generated, it is to say, resident population that works in the same place where they live (resident workers). For that reason, using the normal or aggregated density, it is not possible to distinguish those municipalities that are dense because attract commuters and at the same time retain resident workers (mature subcentres with implications on the territorial structure), from those that are “accidentally” dense without having important attraction flows (employment peaks without functional relations with neighboring municipalities), and from those that are dense but are not able to have population or retain resident workers as it is discussed below.

From a urban perspective it would be expectable that subcentres, beyond employment peaks (including those that are dense because import workers), were truly (perhaps modest) alternatives to CBD as it has been suggested by McMillen (2003, p.2) “Large subcenters can look remarkably similar to a traditional central business district (CBD), with thousands of workers employed in a wide variety of industries.”; and McMillen (2001, p.17) “The diversity of business types may be lower than in the city, but large subcenters sometimes appear to mimic the diversity of CBDs”. Besides a metropolitan subcentre should have a given number of features as:

- Diversity in its economical structure, subcentres should be places that reinforce complex networks of cooperation, complementarity and competence (Rueda, 1996, 1998 and 2002). Diversity understood as complexity, it is to say a group of discrete variables with a significant content of information, about its abundance and interactions (Margalef, 1991).
- Concentration of central activities as retailing and office based activities, namely those activities that produce (by means of their market areas) hierarchical relations on the territorial arena (Nel-lo, 1998), activities that

produce territorial linkages based on services and good distribution (Berry, 1958).

- Concentration of economical activity but also residence, being able to retain the working population because of their attractive and employment diversification. Subcentres double attractive as a place to work and live.

As it is evident, such characteristics are consubstantial to the concept of metropolitan subcentre in the paradigm of European Mediterranean metropolises. Which is quite far from the North American urban paradigm (Dematteis, 1998) where have been envisaged the methods to detect subcentres. The gap increases when it is realized that an important part of subcentres in European metropolises are product of functional integration of ancient cities which were originally independents in labor market terms Muñiz *et al.* (2003).

In contraposition, those zones that do not have these features (e.g. a manufacturing industrial area or a suburban office park) cannot be accepted as *metropolitan* subcentres in the paradigm above said, although it should be recognized as simply employment subcentres⁴. As a consequence simply employment concentrations are more closed to the concept of suburban that to the concept of what urban means (Keating, 2001; Duany & Plater-Zyberk, 2000), it is to say are more close to the urbanization without out the capacity to give structural cohesion to the territory. Suburban is what Salvador Rueda (1998, p. 83) has called “A simplified organizational stage with an elevated consume of resources”, a stage with a scarce entropic level. Even the concept of Edge City proposed by Garreau (1991) might be close a what conceptually is *an emergent metropolitan subcentre*⁵: a non central zone, that having more employment than residents, is economically diversified, since it combines qualified office activities, with consume centres, where specialized and sophisticated goods and services (e.g. art galleries) are offered; also it can be reconigzed as a “place” as defined by Silvestro & Roca (2007)⁶. Definitely, the

⁴ Although, as it has been documented by McMillen (2003) for Chicago (1970-2000), the employment subcentres, formerly mono-specialized, as the time goes, have the tendency to evolve towards a more diverse economical structure, approaching to that of the overall metropolitan system.

⁵ Even Garreau considers the existence of Edge Cities coming from the evolution of former independent satellite cities called “uptowns”.

⁶ A metropolitan subcentre should be a place in the philisophical asception of the term. Silvestro & Roca (2007) support, on the previous work of Caturelli, that the home is the place per excellence, and only in a second logical moment are the streets that soruounds it, coming after the neighbourhood, and finally the city. As a consequence place is a space which is inhabited as a expression of the corporeity, and an extension of home. That is the reason because a simply employment concentration cannot and should not be considered as a (sub)centre when it does not offers enough warranties that beyond the labor aspect, can supply the proper spaces for other human activities.

city depends on the existence on qualified simultaneity and meeting “places” (Lefebvre, 1969).

Coming back to the employment density, in the literature is computed dividing total employment (Localized Working Places or LTL by its Spanish initials) by net urban area (without distinguishing the effective land used by firms). By using total employment (LTL) this calculus lost valuable information. A different way to compute density may help to identify veritable subcentres (in the sense discussed before) from simply employment concentrations.

