Effect of Urban Sprawl on Quality of Life

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Abstract

This paper examines the relationship between low-density areas −urban sprawl− and the quality of life in the urban area of Barcelona. Following Krupka and Noonan (2009), I measure the quality of life using the price per square meter. The results show that there is a negative relationship between low-density areas and the quality of life. Namely, a one standard deviation increase in low-density areas is associated with a reduction of the housing prices by 32%. If I split the sample in tariff rings of public transportation, the effect on prices is increasingly negative as long as I move out of the first ring. Moreover, the distance to Barcelona remains a key factor in determining housing prices despite the polycentric structure of the urban area. In addition, I propose some alternative indicators to measure sprawl given the heterogeneity and morphology of the urban area. The findings are robust to the use of these alternative definitions.

Keywords: urban sprawl, suburbanization, quality of life, housing prices, Barcelona.

JEL Codes: O18, R14, R21, R52.

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1. Introduction

Cities are expanding their footprints outside the urban core with a different morphology than the old town or center of the city (Nechyba and Walsh, 2004). Indeed, we have seen that cities are continuously growing, either in the form of taller buildings, or recently by occupying more land. The concept of sprawl was first used by Black (1996), and its importance has increased due to the continuous growth of cities since the second third of the twentieth century. For instance, between 1950 and 1990, the urban population increased by 92 percent in the US, whereas urbanized land rose by 245 percent, which means that urban density declined or urban sprawl increased. Urban sprawl can take plenty of forms: from low-density residential developments to the rise of office buildings, retail, or manufacturing. They can also arise following a planned community or as residential area and aligned to a lake or a mountain rage, for example. All these areas show different land prices. The scope of this project emphasizes the residential land use through housing prices. When housing prices increase, only those households that can afford the rent or the purchasing price will stay there. Then, individuals will react to the level of housing prices along with the territory in one way or another.

In this paper, I study how individuals' decision of living in low-density settlements affects their well-being. In the last decades, individuals were shaping out of big cities by searching for a lower price of land. The monocentric model (Alonso et al., 1964; Mills, 1967; Muth, 1969) already states that the price per square meter of housing decreases as the distance to the Central Business District (CBD hereinafter) increases. Then, an increase of demand for cheaper housing incentives the construction of dwellings that tend to occupy more land out of the centers of the cities. This fact together with the reduction of travel costs has eased the settlement in the suburbs or low-density areas (O'sullivan, 2007). I will try to see the reasons why housing prices differ for a low-density land use.

This paper addresses the variation in the development of low-density areas to estimate its impact on the quality of life. Due to the difficulty of measuring the quality of life of households, I am going to use housing prices as a proxy (Krupka and Noonan, 2009). Despite the different methods used in literature to measure sprawl, the main variable of interest in this study is not density, but low-density areas. Given the low variability in the variables during the period analyzed (2013-2019), I opt for a pooled cross-section OLS with year fixed effects. I cluster the standard errors at the municipality level to deal with possible problems related to grouped error terms since the scale of the unit of observations is more precise than the level of variation (Bertrand et al., 2004). The results are also robust to heteroskedasticity concerns given the differences between municipalities. The analysis is based on a hedonic regression model for housing prices. I include several dwelling variables to control for the location characteristics and to measure the influence of cities and neighborhoods on housing prices.[1]

[1] Recall that one dwelling in Barcelona or in its metropolitan area may share few similarities with respect to another outside this urban core

The demise of the monocentric model is a reality (O'sullivan, 2007). Large cities worldwide are undergoing suburbanization and employment decentralization processes. The land occupied outside the core is characterized by fragmented and dispersed populated settlements. This paper refers specifically to the urban area of Barcelona. Previous literature has studied which is the effect of suburbanization in the urban area of Barcelona. Garcia-López (2010) found that the urban area has developed to a polycentric scheme, especially during the last decades, whereas Muñiz et al. (2008) identified several employment sub-centers outside the urban core. Although these patterns suggest the appearance of several sub-centers in the urban area of Barcelona, the city itself still exerts a high influence on housing prices.

