Urban sprawl in Spain: differences among cities and causes

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Urban sprawl is one of the most studied urban phenomena. It has a great impact on the environment, public health and socio-economic evolution of cities. The causes are multiple, mainly being connected with the generalization of the automobile in modern cities. Urban sprawl has been occurring in U.S. cities since the 50´s, but in the last three decades it has started to appear in Latin-American and Asian cities and even in the old traditionally compact European ones. In this paper the case of Spain is studied. Spanish cities have been growing fast over the last two or three decades. The country has completed the process of urbanization and has suffered a large real state bubble. In this context we are interested in measuring and explaining where and why urban sprawl appears in Spanish cities. Satellite geo-reference photos are used to calculate an Urban Sprawl Index (USI). It is applied to all urban zones and municipalities throughout the country, providing an objective comparable measurement of sprawl and identifying which areas are most affected by this phenomenon. A second analysis stage is made in an attempt to explain the causes of the differences in sprawl between Spanish cities with a simple regression model based on the literature. We can observe that the most sprawled areas are the new housing estates, especially located in places with good views or close to the sea. In some cases it is starting to be a problem for the environment and urban sustainability with important consequences for the future evolution of the affected cities.

Palabras Clave: *(máximo 6 palabras:) Urban Sprawl, Land Use, Geographical Information Systems and Spain*

Clasificación JEL: *R14, R20 y R29*

Introduction

Urban sprawl is one of the most studied and controversial urban phenomena. Cities grew upward after the industrial revolution, but during the second part of last century most North American cities started a growth pattern that was intensive in land use and pushed them further and further out. This process of sprawl produces very relevant impacts on the environment, public health and socio-economic development of these cities. Two extraordinary pieces of research, with extensive review of the literature and very precise analysis of U.S. cities but with different positions in the debate of the consequences of urban sprawl, were provided by Brueckner (2000) and Glaeser and Kahn (2004).

The North American model of a sprawled city rapidly extended first to Latin America (see Gilbert (1996) or Polèse and Champain (2003)) and later to Asian cities (see Bunnel et al. (2002)), finally becoming a global problem. Traditionally the old European cities are different from the new ones of America or Asia. The cities of the old continent were strongly concentrated around a dense historical center and its commercial and business extensions. There clearly followed a monocentric growth model with a strong center and hierarchical structure of sub-centers. But during the last four decades new tendencies of urban sprawl have appeared (see Couch et al., 2007). According to the European Commission (2006), eastern and southern countries are the ones most at risk from an explosive process of urban sprawl.

The case of Spain is one of the most interesting in Europe. In some areas of the Iberian Peninsula there is very high building pressure due to tourism and the demand for a second residence. The Spanish economy has been drastically affected with the construction sector suffering one of the biggest real state bubbles of all Europe (Romero, 2012). Spain had very fast economic growth during the last four decades of the past century, presenting a very strong, concentrated process of urbanization. Cities such as Madrid and Barcelona doubled their population in less than twenty years. Other big metropolitan areas of the country experienced such growth that different cities or towns grew into one. Rural areas also lost most of their population in just two decades. The strong changes in income per capita, social customs and land use pressures make Spain a possible victim of sprawled urban growth. On the other hand, Spanish cities have very strong concentrated centers and people enjoy walking around the city more than in other countries. This helps to keep the metropolis compact (Muñoz, 2003).

In this context our particular objective in this paper is double. Firstly, we are interested in measuring the sprawl in the main Spanish cities and metropolitan areas to ascertain up to what level these phenomena have started to appear in Spain and which regions or particular cities present higher levels of spread growth. Secondly, we wish to explain why some areas are more dispersed and others less so. Urban sprawl is a very complex phenomenon and in order to explain it, we have to use multidisciplinary approaches in which geographical, cultural, sociological, economic, technological and political factors should be included. Our objective is not as ambitious as proposing a general explanation of the origin and growth of urban sprawl phenomena. We are just interested in understanding why sprawl varies between different urban areas in a single country that shares a similar culture, comparable economic development levels and basically the same social characteristics.

Geographic Information Systems (GIS hereinafter) provide powerful tools for storing and manipulating large amounts of information on spatial relationships (see Foresman, 1998). Particularly, the wealth of information contained in the aerial photos or satellite imaginary often used by geographers, but now starting to be exploited by economists. In this paper this wealth information is used to calculate the urban sprawl index.

The paper is structured as follows. In the next section, we summarize the possible explanations of urban sprawl phenomena in the literature. The possible references to this issue are huge in number so we have organized all the information using the monocentric city model as guide. In the third section the Urban Sprawl Index is calculated. It is based on the satellite imaginary for Spain, so first of all, database and GIS methodologies are presented; additionally, the local Spanish administrative structure is explained. At the end of this third section, the results of the Urban Sprawl Index for Spanish cities and metropolitan areas are presented and briefly discussed. In the fourth section, this index is used in an empirical model of causes of sprawl in which the *distance*, *size*, *geography*, *economic* and *political* factors are included. The main conclusions are summarized in a final section with some policy recommendations.

What urban economic theory tells us about the causes of sprawl

To organize and structure the vast literature concerning the causes and consequences of sprawl, we need an urban economic theory for guidance. Unfortunately, there is no unified model that helps us to understand why urban growth should be scattered or compact. But the most accepted model of urban growth is the monocentric city model proposed by Alonso (1964), Mills (1967), Muth (1969) and Wheaton (1974). In Brueckner (1987), a coherent integration of all these different contributions is presented in a synthetic model.

The basic assumption of this model is that all employment in the city takes place in a single center, the Central Business District (CBD hereinafter). Everybody moves daily from their residence to the CBD. The basic model also assumes that all residents earn the same income. The price of houses is directly related to their distance from the CBD, so urban residents decide their location according to their preferred house sizes, commuting times and consumption of other goods and services and, obviously, their budget restrictions. Under these assumptions the center exerts a strong gravitational force, keeping the city compact and avoiding sprawl (Brueckner, 1987).