An alternative way to compute density is to analyze separately the density produced by commuters coming from other municipalities (incoming flows IF) from that produced by resident workers (RW) (Aguirre, 2008). Note that the sum of IF and RW are the total employment (LTL). The bigger is IF, in proportional terms, the higher is the capacity of a given municipality to attract workers; and the bigger is RW, in proportional terms, the higher is the capacity of a municipality to retain its occupied workers. From a conceptual framework it is possible to distinguish 3 types of subcentres:

1. Municipalities whose density is basically produced by IF would be those specialized in economical activity, having few or none resident population (e.g. an office park), or possible those municipalities which labor force does not match the profile of firm’s labor demand. It is difficult to consider as a *metropolitan* subcentre this kind of employment subcentres.
2. Municipalities whose density is basically produced by RW would be those with few or null functional linkages with its context, it is to say those autonomous or with a high self-sufficiency⁷ in terms of labor market. Again, it is not possible to consider as a metropolitan suncentre this kind of zones without spatial interactions.
3. Municipalities whose density is produced by a, relatively balanced, combination of IF and RW would be those: *a) enough attractive in residential terms to have population, b) enough attractive in employment terms to retain part of their working population, and at the same time, c) enough diverse to attract workers from elsewhere, it is to say, to employ people with a different professional profile that their own residents*. Those triply attractive municipalities would be close of our concept of Mediterranean metropolitan sub centre.

⁷ Self-sufficiency is the relation between resident workers (RW) and total employment (LTL) as follows

$$As = \frac{RW}{LTL}$$

The bigger is AS, the higher is self-sufficiency.

3. A proposal to compute a “compound density”

Therefore the question is include, in some way, in the analysis of identification of subcentres (based on econometric models) the information that brings the desagregated analysis of density. One alternative way to compute a “compound density” is given in (1):

$$Cd = \frac{RW*IF}{a} \quad (1)$$

As it can be notice, instead of sum the components of total employment –LTL- (i.e. incoming flows –IF- and resident workers –RW-) they are multiplied before to be divided by the urbanized area (Ua). This operation intensifies the density of those zones (e.g. municipalities) that have a balanced composition of IF and RW. Therefore the product is bigger in those zones approaching to equilibrium (case d in table 1). It is to say that are triply attractive since they: q) have population, b) retain part of their working population, and c) attract employees from other zones.

Table 1 Proprieties of compound density.

	FE	RW	LTL	Ua (km2)	Ds
Case \ Algorithm	a	b	. = a+b	c	. = (a*b)/c
a	200	800	1.000	10	160
b	300	700	1.000	10	210
c	400	600	1.000	10	240
d	500	500	1.000	10	250
e	600	400	1.000	10	240
f	700	300	1.000	10	210
g	800	200	1.000	10	160

Source: Own elaboration

In order to test whether this compound density correlates better than normal density with some urban indicators conceptually associated to centrality it has been built table 2 using data from MRB at municipal level. Such indicators are:

- Location coefficient⁸ (LC) of information activities based in offices, considering both qualified (managers, professionals, scientists,

⁸ Location coefficient is calculated as follows
$$LC = \frac{LTLxi}{LTLi} = \frac{\sum_i^n LTLxi}{\sum_{ix}^n LTLxi}$$

intellectuals) and semi-qualified (support technicians and clerks). As well the LC of sales assistants and providers of personal services (as a proxy for retail and services oriented to population), and qualified manufacturing. LCs have been computed using data from employment classified according to Spanish Standard Industrial Classification (CNAE –Spanish initials) and National Occupational Classification as it has been suggested by Marmolejo & Roca (2008). It is expected to find central municipalities specialized both in managerial activities and retail. The diversity index⁹ using 2001 Census data of employment classified in 2 digits of CNAE. It is expectable that municipalities that exert centrality functions were diversified.

- Self-sufficiency and self-containment computed using data from residence-work data (from 2001 Census)¹⁰. If a given municipality maximizes both indicators would be autarchic in terms of labor market (i.e. all the residents would live and work in the same municipality and all firm's labor force would be locally supplied).
- The integrated Interaction value¹¹ (built from the interaction value of Coombes & Openshaw, 1982) between each municipality and the remaining municipalities of metropolitan system, using the same data that the other indicators. The bigger is this indicator, the stronger is the reflexive linkage between this municipality and the rest of the metropolis.

Where LTL is employment localized, x is a given industry of economical activity and i is a given municipality of the metropolitan system.

⁹ It has been used the Shannon index: $H = -\sum_{i=1}^n Ln(P_i x) * P_i(x)$, where $P_i(x)$ is the probability to find a x element (i.e.: employment in a given industry) in municipality i . The sum is multiplied by -1 in order to get a positive indicator. Therefore the bigger is H , the higher the diversity.