Individuals may play a role in this suburbanization process. They may shift their place of residence towards the suburbs because of the lower housing price, but they face associated costs. Berger and Blomquist (1992) found that the differences in quality of life do matter for individuals in deciding whether to live in one area or another. Households decide if they are going to live in the urban core, enjoy a higher quality of life but at a higher housing cost or living in the suburbs at a lower housing cost but with some commuting costs. Krupka and Noonan (2009) also relates housing prices and quality of life by arguing that housing prices in small areas tend to increase once the quality of life increases. Housing prices could be considered an indicator for determining the well-being of households. Although there are relevant studies on sprawl and its effects, little attention has been paid to its relation to the quality of life. For this reason, the aim of this paper is to shed some light in the link between both.

My contribution is twofold. First, I analyze the effect of urban sprawl with a pure low-density indicator from the MUC (Mapa Urbanístic de Catalunya) that is able to capture all low-density patterns, from semi-detached to isolated housing settlements, and also garden city structures. Previous literature has used different measures to capture low-density patterns such as density, urban density, urbanized land, or as a composite index of distinct measures. All these measures lack the specific identification of low-density areas. Further, I also use alternative indicators to measure sprawl given the complexity of the concept and the morphology of the urban area. Different proxies of different topics are introduced and analyzed in the model to see their suitability to capture these low-density patterns. The novelty resides in the less frequent use of some of these indicators in the previous literature, such as the distance to the closest hospital or the mobile signal coverage. Second, I also evaluate sprawl with the main low-density indicator but using the three tariff rings in which Barcelona is divided according to the public transportation system. With this approach, I am able to capture whether the disposition of low-density structures in rings along the territory affect housing prices differently.

The results suggest a negative impact of low-density areas on quality of life. This finding goes in line to the results suggested by Ehrlich et al. (2018), in which urban sprawl is negatively associated with real house price growth. It seems that municipalities that have a high share of semi-detached and isolated housing are located outside the urban core of Barcelona. The proximity to Barcelona exerts a big influence on housing prices. To confirm these results, I divide the urban area into three rings according to the different transportation tariffs. I find that the quality of life of the households located in Barcelona and its first ring is not negatively affected if they are living in low-density settlements with respect to the most distant municipalities. In addition, the urban area is not only projecting the continuous development of urban sprawl but also the polycentric scheme. Given the complexity of measuring sprawl, I propose some indicators to simulate this kind of urban scheme. The distance to the nearest hospital from each municipality is going to capture and exploit this polycentric pattern. Alternative proxies contribute to the explanation of the phenomena but, apart from the latter mentioned, only radio and mobile signals coverage remain significant under this setup. Moreover, direct access to the coast has not statistical impact on housing prices. Only the proximity to Barcelona is going to be more relevant in this model.

The paper is organized as follows. Section I accounts for the introduction, Section II relates previous literature with particular characteristics of the urban area of Barcelona, Section III deals with the data, Section IV describes the empirical approach, Section V comments the results, and Section VI concludes.

2. Literature

Urban Sprawl

The term "sprawl" was first coined in 1937 by Earle Draper, which was one of the first city planners in the southeastern United States (Black, 1996). Urban sprawl is related to the tendency towards lower city densities as city footprints expand. Galster et al. (2001) define it as a "pattern of land use in an urbanized area that exhibits low levels of some combination of eight distinct dimensions: density, continuity, clustering, centrality, nuclearity, mixed uses and proximity". This multidimensional definition of urban dispersion tries to cover all possible models that characterize the urban expansion processes. *Density* is the most common variable to measure sprawl in the literature. It measures the average number of residential units per square mile of developable land in an urban area; the lower the population density, the higher the urban sprawl. Another range of authors also use the term "edge cities" (clusters of population and economic activity at the urban fringe) to measure sprawl, since this phenomenon favors the appearance of business activities like office buildings, retail and manufacturing. The main reason behind this fact is the correlation between metropolitan average population density and average employment density. Indeed, Glaeser and Kahn (2004) showed that such correlation for the US major 150 metropolitan areas was 0.77, a sufficient strong value to accept the variable as a proxy.

