CARLOS MARMOLEJO DURATE*, MORIA TORNÉS FERNÁNDEZ**

DO EMPLOYMENT SUBCENTERS STRUCTURE MOBILITY PATTERNS AND LAND CONSUMPTION? A GLOBAL ANALYSIS FOR THE MAIN METROPOLITAN AREAS IN SPAIN

CZY SUBCENTRA ZATRUDNIENIA TWORZĄ STRUKTURĘ WZORCÓW MOBILNOŚCI ORAZ ZUŻYCIA TERENU? GLOBALNA ANALIZA GŁÓWNYCH OBSZARÓW METROPOLITALNYCH W HISZPANII

Abstract

Subcentres are dense concentrations of employment and services that appear across contemporary metropolitan areas, the resulting urban pattern is called polycentric. Polycentrism has become the keystone in a major number of regional and urban policies, since it has been seen as a sustainable and equilibrated urban model. In this paper, using as case study the biggest metropolitan areas in Spain we test whether employment subcentres effectively structure mobility patterns around them, and at the same time whether polycentric urban patterns reduce land consumed around subcentres. For this reason we use effective urbanised area and travel to work mobility matrix to assess whether polycentrism increases the efficiency of urbanisation. The results suggest that effectively employment subcentres do structure travel to work patterns, reducing urban mobility, and consequently being structural places. Nevertheless, from the perspective of land consumption little effect is detected after controlling other urban factors affecting this vector such as orography and urban fabric fragmentation.

Keywords: *nvironmental sustainability, polycentrism, land consumption, excess commuting, Spain*

Streszczenie

Subcentra oznaczają zagęszczenie miejsc zatrudnienia oraz usług występujących na terenie współczesnych metropolii. Wynikający z niego wzorzec urbani-styczny nazywamy policentrycznym. Policentryzm stał się podstawą licznych strategii regionalnych i miejskich, będąc postrzegany jako zrównoważony model urbanistyczny. W niniejszym artykule, przedstawiającym studium przypadku największych obszarów metropolitalnych w Hiszpanii, zamierzamy ustalić, czy subcentra zatrudnienia skutecznie tworzą wokół siebie strukturę wzorców mobilności, a także czy policentryczne wzorce urbanistyczne ograniczają zużycie terenu wokół tych subcentrów. Efektywny obszar miejski oraz matrycę mobilności pracy wykorzystujemy tu, by ocenić, czy policentryzm zwiększa wydajność urbanizacji. Wyniki badań wskazują, że efektywne subcentra zatrudnienia w istocie tworzą strukturę wzorców dojazdu do pracy, zmniejszając mobilność w mie-ście i stając się miejscami o charakterze strukturalnym. Niemniej jednak po skontrolowaniu innych czynników miejskich wywierających wpływ w tym zakresie, takie jak orografia czy fragmentaryzacja tkanki miejskiej, nie stwierdzono znacznych skutków w zakresie zużycia terenu

Słowa kluczowe: *zrównoważenie środowiskowe, policentryzm, zużycie terenu, dojazd do pracy, Hiszpania*

* Carlos Marmolejo Durate, Associate Professor, Centre for Land Policy and Valuations, ETSAB, UPC.

** Ph.D. candidate Moria Tornés Fernández, Centre for Land Policy and Valuations, ETSAB, UPC.

1. Introduction: the emergence of polynucleated landscapes

The spatial arrangement of population and employment is an important issue in contemporary metropolises, particularly in front of the emergence of sprawl and unstructured urban growth, which comprises high risk of environmental damage.

From a social point of view separating employment and residence results into prejudicial consequences for social groups of limited mobility; from an economical point of view distancing firms means losing the opportunity to take advantage of external economies and from an environmental point of view scatteration results in excessive land consumption and environmental costly transport systems. In Spain this latter topic has become especially relevant in the course of the last 15 years, a period in which the real estate sector has produced several times the actual demand for housing, most of the times following a high land consumption scheme. Such a concern has clearly trespassed the national jurisdiction as it is reflected in the Auken Report for European Parliament concerning the impact of extensive urbanisation and environmental menaces particularly in coastal zones [4].

Politicians, especially in Europe, have seen polycentric development as an alternative model to dispersion allegedly leading to cohesion, competitiveness and sustainability [26]; although, the empirical basis of such benefits is still weak and in some cases is contradictory [6]. In such a way, it has been said that polycentricity has much of normative rather than analytical [15]. Our main goal is to explore to what extend subcentres do have an impact on neighbouring densities, reducing in this way the land consumed by urban activities, and thus shed light on the environmental sustainability of polycentricity in the regional context of the metropolises analysed. This objective is aligned with Muñiz, et *al*. statement "The importance of polycentrism lies not only in the possibility of concentrating jobs in a limited number of areas under conditions of high density, but also in its capacity to structure and hierarchize urban growth as compared with a dispersed model, amorphous and destructured, without anchorages" [30, p. 628].

Although the concept of polycentrism remains highly fuzzy two distinguishable features may be observed: the first is related to the scale of analysis and the second to the conceptualization of subcentres and their influence on their hinterland. In the first, the scales may vary from continental to intrametropolitan scale passing thought a regional scale in between [19]. In the second subcentres may be analyzed in a morphological or functional way. In this paper the attention is focused in the intrametropolitan scale and necessarily, although not directly, following a morphological approach. From this junction the rise of polycentrism is rather a contrasting that the decentralisation of central cities of the last two centuries has taken a more polycentric *form* at the time that employment subcentres appear on peripheries [3]. In such a way the formerly low density and monofunctional suburbia has become in a more complex post-suburbia having dense multifunctional employment and housing concentrations on the edge of cities [7].