¹⁰ Self-containment is the ration between resident workers (RW) and resident employed population (REP)

$$Sc = \frac{RW}{REP}$$

¹¹ The integrated interaction value is calculated as follows:

$$SumVI_i = \sum_{j=1}^n \left(\frac{F_{ij}}{REP_i LTL_j} \right) + \left(\frac{F_{ji}}{REP_j LTL_i} \right)$$

Where $Sum VI_i$ is the sum of interaction value between a i given municipality and all j others; F are the residence-to-work journeys, REP is the resident employed population and LTL is the total localized employment.

Table 2: Partial correlations between compound and normal density with selected urban indexes.

	LC Qualified information activities	LC Semi-qualified activities of information	LC Retail employees	CL Qualified industry activities	Diversity Index of LTL	Self-sufficiency	Self-containment	Interaction Value
Ln normal density	0,02	0,10	0,05	0,05	0,07	0,54	0,04	0,40
Sig. (2-tailed)	0,78	0,22	0,56	0,54	0,36	0,00	0,66	0,00
Ln composed density	0,06	0,21	0,03	0,15	0,32	0,68	0,03	0,53
Sig. (2-tailed)	0,46	0,01	0,73	0,07	0,00	0,00	0,74	0,00

Source: own elaboration

Note: the control variable is the distance to Barcelona.

As it can be observed (Table 2) “compound density” is more correlated, in comparison to traditional density, with: 1) information activities, 2) retail, 3) diversity of economical activity, 4) self-sufficiency, and 5) interaction value (although the correlations are significant only in 4 cases). Therefore, compound density, after controlling the distance to CBD, tends to be more correlated with the indicators coherent with our conceptual definition on *metropolitan* subcentre. Nonetheless, it is necessary to test the performance of compound density in the subcentre identification using traditional econometric models. Following the most used models in literature¹², the subsequent functional expressions have been used, and they derive from the linearization of the classical negative exponential model:

$$LnD = C + B_1 Dist_{CBD} \quad (2)$$

$$LnD = C + B_1 Dist_{CBD} + B_2 Dist_{CBD}^2 \quad (3)$$

$$LnD = C + B_1 Dist_{CBD} + \frac{B_2}{Dist_{CBD}} \quad (4)$$

Table 3 contains the results of apply the aforementioned expressions using both normal and compound density for MRB data. It can be observed that models fit better to the compound density, since R^2 and the Anova's F statistics have a significant increase. In all the models have the expect sign: i.e. the bigger is the distance to CBD, the lower is the density. The semilog functions allows for measure the semi-elasticity of density when distance to CBD increases, therefore the coefficient of this latter covariable is the density gradient reduction in percent terms (i.e.: the density % reduction for each Km.). For that reason urban economist consider that such a gradient can be used as a indicator of

¹² According to Greene & Barnbrock (1978), as early as 1892 the negative exponential function was used by H. Bleicher to explain the distribution of population in Frankfurt.

urban dispersion, the lower is the gradient, the bigger the metropolitan sprawl (McMillen, 2001; Muñiz *et al.*, 2003)¹³.

Note that in functional expression (3) the positive sign of coefficient β_2 (squared of distance to CBD) is representative of the influence on the model's fit that have dense municipalities (potential subcentres) located at periphery of MRB as Vilanova and Vilafranca (47,64 Km and 48,51 Km respectively) and, in a less degree, the influence of Pineda and Sant Celoni (54,90 Km and 50,72 Km respectively). Also in functional expression (4) the positive sign of B_2 is what was expected and representative of the direct relation between employment density and proximity to CBD.

While models calibrated following functional expressions (3) and (4) has a higher determination coefficient than the classical model (2), do not suffice the classical assumptions of this kind of econometric models in terms of homocedasticity and multicollineality according to Park test and to the variance inflation factor (VIF). Consequently the attention should be focused on results of model (2). According to this latter model, normal density decreases 3% for each Km from CBD; and 10% for compound density (this bigger coefficient is coherent with the multiplicative nature of this latter density, see (1)).

As it has seen the model (2) fit best the compound density, nonetheless it is necessary to test if the prioritized municipalities as potential subcentres (i.e.: those municipalities with the higher positive residuals) using this model excels the model that uses normal density. In the literature a usual way to validate the municipalities or zones candidates to subcentre is to test whether or not they modify the overall metropolitan density function after having controlled the distance to CBD. This evaluation follows the second condition for a subcentre suggested by McMillen (2001) "sub-centre is a site (1) with significantly larger employment density than nearby locations that has (2) a significant effect on the overall employment density function". However the effect should reach not only the employment density function, but also the residential density as well as the land rent and the mobility patters (McDonald, 1987).

¹³ Although to compare sprawl between different metropolises the scale has to be previously normalized.