The second more used indicator, after density, is *continuity*. It is the degree in which the buildings in their developable land show an unbroken fashion pattern; then, following Galster et al. (2001), we have the rest of signs of sprawl: *concentration* captures if the built land is located disproportionately in space, or it spreads out the area; *clustering* measures if the development of the area has been arranged to minimize the amount of land occupied by residential or nonresidential uses; *centrality* aims at discovering the degree of closeness of residential and nonresidential areas to the central business district (CBD); *nuclearity* is related to mononuclear patterns of development in which the CBD is the only locus of intense development; *mixed uses* account for the existence of two different land uses within the same small area, and *proximity* measures the degree to which different land uses are close to each other across an urban area. Preceding authors have been using some of these indicators in different combinations as the best references to predict urban sprawl. Likewise, urban sprawl has also been measured with urbanized land per capita (Hortas-Rico and Solé-Ollé, 2010), distance and employment and population densities (García-Palomares, 2010), land cover through satellite imagery data (Burchfield et al., 2006; Ehrlich et al., 2018), by adding housing characteristics (Navamuel et al., 2018), or as a composite index of distinct measures (Ewing et al., 2003; Fallah et al., 2011; Berrigan et al., 2014).

Alternative perspectives of the concept include the vigorous spatial expansion of urban areas (Brueckner, 1983), the larger distances individuals do within a city to conduct their daily lives (Burchfield et al., 2006), or as expansions in the city footprints that lower city densities (Nechyba and Walsh, 2004). Wassmer (2000) introduced the concept of housing locations by assuring that sprawl occurs when a large part of the residential areas and business activities are developed outside the core of the urban area. Individuals evaluate if the benefits of living in a suburban, decentralized location with cheaper land surpass the private costs of longer commuting times, and then they decide to live inside or outside the city centre (Wassmer, 2002). Hence, the measurement of our variable of interest −urban sprawl− can take different dimensions. In this paper, I am going to use several indicators, one purely related to low-density areas and then I will proxy sprawl with other variables that are not related specifically to the urban consumption of land.

Urban sprawl has also been analyzed with many other indicators. For instance, Navamuel et al. (2018) studied the relationship between urban sprawl and energy consumption for Spain. They found that electricity consumption increased significantly when living in a detached house and particularly, this electricity demand would increase if urban sprawl phenomena were accelerating during the following years. Other authors have also analyzed the relationship between urban sprawl and productivity (Fallah et al., 2011), costs of providing local public services (Hortas-Rico and Solé-Ollé, 2010), travel to work (García-Palomares, 2010), highways (Garcia-López, 2012), transportation costs (Young et al., 2016), water demand (Morote and Hernández, 2016), fires (Tsilimigkas et al., 2018), and even obesity and cancer mortality (Berrigan et al., 2014). In this sense, this paper is new in establishing a link between urban sprawl and quality of life.

Although most of the studies in urban sprawl are originated in US and Europe, the two territories show completely opposite patterns (Nechyba and Walsh, 2004). On the one hand, US urban development is characterized by a combination of high car purchases, large public investments in road infrastructure, limited public investment in central cities, heterogeneous population within cities and low cultural barriers to household mobility. The distance between the place of residence and the workplace could be so long due to sprawl that the private car turns essential. On the other hand, Europe is more prone to invest more in public transportation within cities. Hence, they are also able to spend greater resources on maintaining central city amenities as well as cultivating a less-residential-mobility culture to improve household welfare, so that population characteristics are more homogeneous. Nonetheless, some policies in Europe have been favoring high urban density concentrations. Nivola (1998) found that in Europe there is a higher cost of personal transportation - in terms of the price of gasoline -, heavier taxes in consumption rather than in income, and higher sales taxes in comparison to the US. The predominance and protection of small neighbourhood shops favor also high-density living in European countries but assuming highly electricity costs for it and consumers being charged with the burden. Likewise, other factors such as the larger agricultural subsidies that small European farmers receive and the higher investment in mass-transit networks for transportation infrastructure contribute to the spread of sprawl.