Using GIS and Teledetection tools we test whether the hypothesis that polycentric urban growth may leads to a more sustainable urban model by reducing the per capita land consumption and journey-to-work trips. For this we use the seven biggest metropolitan areas in Spain. The remaining of the paper is structured as follows:

1) first the theoretic framework on land consumption/density gradients as well as trip generation are presented,
2) after the previous empirical evidence of these issues is reviewed,
3) methodology used in the paper is presented,
4) results are discussed and
5) a general review of the main findings is summarized in the conclusive epigraph.

2. Why polycentrism may impact on land consumption and travel to work journeys?

At the first glance it seems evident that a metropolis that growths by the creation of subcentres is more compact than one that grows by expulsing households and firms to a rapidly expanding sprawl. Nonetheless compacity in a polycentric framework does not only come from the subcentres itself, but mainly from the influence exerted over the neighbouring locations.

The standard urban model as shaped by Alonso (1964), Muth (1969) and Mills (1967) with roots in the pioneering work of Thünen and Laundhardt is the theoretical framework behind the formation of urban densities. This model, originally conceived for a monocentric city, explains that in achieving locational equilibrium households bid for land according to costs saved in commuting. Thus the closer the place of residence to the CBD (where all employment is supposed to be located) the higher the rent transferred to land (which capitalises into higher prices), resulting in a land rent gradient. It is the existence of land rent gradients that underlie the formation of density in a competitive market scenario. If it is considered that house builders invest capital in land and building when developing a site, and constant returns per unit of land are relaxed (i.e. once substitution between land and building cost is allowed), real estate developers economise on the use of land in more central locations where prices peak. In optimising developments they add more building capital per unit of capital invested on land, i.e. they build multi-storey structures instead of low rise ones, resulting in a density gradient following that of land prices. The parallelism between rent and density gradients depends upon the elasticity of substitution between land and capital [18].

Mills and Hamilton (1984) demonstrated, starting from the monocentric city model, that under certain constraints, such as Cobb-Douglas's production function for housing, users with identical tastes and income and unit price elasticity of demand for housing, density gradients adopt a negative exponential function. According to McDonald's excellent review (1989) it was Stewart (1947) who apparently first empirically used the negative exponential function to test whether population densities decrease with the distance to the CBD; although McDonald notes that it was Clark (1951) who popularised such a function amongst scholars.

In the case of employment density, the negative exponential form is derived by Mills (1969) by assuming that the production functions for product and transportation have also a Cobb-Douglas form, and that the demand for product has constant price elasticity; in this case density decreases as we move further away from the CBD because the access to the agglomeration economies generated there is limited by distance.

On the other hand the urban form (i.e. the spatial distribution of employment and population) should influence commuting patterns. So, in a polycentric framework job places are concentrated in several focal points across the city, thus workers have more opportunities for searching a job place near home. Consequently, *ceteris paribus*, in a polycentric metropolis travel to work journeys should be shorter than those produced in a monocentric system where all workers must commute to the unique employment centre in city.

3. Literature review

3.1. Polycentrism and land consumption

Although the seminal empirical work of Griffith (1981) found not significant effects on population density produced by secondary employment centres in Toronto, it laid the path followed for other scholars in more extended urban areas. Such a path broadly consists in testing whether the influence of subcentres is significant in a polycentric exponential negative density model. Following to Griffith, Gordon & Richardson (1986) found in Los Angeles that for both employment and population the polycentric model fitted better than the monocentric, albeit only 6 of 57 candidate sites were found to influence densities. Although their study related not to employment centres (as bid rent theory suggest) but to residential, received initial criticism [34] only recently some authors have recognised that population subcentre may also exert an organising power over the neighbouring density due to the existence of localised amenities: cultural, environmental and consumption amenities [11]. Most of the posterior empirical works have found that proximity to employment subcentres do produce an increase of employment densities after dealing with some problems. One of these problems is the presence of "spatial multicollinearity" produced by the introduction of as many distances as subcentres there are [17]. To avoid such an issue some studies estimate models using only the observations in the area surrounding that centre (e.g. [23, 30]); although most of the studies ascribe zones to the nearest subcentre, in any case both approaches relegate the fact that subcentres influence may overlap in interstitial areas. Also assuming that people commute to the nearest subcentre may be risky in the context or metropolitan areas with orographic accidents and non-isotropic transport systems; and in the context of the so called second demographic transition in which households do have more than one person occupied is implausible to assume that all of them commute to the same subcentre [9]. On the other hand having only one covariate with the distance to the nearest subcentre makes it impossible to assess the different influence exert by different in size and activity mix subcentres. Some authors [23, 34, 24b] create as many variables as subcentres there are and take the inverse of distance to subcentre to minimize multicollinearity assuming that subcentres produce a local influence in front of overall influence exerted by the CBD. McDonald & Prather (*op. cit.*) following such a procedure concluded that distance to O'Hare Airport in Chicago was the second most determinant of population in Chicago after its CBD; also using the same technique Small & Song demonstrated that Los Angeles main centrality is still placed in its downtown and not around the airport as it had previously been stated by Gordon et *al*. (1989).