Table 3 Models with normal density and composed fewer than three functional expressions in Barcelona metropolitan region.

	Ln normal density	Ln compound density	Ln normal density	Ln compound density	Ln normal density	Ln compound density
	.(2)	.(2)	.(3)	.(3)	.(4)	.(4)
R ² adjusted	0.26	0.37	0.31	0.40	0.31	0.41
F	57.81	92.69	36.94	54.06	36.27	56.16
F (sig)	0	0	0	0	0	0
Constant	8.15	16.71	9.14	18.93	7.18	14.19
Dist. Bcn (B ₁)	-0.03	-0.10	-0.10	-0.25	-0.02	-0.06
Dist. Bcn (sig)	0	0	0	0	0.001	0
Dist. Bcn ² (B ₂)			0	0		
Dist. Bcn ² (sig)			0	0		
1/Dist. Bcn (B ₂)					10.97	28.44
1/Dist. Bcn (sig)					0	0
Park test						
(sig. B ₁)	0.76	0.40	0.09	0.36	0.06	0.57
VIF MAX			23.13	22.87	22.83	2.28

Source: Own elaboration

From the perspective of the employment density analysis this second stage involves the introduction a new covariable containing the distance to nearest subcentre, as follows¹⁴:

$$LnD = C + B_1 Dist_{CBD} + \frac{B_2}{Dist_{subC}} \quad (5)$$

¹⁴ Please note that by introducing the inverse of distance to nearest subcentre, the multicollineality problems are reduced. However, this expression assume the hypothesis that the effect exert by subcentres over the overall density function is lower than the effect of CBD, so assuming that the effect of subcentres is more localized in contraposition to a more generalized effect of CBD as it has been suggested by McMillen (2003), McMillen (2004) and García-López (2008). An alternative way to resolve this issue is using factorial analysis to reduce the metropolitan geometry to a non-correlated n-space.

It is important to note that the number of potential subcentres has been established in 13. These numbers correspond to municipalities having residuals superior to average+1 sd. Table 4 summarizes the results, both (polycentric) models have a better fit than the previous (monocentric) models, while the subcentres detected via the compound model excel the other. *This may suggest that municipalities that are prioritized by means of compound density are, as a group, more efficient in the explanation of overall metropolitan employment density than those prioritized by means of normal density.* The sign of the coefficients is what was expected and there are not serious problems of both heteroscedasticity and multicollinearity.

Therefore, as it has been shown, compound density seems to prioritize those municipalities with major influence on the overall metropolitan employment density. Nonetheless, in the bid rent theory (Alonso, 1964; Muth, 1969; Mills, 1972), the tradeoff is between distance to the CBD (where economical activity epitomizes) and residential density not employment density (McMillen, 2003). It is important to note that employment concentrations do not only mean employment opportunities, but also, centres where services and products are distributed, so on, they should have a double influence on residential density since residential urban fabrics contain both potential employees and consumers. For that reason it is necessary to check whether residential density is influenced by employment subcentres previously prioritized. It is important to distinguish two kinds of demographic density: 1) the total population density and, 2) the effective resident employed population (REP). This distinction is not futile since analyses derived from residential mobility data (Statistic of Residential Variations coming from the citizens register –in Spanish Padrón Municipal-) reveals that household's locative decisions depend on the age of their integrants, and consequently on the probability to be employed. So, it is expectable that potential employed people's residence is more dependent to location of employment.

In Table 5 the results of polycentric models are summarized. First of all, in both approaches (normal and compound density) employment subcentres are able (as expected) to explain better the spatial distribution of resident employed population than total population. All the models are statistically significant and meet the requirements of OLS calibration. What is important is that municipalities prioritized as subcentres by means of compound density excel on the explanation of the overall density function of both REP and total population. In all models the density gradient that represents the density decay when distance to CBD increases is constant (-0.03). Furthermore the density gradient is higher in the case of subcentres detected using compound density than from those prioritized using normal density (*1.87 in relation to 0.36 and 1.79 in relation to 0.34 respectively*), therefore compound density outscore results of normal density by prioritizing municipalities as subcentres having a bigger impact on metropolitan density function. On the other hand the best

model of demographic density ($r^2= 0.38$) is quite less adjusted than the best model of employment density ($r^2= 0.56$), this may support the hypothesis that firms location is more conditioned by agglomeration economies than residential location as it has been discussed by Gordon *et al.* (1986). Particularly in the case of qualified knowledge intensive services more represented in the case of Barcelona in CBD, subcentres and surrounding municipalities (Marmolejo & Roca 2008, Pérez & Marmolejo 2008). These latter activities, albeit use intensively TICs as way of interaction, still require face-to-face contacts in their productive process (McMillen, 2001; Marmolejo & Roca, 2006).