O'sullivan (2007) analyzed which were the main causes behind sprawl in the US. He highlights two factors. First, given that land is a normal good, those households with higher incomes are going to consume larger amounts of land. Second, lower travelling costs induce individuals to accept living relatively distant to the workplace or other activities because distance does not suppose any problem for them and land is cheaper. There are other factors that influence low-density patterns due to government policies in the US. One is associated with those distances that individuals who live in the suburbs have to cover, which may result in congestion externalities, especially during the travel peak period. Second, any kind of mortgage subsidy may invite households to ask for more consuming dwellings in terms of land and so reduce the density. A third point is related to the underpricing of fringe infrastructure. Basically, it stresses that new development constructions in metropolitan areas are not totally borned by developers and customers. The last feature that contributes to sprawl is zoning. This activity consists in establishing some minimum lot sizes to incentive the arrival of high-income households who proportionally contribute more to the local public coffers.

However, urban sprawl has resulted in the appearance of several consequences. Kahn (2000) analyzed the consequences of low-density living in the US. Despite the aforementioned higher occupation of land for semi-detached houses, the consumption of energy with respect to cities is quite similar: there is an effort for these new constructions outside the metropolis to be more energy-efficient. Although the use of the private car to commute increased and resulted in higher shares of greenhouse gases, data from Los Angeles showed that air pollution slightly decreased between 1980 and 1995 thanks to technological improvements. Another effect treated is the loss of farmland around cities devoted to urban use, but there is no evidence that it caused a shortage of agricultural products. Brueckner (2000) and Brueckner et al. (2001) delimit his concerns about the negative externalities of sprawl in three. First, longer commuting times are associated with traffic congestion but the imposition of a congestion tax to reduce its use will result in an uncertain impact. Lower accessibility in the urban core from the suburbs to the inner city and decentralization of business activity to remote areas in which they are not taxed are symptoms of aggravating the sprawl situation. Besides, Glaeser and Kahn (2004) also emphasized the role of automobile and truck transportation modes in causing sprawl since they removed the orientation of firms and workers located in the city centre and unfold their infrastructure toward the suburbs. Second, it deals with the relationship between air pollution and urban sprawl. Brueckner (2000) also mentions the fact that newer cars are less contaminant than older and the unclear link between both variables. The U-shaped relationship between car emissions and car speed, together with the decentralization of jobs in metropolitan areas may be the reasons why previous authors struggle to find a clear relationship between both. Last but not least, sprawl may induce the loss of open space areas. Although the relationship between housing prices and sprawl is nonlinear, households value positively open spaces within suburbs such as public parks, privately owned open space, natural land cover surrounding the dwellings or access to natural views.

The continuous processes of urbanization and the concentration of population in Spain have not prevented the surge of sprawl. The strong changes in income per capita, social customs and land use pressure have made it possible. The morphology of the city of Barcelona has been deeply studied: while the urban core projects have really high levels of density, low-density patterns emerge outside. Rubiera Morollón et al. (2016) elaborated an urban sprawl index based on satellite georeference photos in which they delimit urban and rural pixels and count the number of urban pixels around them that are in an area of 1 km^2. In their results, Barcelona's urban area is close to the average urban sprawl values among Spanish urban areas, and it has even more dispersion than Madrid, Valencia, Seville, Málaga, and Bilbao. The main reason behind is explained due to the large number of municipalities that compose the urban area of Barcelona in comparison to the other areas. Garcia-López (2010) investigated the evolution of the population suburbanization in the city from 1991 to 2005 and found that the results are also consistent with a polycentric model. The urban expansion process was characterized by higher consumption in land for the residential areas but also followed by the increase in the occupied land of transportation infrastructure. It will evolve to an accessibility model in which the population concentrates along freeways and highways as long as the role of transportation infrastructure strengthens. Muñiz et al. (2008) studied the effect of the employment sub-centers on population density inside the polycentric framework. There are several sub-centers, and once you get distant to them, density decreases, although some of these sub-centers are located close to each other in space. The list is formed by Mataró, Terrassa, Sabadell, Vilanova i la Geltrú, Cerdanyola, Rubí, Martorell, and Sant Cugat and Granollers. Again Muñiz and García-López (2013) confirmed that individuals tended to locate outside Barcelona and that the density decreased for the period analyzed (1986-2001). The area experienced a structural and defined growth based on the location and the accessibility of transportation infrastructure.