Bearing this basic approach in mind we can revise all the factors that could cancel the compacting effect of the center by considering variations from the basic formulation of the monocentric city model.

Distance matters

Distance matters because higher distances imply higher *transportation costs*, basically including the *opportunity cost* of commuting times. So the higher the *transportation costs* or *opportunity cost* are, the stronger the CBD effect and the lower the sprawl.

But, following the same argument, if some transport technology change appears that reduces the cost and/or commuting times, the compacting effect of the CBD will be reduced. The main transport technology change in the last decades had been the automobile. It permits much longer possible commuting distances, reduces transport time and eliminates the fixed costs associated with public transport (Glaeser and Kohlhase, 2004). If significantly different levels of income exist between cities, it will imply different levels of accessibility to automobiles that could explain different levels of sprawl. Similarly, those cities or particular areas of big metropolis that experience their main growth after the car has come into general use will be more sprawled.

If the analysis is reduced to a country or area that does not present large income differences and the main urbanization process occurs in a similar restricted period, such as in the case of Spain, we may think that this factor is not very relevant. But cities or areas of the metropolis that have grown more intensely over the last two decades have done so in the context of high incomes, which means that the car a relatively affordable good for families, in contrast to the situation just three decades ago. This could be reflected in the structure and trend of that city or particular area to sprawl. Additionally, large monocentric metropolises grow in concentric rings around the center, each of these rings corresponding to a different moment in time. An interesting hypothesis to test is to observe if those rings that appear when the car is widely used are more sprawled or not. In European cities this basically involves finding a positive relationship between distance and sprawl.

Size matters

When the car appears, *distance* is less important, but the city is still monocentric. Cities could grow, keeping their monocentric structure but being more sprawled in the final areas of construction. Even leapfrogging could appear because it may be optimal to postpone the development of certain pieces of land, which in the future could be sold at higher prices (Brueckner, 2000). The effect of the car could disappear or might be reduced, however, if the *size* of the city, in terms of population, were large enough to produce high congestion effects. If motorways are crowded, transport times increase, sometimes dramatically, and location or, in other words, distances will again be relevant (Turner, 2005). The larger the city, in terms of population, the higher the congestion and the pressure to build on empty, well-located pieces of land, thus reducing the sprawl.

Geography matters

The monocentric city model assumes a featureless plain space around the CBD. But space is not a featureless plain. Differences exist in natural resources and amenities around the center, much more so if we compare different cities having different climatology, water availability, slope or temperatures. These geographical factors could explain a fundamental part of the processes of concentration of population (see Ohls and Pines, 1975; Fujita, 1976; Mills, 1981 or Buchanan, 1965, among others). How the water is distributed or natural constraints due to the presence of mountains or a steeper geography could explain urban processes of dispersion or concentration. Even temperature could explain certain traditional ways of building cities: very warm and dry places traditionally tend to be very concentrated. In a case like Spain, a fundamental factor is the presence and proximity of the coast. Coastal areas are much more attractive for building residential areas and building along the city seafront (Catalan et al., 2008).

Economy matters

All the previous factors introduce modifications to the monocentric city model that make it more similar to present-day cities but do not change the essence of the model: the great force of attraction exerted by the CBD. But, as Anas et al. (1998) explain, metropolitan areas are increasingly polycentric and the percentage of jobs located in the central area is going down. Models such as Fujita and Ogawa (1982) and Imai (1982) show how easily a monocentric structure could change to a polycentric one. Recently, Lucas and Rossi-Hansberg (2002) propose a model analyzing under what conditions this change could happen. They identify that it depends on the strength of the forces of agglomeration, which in turn depend on the economic specialization of the city in the sectors most sensitive to agglomeration economies.

In their study, using ZIP code employment data, Glaeser and Kahn (2001) show that the extent of employment decentralization does indeed vary widely both among cities and sectors. In addition, sectors such as business services, where communication is particularly important, tend to be more centralized. General equilibrium models of systems of cities proposed by Henderson (1974, 1987) also show that cities specializing in sectors with stronger agglomeration economies have more expensive land, which offsets the higher wages resulting from such economies. This implies higher buildings with smaller dwelling units and more compact development. Consequently, cities specializing in sectors where employment tends to be more centralized will be more compact. In cities specializing in sectors where employment is less centralized and where it is easier to use a car, residential areas are often more extensive.

And... policy matters

Political factors could be very relevant. In some countries, basically in America, there are very few legal restrictions governing the use of land. If market assignations are free, political intervention could be lower. But in Europe, in general, there are strong regulations that could affect the use of land and the development of cities. Limitations on the number of floors or any type of restriction on the use of land for residential, industrial or commercial purposes will undoubtedly have a relevant influence on sprawl as well as on other urban characteristics (Squires, 2002).

In the case of Spain, it is essential to take into account the effects that the fragmentation of local government could have. Fischel (1985) devotes substantial attention to the political geography of zoning. In his study he points out the connections between local fragmentation and land restrictions. But the Spanish case could be just the opposite. Gonzalez et al. (2013) focus attention on local political fragmentation in the case of the region of Asturias, in the north of Spain, finding that small rural municipalities located close to a big metropolis have strong incentives to increase the offer of land in order to increase population and building in the area and thus attract the natural growth that would have happened in other places located closer to the city center. LeRoy et al. (2000) study a very similar case in the US: the Minneapolis metropolitan area.

Other variables related to urban planification are not easily measurable or sometimes not even available.