Table 4 Influence of the potential subcentres on the overall employment density in Barcelona metropolitan region.

	Ln normal density	Ln composed density	Municipalities prioritized according to normal density	Municipalities prioritized according to compound density
	.(5)	.(5)		
R ² adjusted	0.31	0.56	Vilafranca del Penedès	Barcelona
F	36.88	102.6	Mataró	Vilafranca del Penedès
F (sig)	0	0	Calella	Vilanova i la Geltrú
			Malgrat de Mar	Mataró
			Granollers	Malgrat de Mar
			Barcelona	Sabadell
Constant	8.15	16.24	Vilanova i la Geltrú	Granollers
			Pineda de Mar	Pineda de Mar
Dist. Bcn (B ₁)	-0.04	-0.12	Sabadell	Calella
Dist. Bcn (sig)	0	0	Sant Martí Sarroca	Terrassa
			Puigdàlber	Tordera
1/Dist.sub (B ₂)	0.37	7.21	Sant Sadurní d'Anoia	Sant Celoni
1/Dist. sub (sig)	0	0	Martorell	Martorell
Park test				
(sig. B ₁)	0.58	0.39		
VIF MAX	1.02	1.05		

Source: Own elaboration

Note: Municipalities are sorted in descending order according to the residuals of model (2) and only 13 were selected (equivalent to the municipal residuals in exceeding is 1 standard deviation)

Table 5 Influence of the potential subcentres on the overall demographic density in Barcelona metropolitan region.

	Ln total population density		Ln employed population density	
	Subcentres detected with normal density	Subcentres detected with compound density	Subcentres detected with normal density	Subcentres detected with compound density
R ² adjusted	0.30	0.35	0.33	0.38
F	35.91	44.26	40.87	50.19
F (sig)	0	0	0	0
Constant	9.09	8.96	8.27	8.15
Dist. Bcn (B ₁)	-0.03	-0.03	-0.03	-0.034
Dist. Bcn (sig)	0	0	0	0
1/Dist.sub (B ₂)	0.36	1.87	0.34	1.79
1/Dist. sub (sig)	0	0	0	0
(sig. B ₁)	0.65	0.91	0.34	0.8
VIF MAX	1.02	1.05	1.02	1.05

Source: Own elaboration

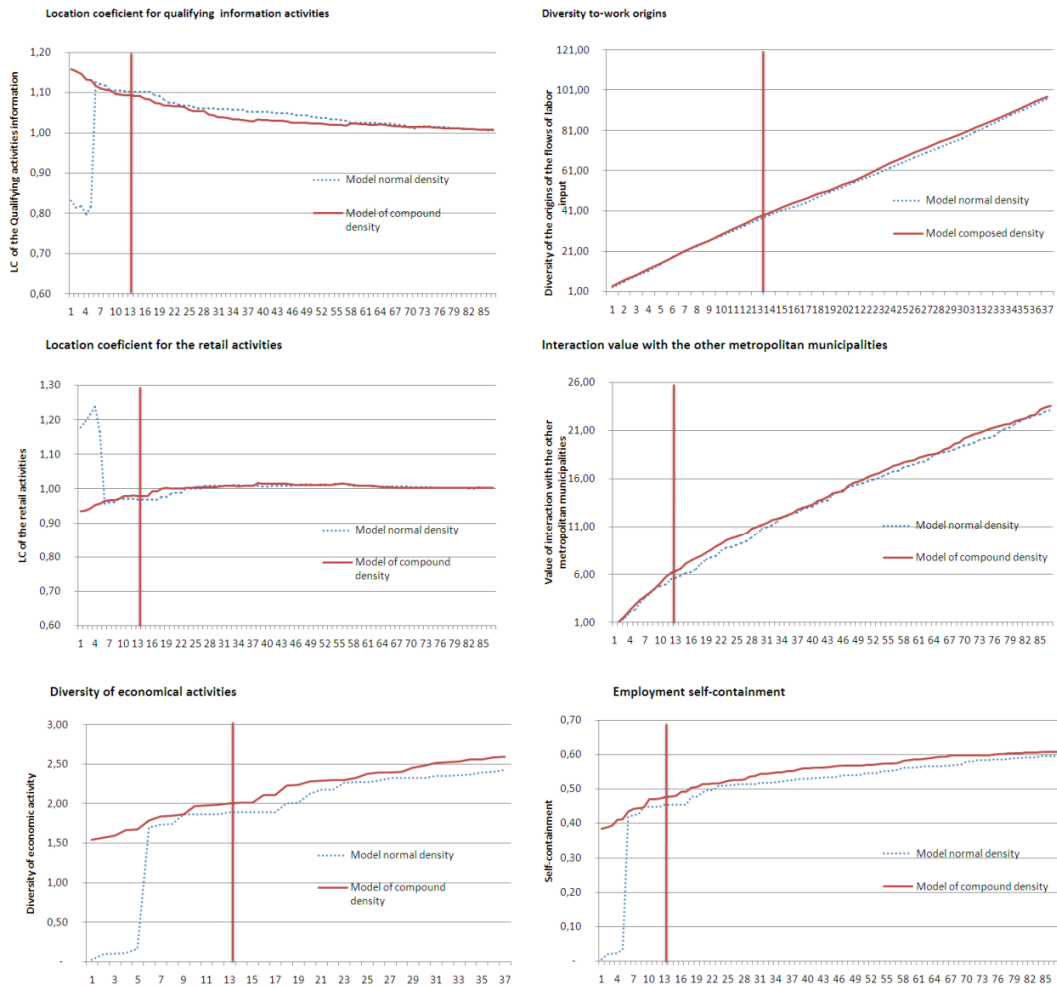
Note: The first 13 municipalities with highest positive residuals where selected as potential subcentres