The Diputació de Barcelona[2] analyzed the current situation and future strategies against the low-density cities pattern that the city of Barcelona is following (Muñoz et al., 2011). Catalonia has

[2]Diputació de Barcelona (The Barcelona Provincial Council) is the local institution charged with the government and administration of the province of Barcelona.

experienced a huge increase in the urban expansion process mainly through a low-density model. During the 1990s, where a lot of municipalities were undergoing a morphological and functional revolution, it emerged a new promotion of isolated and semi-detached houses. Muñoz stated that several phenomena were coexisting, a part from the intensification of low-density dwellings' construction. New semi-detached housing was concentrated in municipalities between 10,000 and 50,000 inhabitants, whereas isolated housing structures were more prone to develop in municipalities with less than 10,000 inhabitants. Nonetheless, the development of the semi-detached houses was more relevant if the units of comparison are the different metropolitan rings. In the period between 1987 and 2005, the share of semi-detached dwellings built was higher than isolated houses in all rings, not only in the metropolitan area of Barcelona as it may be expected. Notwithstanding, this new low-density form of urbanization implied a dispersion of the housing units among the territory, rather than concentrating them as it used to be before. The easier accessibility to consumption goods such as the car together with the lack of active policies to generate an adequate and competitive offer in housing have contributed to this process. The idea projected towards this kind of residential typology has helped consumers towards the association of modernity and quality to low-density settlements.

Housing Prices

Another core topic in urban development is housing prices. Housing differs from other indicators due to its heterogeneous component: dwellings could differ in size, age, style, interior features, utilities (heating and electrical), and location. Socio-economic and real estate determinants have a say in differentiating housing prices between cities. Generally, housing prices tend to go up in municipalities with a higher average income level, higher population density, or even higher population growth, more satisfaction with green areas, or with a larger share of international migration. Likewise, location is one of the determinants of housing prices. One of the assumptions of the monocentric model (Alonso et al., 1964; Mills, 1967; Muth, 1969) is that the price per square meter of housing decreases as the distance to the CBD increases. It surges the possibility for households to live in the suburbs of a city and pay lower housing prices. In this sense, individuals are able to sacrifice part of their wellbeing towards a more distant location. These geographical effects imply that distance and travel-time factors do matter for individuals to reside in one place or another (De Bruyne and Van Hove, 2013). Here it comes the trade-off between commuting and housing costs. Higher commuting costs imply a desire to live in the city center, but lower housing costs will stimulate individuals to move outwards. In cities with better transportation networks, individuals could decide to live far from the city centre and enjoy the lower land and housing prices and besides, dwelling sizes may be higher on average (Kulish et al., 2012). A part from the distance to the CBD, there are other facts that may influence housing prices. Conroy and Milosch (2011) showed for San Diego that a one-mile increase in distance from the coast may decrease the sale price on average by $8,680.

Nechyba and Walsh (2004) also mentioned that Americans were better off once they were growing in sprawling cities since they were able to enjoy higher levels of housing and land consumption for most households, although there are some associated costs. In the same manner, Ehrlich et al. (2018) found that urban sprawl may be strongly and negatively linked with the growth in real housing prices. The theory also states that housing prices in small areas should increase as the quality of life increases, since people will be willing to spend more to live in that area (Krupka and Noonan, 2009). One of the dimensions to measure the quality of life, according to the Eurostat, is the material living conditions. Among this indicator, household income and consumption are the sub-dimensions exposed, with a special reference to housing, which better defines citizen's material living conditions (Stiglitz et al., 2009). Differences in quality of life are also one of the determinants for households to choose the place of living, apart from wages and housing costs (Berger and Blomquist, 1992). Although the quality of life factor has not a direct effect on the decision, it influences the choice of destination once the decision to move is solid. By measuring the quality of life with housing prices, we should notice several aspects. First, the measurement of housing conditions should include all the physical characteristics of the dwellings and areas where the dwellings are located as well as the housing environment and cost burden indicators (Streimikiene, 2015). Hedonic regression models (Kuminoff et al., 2010) allow us to explain the willingness to pay for households given the different location and dwelling features. It can also be referred to as "an equilibrium relationship resulting from the interactions between all the buyers and sellers in a differentiated product market at a single point in time" (Rosen, 1974). All these facts should allow us to analyze if individuals are having a satisfactory accommodation and living standard. He also argues that good housing conditions do influence positively on individuals' health and child development. Second, it is relevant to know that housing prices may be correlated with land prices. Altuzarra and Esteban (2011) showed that there is a bidirectional relationship between both variables for Spanish provinces between 2005 and 2010, although the causality is stronger from housing to land prices but weaker in the other direction. Third, housing prices are a purely economic indicator and, perhaps, it is not able to capture other factors that may influence the quality of life of individuals, such as the level of services, leisure, income, negative externalities but also social relations, feelings, desires or perceptions.