Influence of subcentres on population density is less conclusive. Some studies have found that subcentres result not significant, and even do exert the inverse effect on neighbouring population density (i.e. density increases with the distance to subcentres). At a first glance, such findings are not completely erratic: if accessibility do account less than negative effects produced by the congested, manufacture-unpleasant or decadent-unsafe centres it is feasible to find attractive dense locations for residence well faraway. Does it mean that the standard theory in urban economics has become out fashioned? Or there are subjacent problems in such analyses? In trying to understanding such findings some explanations have been given: in Chicago McMillen & Lester (2003) found that employment growth was concentrated around pre-existing subcentres outbidding residences to more distant locations; McDonald & McMillen (2000) found also for Chicago that new and big housing developments occurred far away from subcentres due the existence of vacant land in peripheral sites and because subcentres tend to attract commercial developments making land unavailable for housing; Baumont et al. (2004) have pointed, in their study for Dijon, the fact that the subcentres are too near to CBD would imply that moving away from them, towards CBD, would mean increasing the density due the more important effect of this later; also having subcentres in the very edge of the city means that they do not exercise any influence in the still not urbanised outward periphery. McMillen (2003) has argued that reversed sign for proximity to subcentres may derives from the use of gross density (all the urbanised land) instead from net density (considering only residential land) which implies that gross residential density is low in centres with most of their land intended for economic activity. For that reasons authors such as Muñiz et al. (2003) have used splines to locally adapt the curve of population density to such central depression. McMillen (2003) also has noted that some subcentres may be not yet large enough to influence distribution of population density. For these reasons McMillen & Lester (2003; pp. 78) have concluded that "subcentres are still primarily a non-residential phenomenon"; a conclusion that is clearly contradictory to that delivered by Small & Song (1994) who concluded for Los Angeles that employment subcentres modest influence employment density, but by contrast, population density is strongly influence by them.

3.2. Polycentrism and journey to work

The relationship between the urban form, as studied here and journey to work is less developed. Shwanen et al. (2001) have found for the Netherlands that polycentric developments encourage the use of cars since the public transport network is basically intended to radial trips. Nonetheless the proximity of subcentres to CBD produce an influence of journey to work travels as has been demonstrated by Pivo (1993) for the case of Toronto and Aguilera and Mingot (2004) in France, so close-to-CBD subcentres present less car trips, basically due the presence of public transport, namely railroad based. Beyond the presence of public transport system, the very nature of subcentres influence travel to work, Cervero and Wu (1997) found that outlying and low density subcentres favour the use of the car. Nonetheless use of car not necessarily means larger commuters; Cervero and Wu (op. cit.) found that in low dense and outlier subcentres travels are shorter than travels to large subcentres since the presence of public transport encourages long distance trips.

Shwanen et *al.* (2001) state that the reduction of travel-to-works patterns rely in the nature of labour markets. So if the labour market of subcentres is different to that present in CBD the travel to work distances are reduced, since peripheral centres capture people living around them, conversely, if the labour markets of outlier subcentres and CBD are not complementary but competitive travel to work patters in such polycentric schemes are the same than in monocentric cities.

Guiliano and Small (1993) have discussed whether housing balance (the ratio of employment to population) is determinant in the reduction of commuting patterns. Their empirical findings have pointed out that other parameters such as housing quality and environment are far more important that the commuting distance when people make their location decision. In that respect Wachs *et al*, 1993, claim that the lack of appropriate housing (according to income) in subcentre location may obscure the effect of housing balance in reducing commuting.

4. Case study, data and methodology

4.1. Case stu-dies

In this paper we study the impact of polycentrism on land consumption and labour commuting in the seven biggest cities in Spain: Madrid, Barcelona, Valencia, Bilbao, Seville, Saragossa and Málaga as delimited by Marmolejo et al. (2012). Using travel to work data such authors, using the so called, interaction value, also identify the structure of metropolitan cities, it is to say, the delimitation of main centre and subcentres, and the area structure by them named subsystem. Ill. 1 depicts the main illustration of the studied cities and Ill. 2 the structural form. Barcelona, Valencia and Bilbao stand as the areas with the highest number of subcentres, that conjointly concentrate a significant share of employment (ranging from 20% in Valencia to Barcelona with 22%); at the same time those metropolitan areas do concentrate the lowest share of employment in their expanded-CBD[1] (ranging from 47% in Valencia to 56% in Bilbao). Exactly in the inverse position are Madrid, Seville and Saragossa, which stand as the most monocentric and less polycentric metropolises in Spain. Málaga is an outlier, because having only 4 subcentres they have an important share of employment (23%), and at the same time its expanded-CBD is not to big as in the case of monocentric metropolises.

4.2. Data

We primary use data coming from the National Census 2001 (the last available) at municipal level (the smallest unit for travel to work data at destination). Departing from such a source we use:

1. Travel to work data used to delimit metropolitan areas and identify subcentres as well as characterize commuting patterns.

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[1] We compute as extended-CBD those municipalities that: 1) are part of the urban continuous of the main municipality – i.e. their urbanized patches are closer than 200 m – and 2) are inside of the functional subsystem of CBD as detailed above in the main text.

2. Characterize the labour market in terms of industrial classification of sectors, diversity of the economic activities, as well as type of occupation.
3. Characterize the income level, departing from the occupation of working population.
4. Characterize the housing market departing from the size and quality of houses.
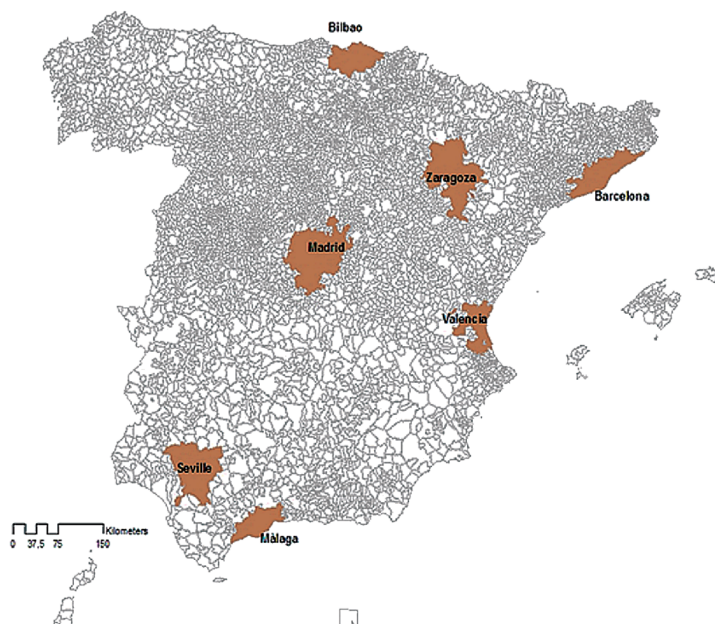