As it has been shown the compound density results suggest that compound density improves the process of subcentre identification by selecting, using standard econometric functions, those municipalities that better explain the spatial distribution of both economic activity and population. Albeit it is still necessary to test whether identified municipalities meet the conceptual requirements of central cities in the framework of the Southern Mediterranean paradigm. For this reason a continuous evaluation (using different urban indicators) of municipality prioritization as subcentres has been performed. Results are contained in Figure 2, for each graphic in the X axis the municipalities have been ranked in decreasing order according to their residuals (using model 2); the blue-dashed line represents the model built using standard density and the red-continuous line represents the model built on compound density (please note that for the same x point there are different municipalities since each municipalities has different relative residuals derived from both density analysis). In the Y axis it is represented the cumulative value of the following urban indicators:

- Location coefficients (LC) of both, qualified information activities and retail. When $LC > 1$ then the municipality is specialized in such activities.

- Diversity index, the bigger is this index, the higher is the complexity of economical activity
- Diversity of residence-to-work origins, the bigger this index, the higher the quantity of municipalities with functional relations with a given municipality.
- Integrated interaction value between a given municipality and the remaining metropolitan subcentres: the bigger is this index, the highest the functional relation between this municipality and the whole metropolitan system.
- Self-containment, the bigger is this index, the higher the capacity to retain resident employed people on firms localized in a give municipality.

**Figure 1: Continues evaluation of potential subcentres
(Blue dashed=Normal density; Continued-red=Compound density)**



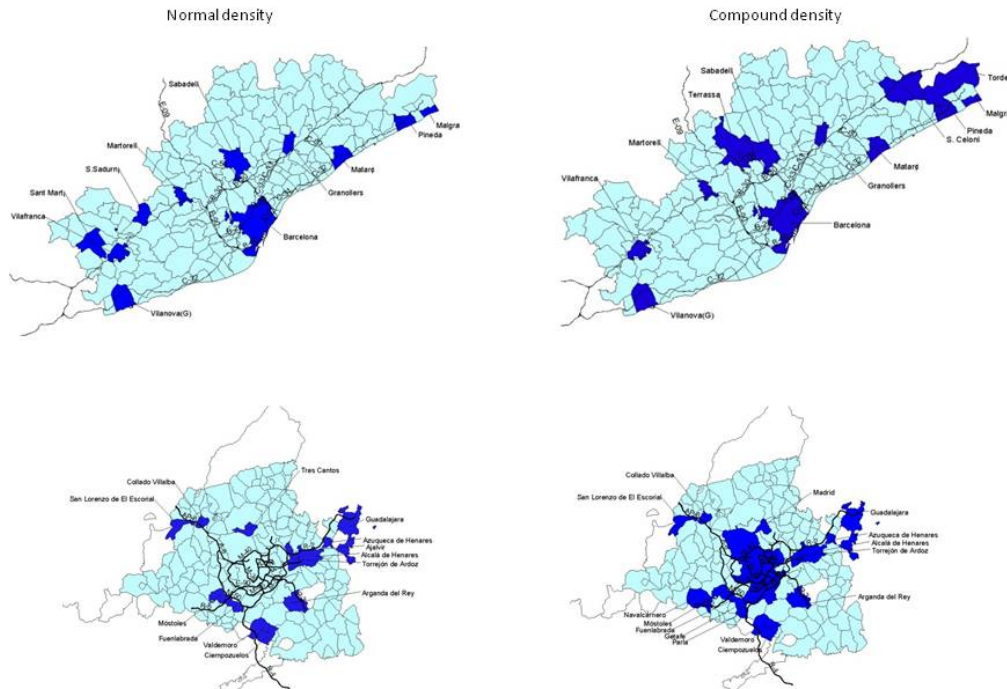
Source: own elaboration
Note: The red vertical line defines the first 13 municipalities