Calculation of an urban sprawl index for Spain

GIS resources for the territory of Spain: IGN ortophoto series

In order to obtain an Urban Sprawl Index (USI hereinafter) we are going to use the large amount of information contained in the orthophoto imagery. Spain is covered by a wide variety of geo-referred photos and maps with different scales and sources. We can find the orthophoto series (1:5000 scale) from 2002 to 2012 in the PNOA program produced in collaboration with the IGN (National Geographic Institute) and the autonomous regions. This is the basis for producing the 1:25000 cartography made by IGN in the BTN25 series. Formerly, from the 70's, IGN published vector maps based on traditional photogrammetric methods. These are the BCN25 maps. Both series, BCN25 and BTN25, form the basis from which we obtain the building surfaces.

For calculation purposes we employ both vector and raster GIS with the INTERGRAPH HEXAGON package. The MAPALGEBRA from Tomlin (1990) is used in raster analysis. Cover for the year 2000 is used in this work.

Spanish local structure: municipalities and urban zones

The highest level of spatial desegregation of the public administration in Spain is the municipality. The country is divided into 8,106 municipalities but less than 1/3 of them are urban areas, most of them being very rural environments. These municipalities are, in general, very small in terms of area, so most of the large cities cover several of them (see figure 2, in which the municipal Spanish structure is mapped and the real urban extensions over the municipal borders are represented). In some specific cases like Madrid or Barcelona, one city includes more that 50 municipalities (see the particular case of Madrid in figure 3). For this reason we should delimit the urban metropolitan areas.

The Spanish Ministry of Civil Works (Ministerio de Fomento) defines Urban Zones (UZ) as those areas in which there is a total population of more than 50,000 inhabitants, according to the National Census of 2011 (Ministerio de Fomento, 2011). This reduces the territory to 85 areas, 77 if we only take into account the peninsular territory (i.e. exclude the Canary and Balearic islands and Ceuta and Melilla). The total population considered is 26 million inhabitants, 55% of the total population, in 716 municipalities. Furthermore, we can take into consideration an Extended Zone (EZ) including municipalities bordering each urban zone and with more than 0.1% of land built on. That means 1,794 municipalities and 4 million inhabitants more. The urban zones and municipalities considered can be consulted in figure 2.

The urban sprawl index definition

In this paper we follow the proposal of an Urban Sprawl Index (USI), using GIS and ortho-photos taken by Burchfield et al. (2005), who used TM LANSAT imaginary with 30x30 resolution meters providing a photo-interpretation in a raster GIS scenario. Basically the USI consists in delimiting the pixels as urban or rural and for each pixel considering as an urban count the number of other urban pixels that are in an area of 1 km^2 around it.

$$\mathrm{USI} = 100\left[1 - \frac{\text{Urban pixel}}{18^2\pi}\right] \qquad [1]$$

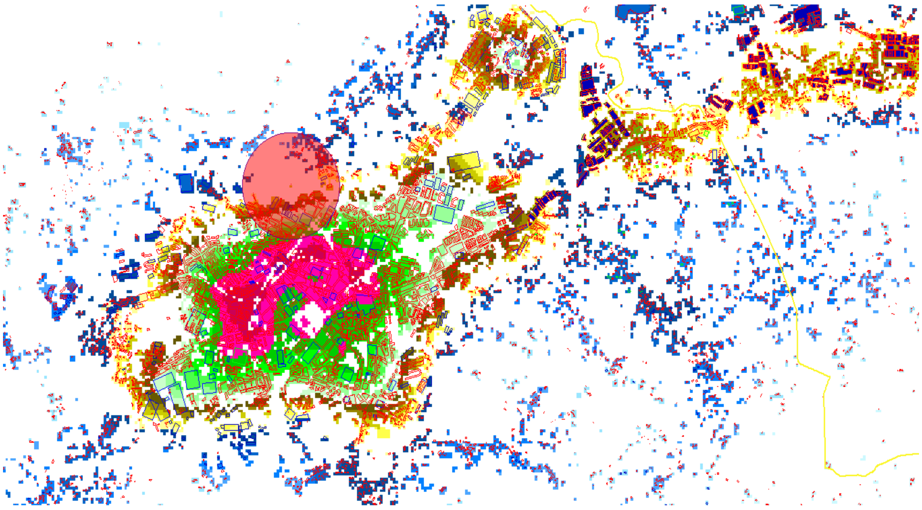
So high values of USI, up to 100, indicate high levels of dispersion or sprawl and low values indicate concentration.

We apply this formula to our data[1]. The housing areas and industrial buildings have been selected through raster procedure. For compatibility with the Burchfield et al. (2005) paper, we have chosen 30x30 resolution, although it could have been greater. USI is a stable index when the scale of reference is changes in the limits of the project[2]. As an example of how it works, figure 1 presents the USI distributions of Oviedo urban zone in Asturias (north of Spain). We may assign the average of individual pixel values of USI contained in each entity to local areas, which could be municipalities or urban zones.

1 The building digitalization used in our study is much more precise than the one used by Burchfield et al. (2006). For this reason the USI results are not directly comparable between analyses.

2 In some regions there is the possibility of having different scale maps. We use the different scale resolution for Asturias, calculating the index with it, and the correlation is closer to 0.99.

Figure 1. Example of USI distribution (Oviedo urban zone)



Note: the color variation (magenta-green-brown and yellow) shows the increase in sprawl.

Firs results: urban sprawl in Spanish cities

The last column of table 1 shows the proposed Urban Sprawl Index, applied to the main Spanish urban and metropolitan areas that were delimited. This table also summarizes other information such as the number of municipalities that are part of each urban or metropolitan area, the total surface area and the built-up surface area, total population and density of each place.

The average USI for all Spanish urban areas is 68.81. However, a strong dispersion exists in this index within the territory: from Seville metropolitan area, with the lowest value of 48.13, to Lleida, with the highest level of 81.12. Other important urban areas with a high level of sprawl include Madrid, Granada and Vitoria. At the other extreme, with the lowest levels of sprawl, are cities like Caceres, Lugo and Santiago de Compostela. Barcelona, for example, is almost at the national average.