	Number of municipalities	Built up land	Employment	Population	Density
		a	b	c	.=(b+c)/a
Madrid	183	860	2,446,400	5,542,843	9,291
Barcelona	184	745	1,903,867	4,530,164	8,636
Valencia	104	308	686,247	1,792,375	8,046
Sevilla	52	237	447,849	1,381,531	7,719
Bilbao	123	112	445,666	1,231,367	15,024
Zaragoza	88	127	301,860	724,335	8,066
Málaga	32	194	366,525	994,984	7,032

Source: Corine Land Cover & National Census 2001 (ICN, INE)

Ill. 1. Main figures of biggest metropolitan areas in Spain

Also we use Corine Land Cover to analyse land use patterns. Corine (Coordination of Information on the Environment) Land Cover project for the year 2000, is leaded by the European Environment Agency, and it uses satellite imagery from LandSat and SPOT to photointerpreted the use of land inside the EU. With such information we calculate:

1. The consumed land per capita at municipal level.
2. The fragmentation of urban fabrics[2], it is to say the level of discontinuity of the urban tissue.
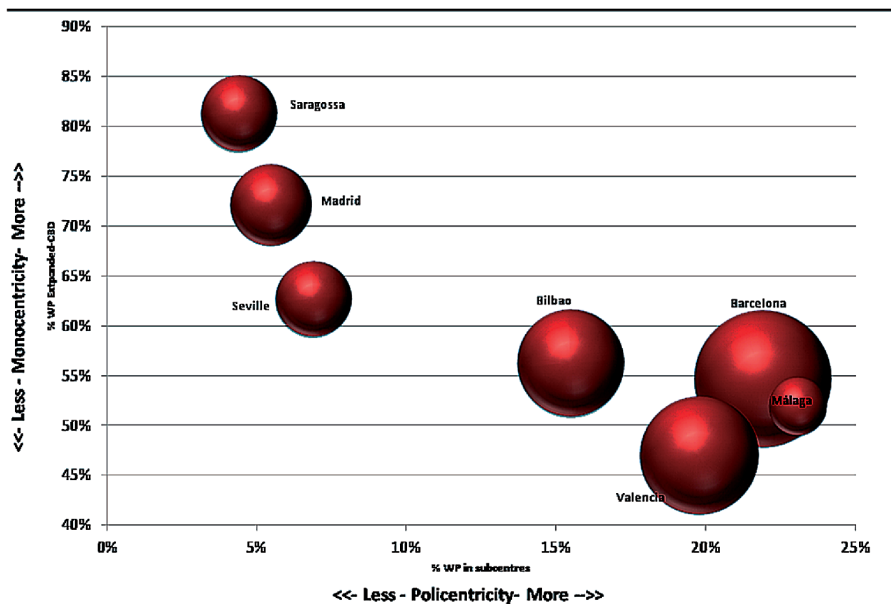
	Employment ('000)	% employment in the expanded-CBD	Number of subcentres	Employment in subcentres (%)	Population in subcentres (%)	Entropy in the employment distribution in all centres	Average number of steeps to integrate all municipalities into the expanded-CBD
Madrid	2,446	72%	8	5%	6%	0.21	1.66
Barcelona	1,904	55%	23	22%	22%	0.83	2.24
Valencia	689	47%	17	20%	19%	0.77	2.07
Seville	448	63%	7	7%	9%	0.25	1.44
Bilbao	438	56%	14	15%	15%	0.50	1.92
Saragossa	302	81%	7	4%	4%	0.14	1.80
Málaga	367	52%	4	23%	16%	0.50	1.66

The size of sphere is significant of the number of subcentres
Source: own elaboration

Ill. 2. Structure of the metropolitan areas

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[2] The fragmentation has been computed using the Shannon entropy formula:

$$H_i = -1 \cdot \sum_{x=1}^{n} Px_i \cdot \ln(Px_i)$$

In this case P is the probability to find urbanized land in a given x spot in a x municipality. In a x municipality are as many spots as urban patches are. If two patches are separated by a gap inferior to 200 m it is considered that form part of the same patch. This later criteria allows for consider the interruptions caused by rivers and other lineal infrastructures (e.g. high voltage electric lines).

Finally using the Digital Terrain Model we obtain the orography of urban areas. Distances between municipalities are computed using TeleATLAS cartography.

All the information is managed and analysed using ArcGIS (for land use and digital terrain model), TransCAD for travel to work modelling and SPSS for the statistical analysis.

4.3. Methodology

Land consumption

In order to test whether polycentrism influence land consumption we construct a regression model where the dependent variable is population/employment density (the inverse of per capita land consumption) and the explaining variables are distance to CBD and to subcenters. If this latter indicator becomes significant, polycentrism has an influence on land consumption, which is positive in the case that the density gradient is reduced as the distance to the subcenters increase.

Also we introduce some others control variables that have a theoretical impact on land values and consequently on urban densities.

Commuting

In order to prove the relation between polycentrism and commuting patterns we correlate average travelled distances with some indicators of polycentrism such as polynucleation (number and homogeneity in employment share of subcenters) and polycentricity (strength of network linkages). After we construct the excess commuting indicator, departing from the optimal commuting index of White (1988), that minimizes:

$$CT = \sum_{i} \sum_{j} (C_{ij} X_{ij})$$

where:

C_{ij} – the cost of commuting (distance),

X_{ij} – the number of workers that Works in zone i and travel to zone j.

Put in simple, such excess commuting index compares the optimal commuting (all the workers commute to the nearest available job place) to the actual commuting. The bigger the indicator is, the higher the unnecessary commuting is. The calculus of optimal commuting has been performed in TransCAD[3] software using the built-in optimization model.