3. Data

The Ministerio de Transportes, Movilidad y Agenda Urbana elaborated a statistical atlas for the delimitation of Spanish urban areas in 2018.[3] The data used came from several sources, which include the Censo de Población y Viviendas de 2011, the Encuesta de Población Activa de 2016 and the Nomenclátor de población 2017 compiled by the Instituto Nacional de Estadística (INE)[4] to

[3] Ministerio de Fomento; DG de Arquitectura, Vivienda y Suelo; SG de Suelo, Información y Evaluación (2018). Áreas urbanas en España 2018. Constitución, Cuarenta años de las ciudades españolas. http://atlasau.fomento.gob.es/

[4] INE (Instituto Nacional de Estadística) is the national statistics institute of Spain.

obtain accurate information to define the size of the population. According to the general criteria, big urban areas will have one municipality with at least 50,000 inhabitants and the municipalities that are included in plurimunicipal urban areas will have at least 1,000 inhabitants. According to this atlas, the urban area of Barcelona is comprised of 165 municipalities.

Given that the data comprehends the period between 2013 and 2019, the number of observations is 1,155. One novelty in the data collection process is related to the indicators extracted from Google Maps, such as the distance to the CBD, Barcelona, in kilometres and minutes. It has been computed manually and uniformly for April 7th, 2020, at 9 a.m. C.E.T. for all observations to keep consistency. Plaça Catalunya is considered the centre of the CBD for this analysis. Appendix B also explains how the alternative variables to measure sprawl, such as the mobile and radio coverage signals, have been computed and which criteria was followed in each case. The other interesting variables related to distance to hospital in time and km have been obtained following a detailed process that is described in Appendix C. Appendix A shows the descriptive statistics for all the variables categorized by main, control and alternative measures of sprawl. Besides, it also shows further details about the sources and periods in which all indicators have been extracted.

In 2019, the total population in the urban area of Barcelona was 5,156,625 persons, occupying an equivalent extension of 3,275.80 km^2. It is one of the most populous urban areas in Europe and some municipalities such as l'Hospitalet de Llobregat (20.422 hab/km^2), Santa Coloma de Gramanet (16.728 hab/km^2) and Barcelona (15.843 hab/km^2) are amongst the cities with the highest values of density in Europe. The centre of the area is Barcelona with more than one million and a half inhabitants. Then, it emerges a first ring with high-density values and formed by 36 municipalities, a second ring with lower density but also with the inclusion of big industrial areas apart from the residential ones, and finally, it appears "an arc with metropolitan corridors mixing urban and rural uses" (Muniz et al., 2003).

All these municipalities belong to 9 smaller areas equivalent to a fictitious level 4 in the NUTS[5] scale in Spain, below regions. From now on, I am going to consider them as counties. These are Alt Penedès, Baix Llobregat, Barcelonès, Garraf, Maresme, Moianès, la Selva, Vallès Occidental and Vallès Oriental. At the same time, some of these counties are subdivided, either by associative reasons, natural reasons, or because they have been historically claimed by their population. These are Baix Llobregat Nord (in Baix Llobregat), Alt Maresme and Baix Maresme (in Maresme), Baix Montseny (in Vallès Oriental), and Selva Marítima[6] (in Maresme and la Selva).

[5]The NUTS classification (nomenclature of the territorial units for statistics) is a hierarchical system for dividing up the economic territory of the EU and the UK.

[6]The 6 municipalities that belong to Alt Maresme and Selva Marítima counties at the same time are considered to belong only to the latest.