In figure 2 these results are mapped, providing some clues about the distribution and potential causes of sprawl in the Spanish case: population size and density appear to produce more concentration, the sprawling tending to occur more in coastal areas, while polycentric areas are, in general, more disperse that those that grow around a clear center, etc. Nevertheless, this is a hypothesis derived from the simple observation of USI distribution on the map and should be tested with an econometric approach.

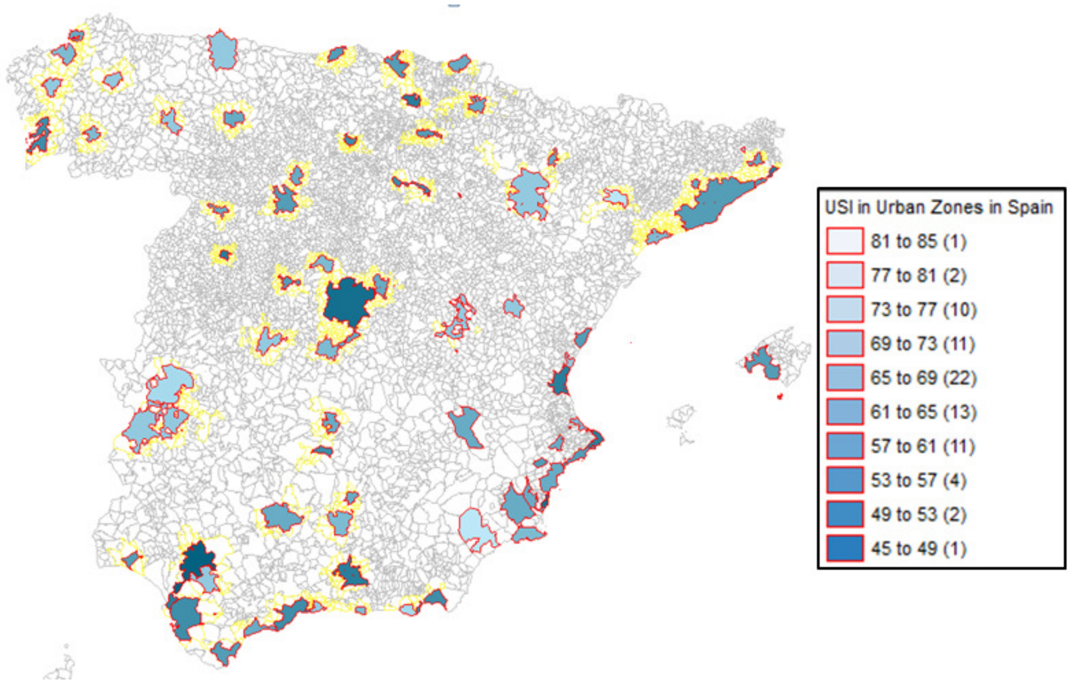
Table 1. Urban sprawl index for the main Spanish urban and metropolitan areas

Metropolitan or urban area	Number of municipal-lities	Surface area (Km²)	Percentage of built-up area	Population (2011)	Density, inhabitants per Km²	Urban Sprawl Index
Madrid	52	2,890.10	4.03	6,052,247	2,094	52.94
Barcelona	165	3,271.50	5.08	5,030,679	1,538	64.62
Valencia	45	628.80	6.39	1,551,585	2,467	58.15
Seville	24	1,529.20	4.79	1,294,867	847	48.13
Malaga	8	817.40	3.93	953,251	1,166	58.84
Bilbao	34	504.00	4.15	910,578	1,807	62.57
Central area of Asturias	18	1,462.90	1.86	835,053	571	73.77
Zaragoza	15	2,295.40	1.27	746,152	325	72.81
Alicante and Elche conurbation	5	683.30	3.40	698,662	1,022	67.38
Murcia	10	1,230.90	2.34	643,854	523	67.28
Cadiz	6	1,792.00	1.49	642,504	359	58.74
Palma	8	913.10	2.65	548,211	600	64.24
Vigo and Pontevedra conurbation	14	743.20	3.22	587,843	791	60.21
Granada	30	829.60	3.09	517,580	624	55.89
Coruña	10	493.90	2.67	410,401	831	71.61
Valladoliz	17	746.40	2.22	408,647	548	62.96
San Sebastian	13	376.80	2.99	403,807	1,072	65.71
Tarragona	16	356.70	4.73	382,304	1,072	70.07
Panplona	18	391.60	2.05	340,691	870	66.89
Cordoba	1	1,255.20	0.90	328,659	262	66.30
Santander	8	256.80	4.46	328,635	1,280	63.16
Castellon	6	292.60	4.09	315,617	1,079	64.04
Vitoria	1	276.80	3.16	239,562	865	56.18
Conurbation of Costa Blanca	9	316.40	2.82	237,458	750	61.78
Algeciras	4	583.30	1.17	235,572	404	62.86
Cartagena	2	582.90	2.68	233,743	401	69.74
Almeria	5	400.40	2.20	219,650	549	60.80
Conurbation of Costa del Sol	3	399.80	1.91	209,815	525	66.50
Leon	8	411.20	2.04	199,597	485	67.87
Salamanca	6	112.50	4.82	191,034	1,697	58.05
Burgos	2	148.60	3.76	181,187	1,219	58.44
Hueva	3	230.50	2.25	176,229	765	62.27
Logroño	6	217.90	3.22	175,230	804	64.04
Alvacete	1	1,125.90	0.83	171,390	152	66.50
Lleida	8	426.30	2.21	166,874	391	81.12
Badajoz	2	1,531.90	0.58	157,122	103	73.38
Gadalajara	7	391.20	1.42	155,245	397	66.50
Gerona	9	180.30	3.60	152,477	846	67.06
Santiago de Compostela	3	379.30	2.25	142,325	375	74.36
Jaen	4	733.40	0.74	141,742	193	70.82
Ferrol	5	212.30	3.12	136,698	644	67.09