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[3] The sources of information are two, in terms of demographics and mobility from residence to work in 2001 are extracted from the National Statistics Institute (INE) of Population and Housing provided by the Census and in terms of infrastructure the road network of Tele Atlas year 2001. With all of these three matrices of travel flows have been developed with TransCAD 5.0 software. In this software has been worked with three covers, one with municipal information, another with the network calculated with Tele Atlas and other last, that of centroids of each municipality, which represents the centre of gravity of each municipality.

With data and cover three matrices of travel flows are calculated. First, the current commuting between each centroid of each municipality. The second, the distance matrix, in kilometres, where distances that cross population of a municipality of residence to another to work are shown. And finally the third matrix, the optimal commuting matrix, that means, repositions in simulated way so people have to travel the shortest distance (minimal cost) to get from his home to his work.

Finally, we do a regression model of excess commuting indicator over indicators of urban form: housing balance, distance to CBD and subcentre, transport facilities, income level, employment mismatching (the level of coherence between the employment and work force qualification), employment diversity.

5. Results

5.1. Land consumption

Until know the analyses have depicted an image of divergent metropolises, is time now to study what extend polycentric urban growth is more sustainable from the perspective of land consumption. The average land consumption (built up area/(employees + residents)) in CBDs is 52 sq. m. per capita, while in subcentres it is almost three times bigger equivalent to 143 sq. meters per capita and finally in the remaining of zones it reaches 178 sq. meter per each resident and employee. Whereas such findings are not surprising at all, it remains unclear whether subcentres exert any influence on land consumption beyond themselves. Table 1 reports the result of polycentric semi-log models in which the dependent variable is the logarithm of the urban density (i.e. the inverse of land consumption per capita) and the independent variables are those related to accessibility. In order to avoid multicollinearity problems regarding to the subcentres lying near the CBD, the inverse of the distance to the functional subcentre is taken. In doing that it is assumed that subcentres exert a more localised influence on urban densities in front of the overall influence of CBD. One differentiating point in relation to previous studies is the adscription of each zone to the functional subcentre and not to the nearest. To avoid endogenous problems both the CBD and the subcentres are not considered in the analysis, such elimination also corrects the bias that would introduce the inclusion of central municipalities with a bigger area due their administrative roles; also this exclusion is justified since what is pursued here is the impact of proximity to centres.

Using only accessibility variables it is possible to explain urban densities *only* in 5 of the 7 studied cities, albeit the models for Bilbao and Saragossa poorly explain the inverse of per capita land consumption. Proximity to CBD exert a very similar influence in the biggest cities, both in Madrid, Barcelona and Valencia urban density declines about 3% for each km that the distance to their CBDs increases. Nevertheless in Bilbao and Saragossa proximity to the CBC seems not to exert any influence over urban density. The null or inverse influence of CBD on urban densities is not rare, McMillen (2001) found in Dallas, Houston and San Francisco that the CBD gradient was positive, suggesting that their CBD is no longer the critical determinant of the broad spatial trend in densities, and that a more realistic specification would be treat the CBD as a simply another of the multiple centres in these metropolitan areas.

On the other hand, proximity to subcentres exerts different influences. In Barcelona and Madrid the influence of subcentres is very similar, although the latter denotes a bigger coefficient, such divergence might come from the fact that Madrid has only 8 subcentres and Barcelona 24 distributed in a very similar area, so it is possible that in Barcelona the influence of subcentres overlaps due the proximity between them. The influence of subcentres on urban

density in Bilbao and Saragossa is bigger than in the remaining of the cities, what is important to note is that in absence of the influence coming from CBD in these two cities subcentres appear as clear structuring elements of the urban form, although in general poorly explain the overall metropolitan density. Whether such a cities have achieve a more subtle level of morphological polycentrism remains on the result of these findings.

Table 1

Models for urban density using only proximity to functional subcentres

Mod 1 only distance variables

	Barcelona			Bilbao			Madrid			Málaga			Seville			Valencia			Saragossa		
r2 adj	0.38			0.06			0.28									0.26			0.09		
F ANOVA	57.42			6.37			33.36									30.94			8.39		
	B	Beta	t-value	B	Beta	t-value	B	Beta	t-value	B	Beta	t-value	B	Beta	t-value	B	Beta	t-value	B	Beta	t-value
Constant	9.26		63.82	8.83		37.88	8.89		46.32							9.46		52.88	7.40		56.06
Dist CBD	-0.03	-0.60	-9.79				-0.03	-0.51	-7.86							-0.03	-0.52	-5.56			
Inv Dist Sub	3.68	0.22	3.63	4.90	0.27	2.52	3.82	0.16	2.40										6.11	0.31	2.90

Only variables significant at 95% of confidence are presented

As it has been said, proximity to centres appears as an incomprehensive factor to explain urban densities for a number of reasons. For example low-density housing (e.g. garden city fashion) are placed general in the outskirts of the cities, but when they growth and integrate subcentres, as it is quite common in Mediterranean metropolises (in our sample 65% of the subcentres can be considered as integrated), such a low density developments get located in central locations or in between centres. Such an overlapping process related to the arrangement and typologies of urban development may obscure the influence of proximity to centres: for example it is very well know that in Málaga area the low density developments stand out as the primary model of urban growth with independence of their position in relation to the centres. In the cities analysed the correlation between the index measuring the presence of low-density-fragmented developments and distance to CBD is $r = -0.01$ and $r = -0,051$ to subcentres but is not statistical significant in both cases.