As observed, only with the exception of the CL of information activities, according to the rest of the indicators the compound density seems to prioritize those municipalities that are: 1) more specialized in retail activities, 2) more

diverse in terms of economical structure, 3) more linked with the rest of the metropolitan system according to the intensity and complexity of linkages, 4) that have a higher attractive to retain resident employed population. This prioritization is evident when a cutoff is posed in the first 13 municipalities (which correspond to those with positive residuals above 1sd using normal density and model 2).

Finally, only with the aim to verify the conclusions extracted for Barcelona the analyses have been repeated in Madrid Metropolitan Area (MMA)¹⁵, this latter system is structurally different since the level of polycentrism is lower than in Barcelona. Nevertheless as it has been suggested by McMillen & Smith (2003; p 336) “developing the necessary cross-sectional data set is difficult because most subcenter identification procedures require a great deal of local knowledge to produce reasonable results”.

Figure 2: First 13 municipalities prioritized as possible subcentres to the different densities in the Barcelona an Madrid metropolitan region.



Source: Own elaboration.

¹⁵ The metropolitan system of Madrid is different according to the delimitation methodology used. According to NUREC in 1996 it had 14 municipalities in 1,185 SqKm, on the other hand, GEMACA (1996) suggests that in 1996 had 136 municipalities in an extension of 6,239 km². In this research, only with the aim aforementioned, the delimitation of GEMACA (1996) has been used plus 4 municipalities from the Guadalajara's province which are clearly metropolitan in physical and functional terms: Alovera, Azuqueca de Henares, Guadalajara y Cabanillas

Table 6 reports the results of the policentric¹⁶ model for MMA, as it can be seen, as in the Barcelona case; in Madrid the compound density also prioritize the municipalities with higher capacity to give structure to the overall function of employment density. Again, the results of Table 7 suggest that municipalities prioritized as potential subcentres using compound density has a bigger explanatory power in the metropolitan distribution of population, specially again on the effectively employed population, in comparison with those municipalities prioritized by normal density. Hence the analyses in Madrid coincide with those for Barcelona's Metropolitan Region.

Table 6 : Influence of the candidates potential subcentres on the overall employment density, in the Madrid metropolitan area

	Ln normal density .(5)	Ln compound density .(5)	Municipalities prioritized according to normal density	Municipalities prioritized according to compound density
			Guadalajara	Guadalajara
R ² adjusted	0,473	0,637	Torrejón	Alcalá
F	63.398	122.783	Arganda	S.Lorenzo
F (sig)	0	0	S.Lorenzo	Collado
			Ajalvir	Azuqueca(Hen)
			Alcalá	Madrid
Constant	7.79	16.91	Collado	Arganda
			Valdemoro	Fuenlabrada
Dist. Bcn (B ₁)	-0.038	-0.141	Ciempozuelos	Valdemoro
Dist. Bcn (sig)	0	0	Azuqueca(Hen)	Móstoles
			Fuenlabrada	Torrejón
1/Dist.sub (B ₂)	1.4636	5.72	Tres	Getafe
1/Dist. sub (sig)	0	0	Móstoles	Ciempozuelos
Park test	0.549	0.083		
(sig. B ₁)				
VIF MAX	1.037	1.037		

Source: Own elaboration

Note: Municipalities are sorted in descending order according to the residuals of model and only 13 were selected (equivalent to the municipal residuals in exceeding is 1 standard deviation)

¹⁶ The number of subcentres has been remained, as well as in Barcelona's system, in 13 to control the differences that may emerge produced by the inclusion of a different number of potential subcentres. Ultimately, the aim of this paper is not to discuss the exact number of subcentres in Madrid's system, but the efficiency of compound density.

Therefore, the distinction between municipalities that are dense because they attract work-commuters and, at the same time, retain part of their own employed population is not futile. Consequently a compound density built on the distinction of incoming flows and resident workers allows for prioritizing those municipalities that are close to the concept of central city in the (still-valid) paradigm of Mediterranean metropolises in Europe.

Table 7 Influence of the potential subcentres on the overall demographic density in Madrid metropolitan area.