Table 1. Urban Sprawl Index for the main Spanish urban and metropolitan areas (continuation)

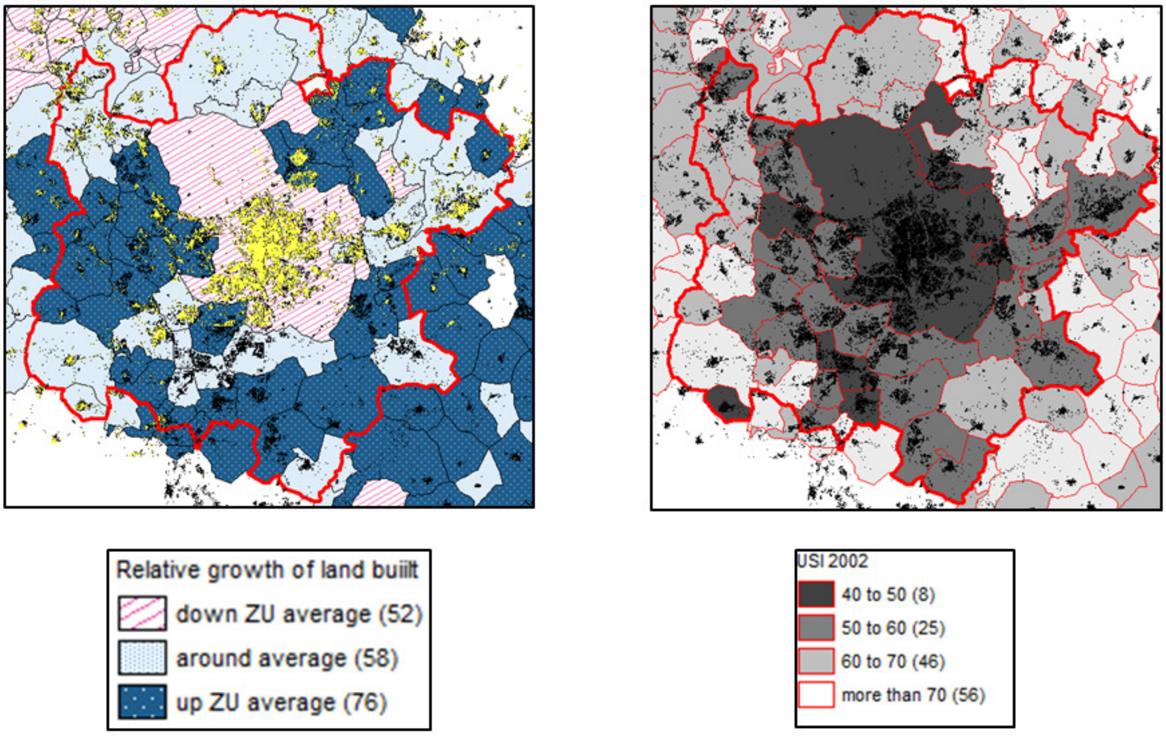
Metropolitan or urban area	Number of municipal-lities	Surface area (Km^2)	Percentage of built-up area	Population (2011)	Density, inhabitants per Km^2	Urban Sprawl Index
Ourense	5	253.30	2.75	131,695	520	71.31
Gandia	13	148.10	3.32	131,289	886	69.25
Torrevieja	2	107.00	4.61	118,999	1.112	52.84
Toledo	8	548.10	1.24	118,174	216	68.95
Denia-Javea	6	253.00	4.90	114,415	452	56.77
Orihuela	6	273.10	2.74	112,538	412	68.17
Caceres	4	405.20	1.45	111,213	274	75.44
Manresa	4	1,938.00	0.29	106,345	55	65.52
Talavera de la Reina	4	96.90	5.65	102,739	1,060	72.98
Lugo	1	329.80	1.42	98,007	297	74.85
Palencia	4	273.60	1.54	97,156	355	67.38
Lorca	1	1,675.20	0.48	92,869	55	78.98
Roquetas del mar	1	59.70	5.84	89,851	1,506	58.84
Elda-Petrer	2	150.00	1.90	89,336	596	62.67
Ciudad Real	2	403.40	0.99	89,315	221	66.50
Vélez	3	173.40	2.33	86,627	500	74.55
Lloret del Mar	3	104.70	3.08	86,033	822	61.68
Ponferrada	6	449.80	1.16	85,070	189	73.38
El Ejido	1	225.80	1.91	83,774	371	78.09
Alcoy	3	213.00	2.00	81,699	383	66.40
Segovia	5	360.90	1.00	71,664	199	68.56
Sahagunto	2	136.20	1.96	71,448	525	74.55
Merida	6	985.60	0.55	70,975	72	73.57
Zamora	3	195.00	1.96	70,194	360	65.61
Sanlucar de Barrameda	1	170.90	1.93	66,944	392	55.50
Linares	1	196.70	1.42	61,110	311	65.61
Sant Feliu de Guixols	4	85.50	4.67	60,913	713	57.66
Motril	1	109.80	2.08	60,887	555	71.02
Avila	1	230.70	1.20	59,008	256	63.85
Cuenca	1	911.10	3.11	56,703	62	73.08
Aranjuez	1	201.10	0.85	55,755	277	65.03
Hueca	1	161.00	1.40	52,443	326	68.17
Puertollano	1	226.70	0.88	52,200	230	59.33
Utrera	1	684.30	0.51	51,630	75	72.49
Soria	1	271.80	2.74	39,987	147	58.25
Teruel	1	440.40	1.82	35,288	80	72.98
Total	**721**	**45,871.10**	**2.33**	**30.419.070**		

Figure 2. Map of urban sprawl index for main Spanish urban and metropolitan areas



We can focus our attention on each one of the urban zones or metropolitan areas of the map and make an intra-area analysis. As an example, figure 3 shows the details for the specific case of Madrid, the main metropolitan area of the country. Yellow dots represent buildings constructed before 1982 and black ones new edifications from then to 2006. We can calculate the USI for all the metropolitan area, as was presented in figure 2, or the level of sprawl for each of the municipalities that are part of the metropolitan area, as in figure 3. As can be observed, the development of the city in the last three decades has mainly been at the periphery, basically around east and west. These new areas of development are the ones that present the highest levels of sprawl. By contrast, the traditional city of Madrid remains very concentrated, with the lowest values of all the metropolitan areas. This behavior is usual among the main cities and metropolitan areas of the country.