Also it becomes unclear in such large cities whether distance to centres is masking other variables such as those regarding the topographic nature of territories, as bigger the pressure to urbanise land, higher the probability to use far-from-the-CBD-less suitable zones like hills and mountains in which high-rise development is difficult/costly. In the cities analysed the correlation between distance to CBD and orographic complexity is positive $r = 0,248$ (sig $= 0.000$) and the correlation between distance to CBD and slope is also positive $r = 0,146$ (sig $= 0.000$). What confirms that ancient urban settlements (which eventually became in centres) where located in the plateaus of valleys or along hydric basins. So increasing the distance to such centres means also increase the difficulty/cost to urbanise with high densities, and not only proximity (transport cost saving) to centres.

Table 2 reports the results of models that take into consideration, besides proximity to centres, other control variables.

Unlike the previous models, in all cities it is possible to explain urban densities: in all of them, but in Bilbao and Saragossa, the percentage of the variance explained increases. The sing of the other control variables are as expected when they are present in the models: the dummy controlling the existence of suburban rail stations is positive indicating that municipalities that have such a transport system are more dense; the dummy indicating that

a municipality is on the coast is positive indicating the historical effect produced by sea accessibility in the past and the sea externalities in the present; the orography complexity and slope indicators depicts a negative sign which implies that in complex territories the density is reduced; the index of fragmentation of urban fabrics that is a proxy for urban policies allowing low dense/sprawled developments appears with the expected negative sign; the factor synthetizing the presence of service sectors/absence of manufacturing is positive indicating that in tertiary areas the per capita land consumption is reduced due such activities consume less urban land in relation to manufacturing; and finally the income factors are coherent with the hypothesis that wealthy households prefer big houses in detached styles reducing urban densities and conversely poor households only can afford small dwelling most of them in apartment-like arrangements[4].

Table 2

Models for urban density considering proximity to functional subcentres and other control variables

	Barcelona			Bilbao			Madrid			Málaga			Seville			Valencia			Saragossa		
r2 adj	0.59			0.06			0.44			0.59			0.36			0.66			0.09		
F ANOVA	33.26			6.37			34.82			13.21			9.00			28.50			8.39		
	B	Beta	t-value	B	Beta	t-value	B	Beta	t-value	B	Beta	t-value	B	Beta	t-value	B	Beta	t-value	B	Beta	t-value
Constant	9.22		36.10	8.83		37.88	9.60		44.07	13.37		6.92	9.21		64.18	8.94		74.85	7.40		56.06
Dist CBD	-0.03	-0.46	-6.47				-0.03	-0.60	-8.74												
Inv Dist Sub	1.87	0.11	2.08	4.90	0.27	2.52													6.11	0.31	2.90
Suburban railway							0.47	0.20	3.14							0.32	0.18	2.30			
Orography complexity										-2.09	-0.29	-2.17	-0.34	-0.31	-2.47	-0.43	-0.37	-4.53			
Slope	-2.83	-0.19	-3.15																		
Coast	0.46	0.17	2.94																		
Fragmentation	-0.31	-0.17	-2.97				-0.62	-0.33	-5.39	-0.97	-0.72	-5.29	-0.53	-0.52	-4.16	-0.61	-0.40	-5.58			
Tertiary/non-manuf.	0.26	0.20	2.79													0.26	0.23	2.84			
Medhigh-high income																-0.28	-0.25	-3.32			
Medlow_low income	0.22	0.18	3.01				0.22	0.28	4.79	0.63	0.62	4.65	0.16	0.26	2.07	0.25	0.23	3.38			

Only variables significant at 95% of confidence are presented

The effect of proximity to subcentres in urban density falls in the two biggest metropolitan systems. In Barcelona other variables such as the structure of economic activity, the fragmentation of urban fabric, and those related to the orographic complexity/slope of territories become more important that proximity to subcentres. In Madrid the proximity to subcentres completely fadeout in front of other variables such as: urban fragmentation, the income of population or the presence of suburban railway stations (linking suburban zones basically with the CBD due the radial structure of the network). It is important to note that in both cities proximity to CBD remains as the principal factor explaining urban densities according beta coefficients. Both the permanence in Barcelona of the inverse of the distance to subcentres (which was not significant in the Madrid Model), as well as the slightly smaller beta coefficient for proximity to CBD in relation to Madrid (–0,46 for Barcelona and –0,60 for Madrid), support the idea laid before that Barcelona exhibit a higher level of polycentrism, not only because it has more subcentres in relation to Madrid, but also because its subcentres

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[4] Please note that the inclusion of medium high-high income variable is not incompatible with the introduction of medium low-low income variable since they are orthogonal due they are obtaining by means of a principal component analysis.

exert a stronger influence over their functional subsystems, and its CBD a lower influence, once all the other control variables are taken into consideration. *In Barcelona both the daily life of commuters (which produce subcentres in our methodological approach) as well as urban form is more dependent of subcentres in comparison to Madrid where its CBD still exert an extraordinary influence on such variables.*

T a b l e 3

Models for employment and population density considering proximity to functional subcentres and other control variables

Employment density

	Barcelona			Bilbao			Madrid			Málaga			Seville			Valencia			Saragossa		
	B	Beta	t-value	B	Beta	t-value	B	Beta	t-value	B	Beta	t-value	B	Beta	t-value	B	Beta	t-value	B	Beta	t-value
r2 adj	0.57			0.17			0.53			0.47			0.32			0.65			0.21		
F ANOVA	34.88			9.24			38.88			12.14			7.80			31.64			8.04		
Constant	7.85		27.49	7.55		30.33	8.14		30.93	7.37		56.26	7.75		31.56	7.41		53.90	6.35		23.40
Dist CBD	-0.03	-0.52	-7.50				-0.04	-0.66	-10.52										-0.01	-0.25	-2.30
Inv Dist Sub	2.66	0.15	2.64	5.53	0.29	2.80	5.09	0.17	3.03										5.72	0.22	2.11
Suburban railway							0.54	0.19	3.20							0.58	0.29	3.83			
Orography complexity																					
Slope	-3.61	-0.22	-3.62										-8.67	-0.37	-2.81						
Coast	0.50	0.17	2.85	-0.86	-0.31	-3.07															
Fragmentation							-0.49	-0.21	-3.80	-0.62	-0.56	-3.72	-0.38	-0.33	-2.54	-0.46	-0.27	-3.61	0.24	0.24	2.32
Tertiary/non-manuf.	0.23	0.16	2.18																		
Medhigh-high income																-0.20	-0.16	-2.17			
Medlow_low income	0.26	0.20	3.16				0.22	0.24	4.07	0.51	0.61	4.04	0.21	0.30	2.25	0.30	0.24	3.50			