4. Empirical Approach

Model

Royuela et al. (2010) studied the influence of quality of life on urban growth in the province of Barcelona. They highlight the high degree of heterogeneity between the municipalities and the need to be aware of some connected areas that will experiment a growth in population and a need for institutions to expand the provision of public services. Quality of life plays a role in driving urban growth, but with a lower extent than the main indicators suggested in the literature: urban size, network economies, and distance from the centre of the metropolitan area.

My hypothesis goes the other way around. I develop a pooled cross-sectional approach to analyze the impact of urban sprawl on quality of life – proxied using in housing prices - between 2013 and 2019. Individuals who decide to live outside the city pay less for housing, but are willing to accept all the issues derived from staying far from the urban core. For this reason, I start with the following equation:

$$Price\ per\ sq.\ meter(ln)_{it} = \alpha + \beta_1 \times low - dens_{it} + \beta_2 X_i + \beta_3 X_{it} + \gamma_t + \epsilon_i \quad (1)$$

Where the price per square meter in logarithms is the dependent variable and low-density areas is the main variable of interest. There are two types of control variables: X_i refers to a set of time-invariant controls for one year, whereas X_{it} is associated with controls that vary each year. Finally, γ_t accounts for yearly fixed effects and ϵ_{it} is the error term. Now, I am going to explain in detail all these variables.

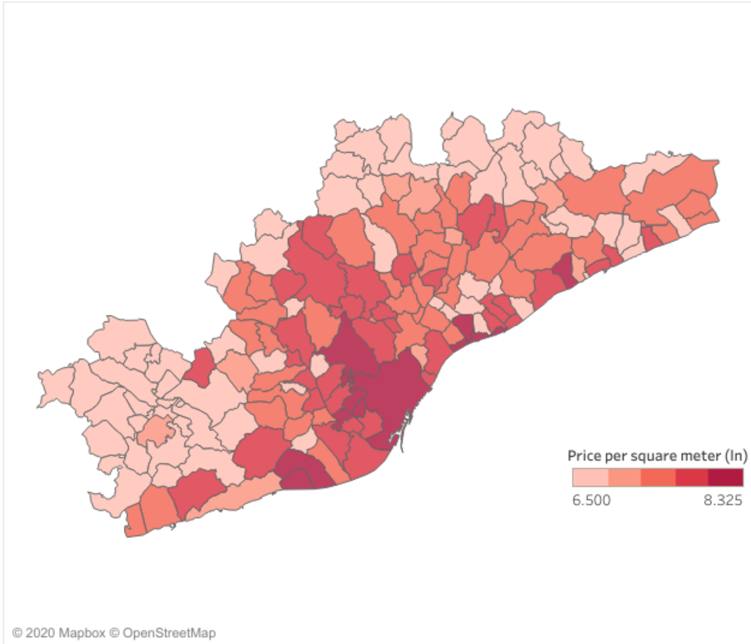
Dependent variable

The proper measurement of the quality of life of individuals is complex and subjective. I mentioned the different methods used in previous literature and the good approximation of doing it with housing prices. Krupka and Noonan (2009) already used housing prices as a proxy for quality of life. The idea behind this reasoning states that, in a small area, housing prices should increase as the quality of life increases. Individuals will be willing to pay more money to live in that area, and here we can deduce why some municipalities ask for a higher housing price to buyers and why others do not. The reasons could be diverse: closer distance to the CBD and/or the workplace, higher accessibility to a great number of services and leisure activities, efficient transportation networks, etc. Individuals decide where to live but they face a price for living there. Since it is possible to know the *price per square meter* for municipalities in the urban area of Barcelona, I am going to use this variable as a proxy for quality of life. There are some implications for its use. First, the information is only available for municipalities that have more than 5,000 inhabitants, and it refers to all dwellings involved in buying and selling activities for each year, no matter if the building was new or second-handed. Nonetheless, I expect that the core of the question will be captured, considering that there are also municipalities with more than 5,000 inhabitants outside the metropolitan area of Barcelona, which is formed by 36 municipalities from a total of 165. A second implication will be the use of the log form of regression. It grounds on the fact that this method allows controlling for possible nonlinear relationships between housing prices and its causal factors (Potepan, 1996; Malpezzi, 1996; Glaeser and Gyourko, 2002; Wassmer, 2000).