Figure 3. Growth and sprawl in the metropolitan area of Madrid (1982-2007)



Explaining urban sprawl differences in Spain

An empirical model to explain urban sprawl differences in Spain

In the section 2 revision of the literature relating to urban sprawl, using for guidance the monocentric city model, we conclude that *distance*, *size* (population size), *geography*, *economy* and *policy* all matter in the understanding of this phenomenon. An empirical model which tries to explain the differences in sprawl between different cities or within metropolis should take all these factors into consideration. Some of them, like *distance* or *geographical* variables, are easy to measure and include in a set of observable variables. Others are more complicated due to the limited information or the level of spatial desegregation of the data.

Distance, as a relevant factor, could easily be introduced as the distance between the *centroid* (geographic center) of each municipality and the center of its urban zone, measured along the road network. This is the variable called *DISTCENTER.*

Size factor are related to possible congestion costs, meaning that the *distance* factor continues to be of relevance even with modern transport systems, particularly automobile. We can approximate the probability of congestion effects by using several demographic variables, such as the population size in some previous year. We use the population in 1970 in variable *POP70*. We can also consider the growth rate during the decades of the 70´s and 80´s (*POPG70s* and *POPG80s*). Finally, to give a measure of congestion, we introduce the density of the area in 1980 by means of the *BUILTDENS* variable, which is the quotient of inhabitants in 2001 and land built upon. It could be considered as a measure of average building height in the area.

Measuring *geography* factors is relatively simple. In our case we have information about average rainfall (*RAINFALL*) and maximum and minimum temperatures (*TEMPMAX* and *TEMPMIN* respectively) to evaluate the relevance of climatology and the presence of water. The slope of each area (*SLOPE*) and the average altitude (*ALTITUDE*) could give us some relevant information about the physical restrictions on the spread of the city due to the presence of mountains or roughness of the terrain. Coastal conditions could be introduced with a simple dummy variable (*COAST*) having the value 1 on the coast or 0 otherwise. Finally, the precise location of each area could be introduced by means of longitude and latitude values (*LONG* and *LAT*).

Some general *economic* variables could be useful to approximate the economic situation and development of the area. In this case we are very limited by the reduced information available at very local level. As we have no information of GDP at this level, we propose to consider the economic growth of the area by means of employment growth during the decade of the 90´s: *EMPG90s*. Even more important is to have information on the economic structure through at least two standard location quotients of employment in services (*LQSERV*) and manufacturing (*LQIND*). But the most relevant of this block of factors is to approximate in some way up to what level a metropolitan area maintains a monocentric structure or loses most of it. A very simple way of doing this is to use a location quotient of employment over population: $LQCBD = {\left({e_i}/{e}\right)} \Big/ {\left({P_i}/{P}\right)}$, where e_i is the total employment in area i and e is the total employment in the whole metropolis, P_i is the population in the same area i and P is the population in the metropolis. So if the metropolis is totally monocentric, all the areas i will assume a value of 0, except the center, which will take on very high values. If the metropolis is losing its monocentric structure, *LQCBD* could take on high values in many areas.

In European cities, very planned as they are, *political* factors are as important as the rest, or even more so. The problem now is the impossibility of having good variables to measure these factors in a suitable way. We can estimate only the effects of fragmentation, using rate municipalities per 100 km^2 (*FRAGM*).

Table 2 summarizes all the variables proposed for studying the sprawl in the case of Spain.

The model to be estimated is the one presented in equation [2]:

$$\begin{aligned} USI = a &+ [d\ DISTCENTER] + [s_1 POP70 + (s_2 POPG70s + s_3 POPG80s)] \\ &+ [g_1 RAINFALL + g_{2x} TEMP_x + g_3 SLOPE + g_4 ALTITUDE \\ &+ (g_{51} LONG + g_{52} LAT) + g_6 COAST] \\ &+ [e_1 BUILDENS + e_2 EMPLG90s + (e_3 LQIND + e_4 LQSERV) + e_5 LQCBD] \\ &+ [pFRAGM] + \varepsilon \end{aligned} \qquad [2]$$

The dependent variable is the urban sprawl measured by USI (equation [1], table 1). The independent or explicative variables are summarized in table 2. This empirical model could be estimated by municipalities or by urban zones.

Table 2. Variables included in the urban sprawl analysis

Variable name	Time period	Explanation	Source
Distance			
DISTCENTER	-	Distance along the roads from each municipality´s centroid to the geographic centre of its urban zone	CNIG & INE
Size: demography			
POP70	1970	Municipality's Population in 1971	Spanish Census of population carried out by National Institute of Statistics (INE)
POPG70s	1971-1981	Population growth during the 70´s	
POPG80s	1981-1991	Population growth during the 80´s	
Geography			
RAINFALL	1987-2007	Average rainfall using monthly information for the twenty years chosen	AEMET and University of Extremadura
TEMPMAX *TEMPMIN*	1987-2007	Average temperature using monthly information for twenty years chosen. TEMPMAX is the average maximum temperature for each month, TEMPMIN the average of minimum and TEMPMED the promethium of maximum and minimum temperatures	
SLOPE	-	Average slope of the territory	Spanish National Centre for Geographical Research (CNIG)
ALTITUDE	-	Average height of the territory	
COAST	-	Dummy variable that takes on value 1 if the area includes coast, otherwise 0	
LONG	-	Longitude coordinates	
LAT	-	Latitude coordinates	
Economy and monocentric condition			
BUILTDENS	2001	Inhabitants per km² built upon	Spanish Census of population carried out by National Institute of Statistics (INE)
EMPG90s	1991-2001	Employment growth during the 90´s	
LQIND	1991	Location quotient of employment in industrial activities	
LQSERV	1991	Location quotient of employment in industrial activities	
LQCBD	1991	Location quotient of employment over population as indicator of monocentric degree	
Policy fragmentation			
FRAGM	-	Ratio of municipalities in 100 km²	National Institute of Statistics (INE)