Population density

	Barcelona			Bilbao			Madrid			Málaga			Seville			Valencia			Saragossa		
	B	Beta	t-value	B	Beta	t-value	B	Beta	t-value	B	Beta	t-value	B	Beta	t-value	B	Beta	t-value	B	Beta	t-value
r2 adj																					
F ANOVA																					
Constant	9.15		43.97	8.55		35.15	9.23		42.19	14.03		6.93	8.97		62.27	8.78		80.07	7.02		49.49
Dist CBD	-0.02	-0.43	-5.95				-0.03	-0.56	-7.91												
Inv Dist Sub				4.31	0.23	2.13													5.00	0.25	2.34
Suburban railway							0.46	0.20	3.05												
Orography complexity										-2.51	-0.32	-2.49	-0.38	-0.35	-2.80	-0.40	-0.34	-3.89			
Slope	-2.99	-0.20	-3.36																		
Coast	0.48	0.18	3.01																		
Fragmentation	-0.35	-0.19	-3.31				-0.66	-0.36	-5.68	-1.04	-0.73	-5.46	-0.51	-0.50	-4.00	-0.60	-0.38	-5.04			
Tertiary/non-manuf.	0.28	0.22	2.91													0.38	0.33	3.94			
Medhigh-high income																-0.26	-0.22	-2.79	-0.30	-0.30	-2.88
Medlow_low income	0.20	0.17	2.64				0.21	0.27	4.47	0.66	0.61	4.67				0.21	0.19	2.54			

Only variables significant at 95% of confidence are presented
In bold are non stationary variables (at least a 90% of confidence) according to the Test of Montercarlo in the LWR analysis

Only in Bilbao and Saragossa proximity to subcentres retain its explicative power since the remaining of the control variables fail to enter to the model; albeit, as said before, the overall explicative power is very poor. One could argue that distance to centre (subcentre) reduce its importance when topography measures are considered since distance do not include the fact that streets in hilly terrains are longer because they have to adapt the pendent to the technical possibilities of vehicles; nonetheless in our distance measure such irregularities are already taken into consideration since TransCAD measures actual paths following streets. Although such precaution has been taken, in order to prove that

effectively topography has incidence on urban densities, an alternative set of models have been constructed taken into consideration the *time* to centres calculated in TransCAD, and consequently to include the fact that vehicles slowdown they velocity in sloped longer streets. The result of such a set of models suggest that, as well as in models reported in Tab. 2, distance to subcentres reduces its importance, and even it tends to disappear in Barcelona and Madrid. *These results suggest that terrain topography adds new information to the explanation of urban densities.*

The remaining of the coefficient variations are as expected, but some explanations are needed, for example: the slope variable seems to reduce more the employment density since steeper areas are less suitable for economic activities (mostly for those extensive); urban fragmentation is more correlated with low-density housing fabrics since those urban--sprawl-developments are primarily residential, while the factor synthetizing the presence of tertiary activities seems to positively affect more the population density than economic activity. This latter paradox is solved when it is considered that in compact cities (like these analysed) service sectors and housing coexist in the same buildings (because externalities of services are quite compatible with residential uses) in dense fabrics, for instance using the ground level for retail, the first levels for office activities and the remaining for flats. So increasing the proportion of service activities also means an increase in the density of population. The same is valid for medium low-low income (with a higher positive incidence on the employment density), since mixed activity buildings are not seen as exclusive high standing alternatives for living, and rarely are chosen by high-income households, who prefer only-housing-buildings and even only-housing-neighbourhoods.

5.2. Commuting

Regarding the relationship between commuting and polycentrism the inferior table summarises the results of a family of models where the explained variable is the natural log of excess commuting. It is worth to say that polycentrism is intrinsically controlled by the excess commuting index, since there is a clear reduction of travelled distance produced by polynucleated structures as depicted in the following illustration.
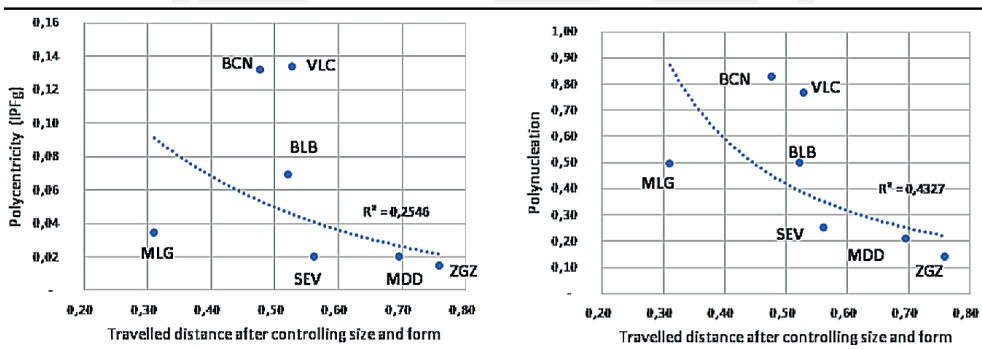
Source: own elaboration

Ill. 3. Polycentrism and travelled distance (home-work)