	Ln total population density		Ln employed population density	
	Subcentres detected with normal density	Subcentres detected with composed density	Subcentres detected with normal density	Subcentres detected with composed density
R ² adjusted	0.304	0.363	0.381	0.43
F	31.299	40.659	43.835	53.536
F (sig)	-	-	-	-
Constant	8.719	8.622	8.013	7.949
Dist. Bcn (B ₁)	-0.03	-0.03	-0.033	-0.032
Dist. Bcn (sig)	0	0	0	0
1/Dist.sub (B ₂)	0.75	1.38	0.75	1.32
1/Dist. sub (sig)	0	0	0	0
Park test (sig. B ₁)	0.711	0.377	0.895	0.301
VIF MAX	1.038	1.038	1.038	1.041

Source: Own elaboration

Note: The first 13 municipalities with highest positive residuals were selected as potential subcentres

Conclusions.

One of the more plethoric research fields in the analysis of metropolitan structures is the identification of employment subcentres. Two research lines have clearly emerged: those based on the analysis of employment density (i.e. work places/urbanized area); and those based on the analysis of functional relations (residence-to-work commuter flows). Notably the first line has been the most used. So, the method based on density analysis has progressively gained complexity, by introducing new statistical approaches that have allowed for the consideration of spatial interdependences.

Nonetheless, in the literature few or null attention has been paid to the very analysis object: employment density. The aggregated treatment of the numerator (total number of employees), in the calculus of normal density, does

not allow for considering the density produced by incoming commuters coming for other zones (e.g. municipalities) from that endogenously generated as a consequence of resident employed population that decide to work in the same zone. That is the reason because, the classical density work, does not allow for identify those zones triply attractive: 1) given that they have residents, 2) since they are in labor terms enough attractive to retain part of this employed population, and 3) because they are enough attractive (e.g. economically diversified) to attract workers from other metropolitan municipalities. In the urban paradigm of Mediterranean central cities it would be acceptable to recognize as metropolitan subcentres to those zones that being adequately dense: have, retain, and attract employed population. Of course there a some exceptions as office or manufacturing parks that being employment concentrations do not have residents, these zones cannot be considered as (sub) central cities in the abovementioned conceptual urban framework.

Daniel McMillen (2001) has recognized that although a (employment) subcentre is a place that has a significant superior density that neighboring zones, and has an influence on the overall density, also “Large subcenters can look remarkably similar to a traditional central business district (CBD), with thousands of workers employed in a wide variety of industries” (McMillen 2003, p. 2). Furthermore, in the (still) valid Mediterranean framework subcentres should be characterized by: 1) have a complex economical structure, 2) concentrate activities with capacity, by means of their spatial markets, to give hierarchy to the territory, and 3) concentrate, beyond economic activity, residence. Thus, necessary conditions to meet the aforementioned triple attractive.

An alternative way to re(consider) the density is by differentiating in the numerator the incoming flows of employment (IF) from those retained (resident workers RW). So this compound density is computed as follows: $Cd = IF * RW * Ua^{-1}$ (being Ua the effective urbanized area). The multiplicative effect of the numerator allows for prioritize those zones that have a kind of equilibrium between IF and RW, thus has the advantage to stand out those municipalities triply attractive.

This compound density has been tested in the context of the Metropolitan Region of Barcelona (MRB) which has been said as one of the most polycentric urban systems in Spain. Namely this test has consisted in contrast the results of compound density with those of normal or traditional density in a standard semi-log model addressed to detect subcentres by means of the analysis of positive residuals. The comparison of results suggests that municipalities prioritized as potential subcentres using the compound densities have: 1) a major potential to explain, together with the CBD, the overall employment density function ($R^2=0.56$ in comparison to $R^2=0.31$ derived from traditional density); 2) the same about the overall demography function ($R^2=0.35$ in relation to $R^2=0.30$ for total population, and $R^2=0.38$ in relation to $R^2=0,33$ for effectively employed

population); 4) a major impact on the density gradient of neighboring zones according to coefficient B of distance to nearest subcentre; 5) a higher specialization in retail activities; 8) a stronger functional linkage with the remaining metropolitan municipalities; and 9) a major potential to retain to their employed residents.

Only to ratify the aforementioned conclusions the analyses have been repeated in a structurally different metropolitan area: Madrid. Unlike Barcelona Madrid has a more monocentric structure. The results seems to reinforce the general conclusions for Barcelona's system: again the model fits better when compound employment density is used, and prioritized municipalities have more explaining power over the metropolitan density function of both employment and population.

In this way, the disaggregation of the essential components of employment density, seems to reveal significant information in the subcentre detection process. Stressing those that, being important employment concentration, do comprise the (still) paradigmatic features of central cities in Southern European Cities.

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