Main results

The estimation of equation [2] has been made using a standard OLS procedure. Table 3 shows the results of the estimations using this model for the whole country, divided into municipalities in the first set of results, first column, and into peninsular urban zones in the second one, second column,. This allows us to compare the general behavior of the different areas with a more local behavior of municipalities. We use 654 municipalities and 74 urban zones. Those not included are in the islands or in Ceuta and Melilla, and constitute very particular cases. R^2 of regressions in all estimations and other general tests show that any relevant statistical problem, such as multicolinearity, non-normality of the residuals or heterocedasticity, among others typical issues, do not occur in these cases.

Our first hypothesis was that *distance matters*. The *d* parameter, the one which goes with the variable *DISTCENTER,* can be estimated only for municipalities in the global model for all urban areas (see first column of results in table 3) or for Madrid and Barcelona (see table 4). Obviously, it is not possible to estimate this parameter for urban zones. The result for the whole country is that it is significant and positive, meaning that the municipalities which are far from the center, the CBD, have a greater tendency to sprawl than the ones closer to it. Usually those areas that are far from the CBD developed later, confirming the idea that areas that developed after the automobile came into general use are more sprawled. This result is absolutely coherent with the conclusions of Glaeser and Kohlhase (2004) and in line with other empirical results for the U.S. such as those obtained by Calfee and Winston (1998) or Burchfield et al. (2005). It is also coherent with the expectations for the monocentric city model summarized by Brueckner (1987). The introduction of the automobile reduces the relevance of the proximity to the CBD and produces greater spread of cities.

The second set of factors is the one that refers to the *size* and the congestion effect associated with it: parameters *s*. The growth of population appears as significant variable *y* in most cases, especially in the urban zones analysis (second column of table 3). So, fast population increments generate higher concentration and less sprawl, especially in metropolitan contexts. This conclusion is again coherent with literature for American cites (see, among others, Downs, 1992).

Several *geographical* variables were introduced, each of which was assigned a *g* parameter which informs us about the relevance of space characteristics. We can observe that, in general, the *geographical factors* do not help in the understanding of the sprawl differences between urban zones but are very relevant for explaining local differences between municipalities. The presence of coast, dummy *COAST*, is one of the clearer examples. It leads to sprawl at municipal level, though it is not relevant at urban zone level. The part of the metropolitan area that are on the coast are much more sprawled than those further away from it and follow a spread structure along the seafront. The *ALTITUDE* variable behaves in a similar manner: higher areas also present higher levels of sprawl. This usually happens because these are the areas preferred for residential housing estates with good views and locations in the context of the metropolitan area. The municipalities located in the northwest of the country are more sprawled. But this phenomenon could be explained by the weight that the regions of Galicia and Asturias have in the whole country. Both cases are located in the northwest and have a traditional sprawled behavior due to the type of agricultural specialization and urban structure.

Regarding the set of *economic* factors, *e* parameters, we note that specialization has a significant influence. Specialization in services reduces the sprawl in the municipality but does not have the same effect in the entire urban zone, which is logical, as services tend to be concentrated in the center of cities but not particularly in the surrounding areas. Industry tends to concentrate at the municipal level as well as the metropolitan level. This result is in line with Henderson´s (1987) conclusions.

Among the *economic* factors, the *LQCBD,* as an approximation of the level of monocentrism, deserves a special attention. This is one of the most important variables in all the estimations, always significant and having a clearly positive influence on sprawl. So the more decentralized the metropolitan area is, the higher the sprawl will be, a conclusion absolutely coherent with Glaeser and Kahn (2001) and all the reasoning made in the second section of this paper with regard to the relevance of the monocentric structure in the compacting or sprawling tendencies.

Contrary to our expectations, political fragmentation in not significant. Nevertheless it would be significant at 15%. This variable is especially important in polycentric areas. Gonzalez et al (2013) show how in the case of Asturias, a region in the north of the country with three cities very close together, the fragmentation of the emerging metropolitan area of this region has a strong influence on the processes of sprawl of the municipalities that are close to them. These results of Gonzalez et al (2013) are coherent with LeRoy et al (2000). If this behavior only occurred in some specific areas, a general result of weak significance of the *FRAGM* variable could be obtained.

In table 4 the independent results for two main metropolitan areas of the country, Madrid and Barcelona, are presented so the particular behaviors of both cases can be observed. As can be seen, the results for Barcelona follow the same general pattern as for the general analysis, with some specificities. Madrid, however, is quite different. A reduced number of variables are significant. This could be explained because of the leapfrogging behavior of Madrid's expansion that produces the spread of the city, albeit in compact subcenters. The new residential areas of Madrid are at any rate more sprawled that the old ones.

In general, what we found for Spanish cities is very similar to what was found for the U.S. or Latin-American cities. Old centers and adjacent areas are very compact, but new residential areas tend to be dispersed, especially in coastal areas or places at higher altitude, which offer the best views of the cities. The greater the lure of the center, the lower the sprawl. In accordance with these results, the potential problem of sprawl in Spanish cities is focused in new distant residential areas far away from the city centre.