The first model "Transport" is able to explain only 3% of the variance of excess commuting, according to such a model the higher is the presence of railway stations (most of them rendering a suburban-radial train service), the higher the excess commuting, such a finding suggest that working population living in well-connected areas serviced by high capacity transport network do travel more that those living in poorly connected areas. The second model "urban form" is able to explain 19% of the excess commuting, which is relevant to the interest of this research since its explanatory capacity is the highest among individual models. According to such a model, the higher is the presence of manufacturing activity the higher is the excess commuting; such a finding is relevant, since during the last four decades in Spain, as well in other parts of the world, most of the new and decentralising economic activity has been accommodated in industrial parks located in suburban places. The positive sign of the coefficient suggest that manufacturing plants does not encourage the self-contention of site's working population, on the contrary those municipalities depicting a high level of such activities denote the highest commuting patterns, and behind this issue is the fact that manufacturing locations are well serviced by motorways connecting them with the remaining of the metropolitan system. The second coefficient is the dwelling diversity, such an indicator represents the diversity of housing in terms of size (as a proxy of housing typologies), the negative relationship with excess commuting suggest that well developed residential areas (with a diverse offer of dwellings matching different income levels) do have a higher self-containment of commuters, since they are able to find the house they can afford or that fulfils their residential expectative. The mismatching CNO coefficient is significant of the non-correspondence between the working population and the employment in a given site in occupational terms. The higher this coefficient is, the bigger the mismatch between the offer and demand of jobs in qualification terms is. The positive correlation of this index and excess commuting ratifies that very specialized job places, which labour force do not match the qualification required by firms do produce higher commuting patterns that balanced zones. Finally the job ratio (the number of job places to working population) confirms that very economic specialized zones (e.g. manufacturing parks); paradoxically do not contribute to the reduction of commuting, the reversed sign of the square of job ratio suggest and exponential function in the relation with excess commuting.

The income model is constructed over the principal component analysis that summarizes the socio-professional structure of working population. In such a factorial analysis high income is assumed to be related with managerial and professional working population, medium income is related to workers employed in the personal service sectors, and medium-low profiles includes also the medium qualified manufacturing working population. As suggested by the model there is not a linear relationship with excess commuting and income as theory suggest, high qualified workers depict a negative relationship with excess commuting which indicates that these professional profiles tend to live near their job locations, exactly the same is true for medium-low profiles. The operational principia is the same in both cases, since their income make wealthiest workers live in expensive locations near office based jobs, at the time that blue-collar-workers only can afford housing in the poorest residential areas that are quite often located next to manufacturing locations. On the contrary, medium income population seems to have longer commuting patterns, since their employment oriented to people services is more sprawled across city.

In the integrated model all the precedent models are integrated in a unique one. Some of the variables are introduced and other eliminated. For example in the transport infrastructure dimension the motorway service (expressed as the number of entries by 10.000 inhabitants) is introduced with the expected positive sign, in the urban form dimension distance to CBD is introduced with a positive sign which suggest that peripheral municipalities show higher excess commuting as expected, other control variables include the orographic complexity with a positive sign that reveals that hilly territories increase the commuting patterns and dummies controlling the cities.

As observed the distance to subcentre does not have any influence on excess commuting, as well the dummy representing the subcentre is not introduced in any model.

T a b l e 4

Excess commuting models

		MOD1 Transport		MOD2 Urban form		MOD3 Income		MOD4 Integrated	
	R	0,17		0,44		0,24		0,52	
	Sq R	3,0%		19,2%		5,9%		27,3%	
	Sq R adjusted	2,9%		18,7%		5,5%		26,2%	
	Error típ.	0,94		0,86		0,93		0,82	
		B	t	B	t	B	t	B	t
Dim	Constant	1,06	29,82	1,90	5,07	1,10	31,85	0,86	2,23
T	Stations/10.000 inha	0,03	4,74						
	Motorway acc/10.000 inhab							0,00	3,49
UF	% manufacturing			1,88	8,95			1,04	4,65
	Dwelling diversity			- 0,90	- 4,77			- 0,49	- 2,51
	Mismatching C N O			0,57	3,44				
	Job ratio			- 0,02	- 4,14				
	Job ratio^2			0,26	3,62			- 0,03	- 5,80
	LTL/Viv tot							0,51	5,66
	Distance to CBD							0,01	3,23
TM	Orographic complexity							0,14	2,34
INC	Medium low					-,169	-4,853		
	Medium					,119	3,380		
	High					-,112	-3,239		
I	Bilbao							0,41	3,83
	Valencia							0,59	5,86
	Málaga							- 0,47	- 2,86
	Zaragoza							0,34	3,32

T = Transport, UF = Urban Form, TM = Territorial matrix, INC = income, I = dummy for diferent cities

6. Conclusions

Concentrated decentralization of employment and housing in a polycentric scheme has been seen as a sustainable alternative to monocentrism where all employment and services remain concentrated in a unique location obligating people to commute for working and other purposes. Polycentrism has been also seen as an alternative to scatteration where both employment and housing sprawl across the city in low dense scheme making it impossible to provide sustainable transport systems and consuming high quantities of land per capita. Nonetheless such a posture is more normative than analytical. Using GIS and Teledetection technologies in this paper we investigate whether polycentric urban growth does contribute to reduce land consumption and excess journey-to-work commuting. The problem has been answered through our empirical programme carried out for the seven biggest metropolitan areas in Spain gives little support to the role of polycentrism in the reduction of the aforementioned issues.

• In reducing land consumption other urban features, such as the typology of urban fabrics, have a higher impact rather than the number or proximity to subcenters.
• As well, in commuting terms the diversity of housing estates and diversity of employment encourage the reduction of excess commuting.

Such findings suggest that, except for mobility where polycentrism do reduce travelled distances, policy makers should change the target of their normative recommendations, putting more attention to other aspects of urban form rather than the way in how employment is spatially distributed across the city.

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