Table 3. Causes of urban sprawl in Spain: a general view

Variables		Coefficient (t-Student)	
		All municipalities	Urban zones
Constant		**-44.451** (-1.663)*	**-23.270** (-0.597)
Distance	*DISTCENTER*	**0.185** (5.019)***	
Demographic factors	*POP70*	**-0001** (-3.408)***	**-5.8E-6** (-2.418) **
	POPG70s	**0.003** (0.021)	**-6.340** (-1.975)*
	POPG80s	**-2.962** (-4.574)***	**-18.112** (-2.554)**
Geographic factors	*RAINFALL*	**-0.077** (-2.882)***	**-0.110** (-2.438)**
	TEMPMAX	**0.434** (0.863)	**0.312** (0.395)
	TEMPMIN	**0.138** (0.835)	**0.199** (0.597)
	SLOPE	**0.257** (3.260)***	**0.453** (2.596)**
	ALTITUDE	**6.0E-3** (3.070)***	**-0.005** (-2.027)**
	COAST	**1.970** (1.782) *	**2.919** (1.194)
	LONG	**-5.2E-1** (-2.625)***	**-0.796** (-2.038)**
	LAT	**2.356** (5.007)***	**1.487** (2.075)**
Economic factors	*LQCBD*	**0.194** (4.159)***	**89.195** (3.350)***
	EMPG90s	**-0.174** (-0.503)	**2.627** (0.675)
	BUILTDENSPOP	**-1.6E+0** (-7.042)***	**0.005** (2.159)**
	LQIND	**-0.487** (-3.995)***	**-0.446** (-1.707)*
	LQSERV	**-2.074** (-6.976)***	**-0.571** (-0.504)
Fragmentation	*FRAGM*	-	**0.086** (1.387)
R^2		**0.426**	**0.556**
Number of observations		**654**	**74**
F-Snedecor		**27.778*****	**3.929*****

Note: */** and *** indicates the significance at 10/5 and 1%

Table 3. Causes of urban sprawl in Spain: Madrid and Barcelona

Variables		**Coefficient** (T-Student) Madrid	Barcelona
Constant		**-870.984** (-1.293)	**127.069** (0.238)
Distance	*DISTCENTER*	**0.225** (0.945)	**0.178** (2.348)**
Demographic factors	*POP70*	**-1.6E-6** (-0.644)	**-3.8E-6** (-0.854)
	POPG70s	**-0.065** (-0.444)	**-1.372** (-1.582)
	POPG80s	**-1.056** (-1.397)	**-9.326** (-5.222)***
Geographic factors	*RAINFALL*	**-1.493** (-1.491)	**0.032** (0.365)
	TEMPMAX	**-4.826** (-0.835)	**-3.647** (-1.718)*
	TEMPMIN	**-4.662** (-1.173)	**0.208** (0.469)
	SLOPE	**0.796** (0.632)	**0.405** (2.562)**
	ALTITUDE	**-1.70E-3** (-0.058)	**-9.36E-3** (-0.992)
	COAST	**-**	**2.001** (0.966)
	LONG	**-19.902** (-1.672)	**-4.227** (-0.722)
	LAT	**23.255** (1.479)	**-0.379** (-0.029)
Economic factors	*LQCBD*	**6.4E-1** (2.177)**	**0.530** (4.139)***
	EMPG90s	**0.547** (0.454)	**-1.555** (-0.764)
	BUILTDENSPOP	**-1.639** (-1.725)*	**-5.8E+0** (-8.025)***
	LQIND	**-0.175** (-0.228)	**-0.869** (-3.167)***
	LQSERV	**-1.148** (-1.273)	**-2.457** (-4.272)***
R^2		**0.692**	**0.803**
Number of observations		**51**	**157**
F-Snedecor		**4.919*****	**33.651*****

Note: */** and *** indicates the significance at 10/5 and 10%

Summary and conclusions

Urban sprawl is one of the most relevant issues in urban analysis. It is a phenomenon that started several decades ago in the development of many North American cities in association with the generalized use of the automobile and rapid growth of some of these cities. Latin American and Asian cities are undergoing similar processes of sprawl. Normally has been accepted that, with some specific exceptions, European cities do not present relevant problems of sprawl. Urban areas of the old continent are much more compact and mainly expanded before the automobile came into such wide use. But customs are changing rapidly and we are beginning to notice how the new development of Eastern Europe, Germany and Southern European countries tending to sprawl.

In this paper we study the case of Spain. It is a very interesting one due to the relevance of the building sector and the great real estate bubble that occurred during the last decade. Pressure on urban land on the Mediterranean coast is very high, as is that exerted on the main metropolitan areas such as Madrid, Barcelona, Bilbao and Valencia, among others. Our first objective is to measure whether or not the growth of Spanish cities presents a sprawl problem. Secondly, we are interested in identifying the areas in which sprawl is more frequent and trying to explain its causes.

An urban sprawl index is calculated using the geographical information contained in satellite ortophotos. This geographically referenced information is very rich and suitable for our objective. The index gives us precise information about the level of sprawl in each urban area. We apply the official division of territory in urban zones, identifying the level of sprawl in each metropolitan area of Spain. But we can also identify the sprawl index by municipalities, observing internal differences.

The sprawl level of new building areas in Spain is similar to that observed in North American cities, in some cases even higher. When we zoom inside the zones we can observe that the more peripheral areas are the ones most affected by dispersion. This is also very usual in coastal areas as well as those that are located in good positions in the metropolitan context. The rapid growth in population tends to keep the city compact but, at the same time, a debilitation of the CBD concentration power, which is happening in many cities, clearly produces greater dispersion.

Considering the conclusions of this paper, urban authorities should design urban plans with a clear strategy regarding sprawl phenomena, which are starting to appear in Spanish cities. If the objective is to maintain the traditional type of European city, restrictions on land use should be introduced, especially in coastal areas or those with the best environment conditions. Actions to reinforce the relevance of the main CBD should also be considered, as should urban planification to avoid leapfrogging.

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