The continuous increase in housing prices during the 1990s resulted in a higher effort for families to access housing. Muñoz et al. (2011) documented that, at the end of that decade, the economic expenditure devoted to the payment of the mortgage achieved 54% of the total amount of young family revenues. During those years, it surged the maximum difference in housing accessibility in terms of prices between metropolitan municipalities. Barcelona, Begues, el Masnou, Sant Cugat del Vallès, and Sant Just Desvern became examples of less accessible municipalities for new construction buildings. Conversely, municipalities such as Castelldefels, Cerdanyola del Vallès, Granollers, Mollet del Vallès, Sabadell, Sant Boi de Llobregat, Terrassa, Viladecans, or Vilanova i la Geltrú became more attractive and affordable for those families. This range of new buildings was semi-detached and characterized by offering more competitive prices rather than the more compact and dense urban forms than the city center. All these urbanization patterns have eased the appearance of semi-detached or scattered dwellings, in most of the cases, urban dispersed. Still, the presence of building blocks was relevant in the cores of the municipalities.

Figure 1 displays the natural logarithm of the price per square meter for the municipalities of the urban area of Barcelona. For simplicity, the map is based on 2019 data since not many changes are expected in the period analyzed (2013-2019). With the data available for municipalities with more than 5,000 inhabitants, Barcelona, its metropolitan area and coastal municipalities show higher prices in comparison to the rest of municipalities. From Muñoz et al. (2011), the less accessible municipalities in terms of prices still continue to be the most expensive ones, especially highlighting the cases of Barcelona, Sant Cugat del Vallès, and Sant Just Desvern. The latest two are adjoined with Barcelona through the Collserola mountain range and are also characterized by possessing high income per capita. The so-called metropolitan rings could also be identified in the figure by taking Barcelona as the centre of the first ring. Once we move outwards, housing prices tend to decline.

Figure 1: Price per square meter (ln)for each municipality, 2019



Note: The figure plots the price per square meter (ln) for municipalities with 5,000 or more inhabitants for 2019. The data for municipalities with less than 5,000 inhabitants is not available and is depicted in the lightest color. The municipality of Barcelona is the one located in the centre of the whole coastline, colored with a dark red and occupying a big area in km^2.

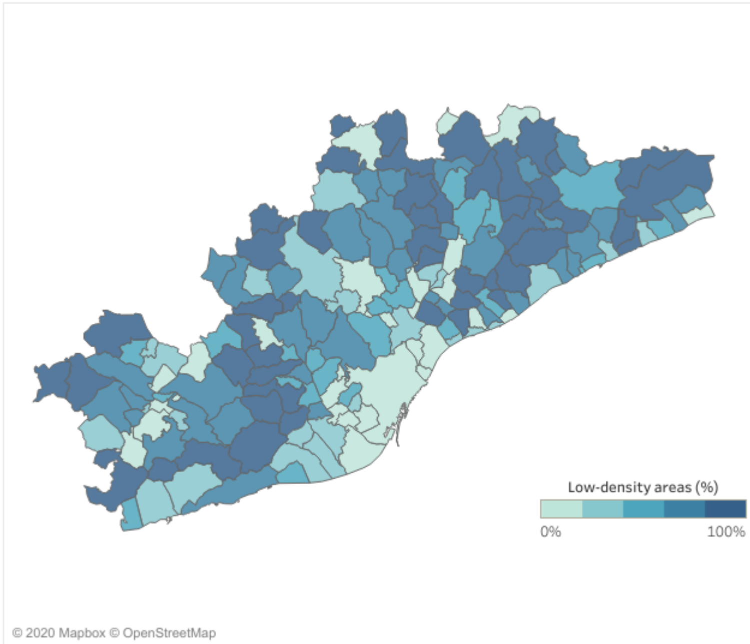
Independent variable

There is no general consensus in the measurement of urban sprawl since the concept arose. Recalling previous research, urban sprawl patterns have been predominantly linked with density indicators. Other measures of low-density pattern include urban land, land cover or employment densities. Since these concepts may be too generic, I will try to get a more accurate proxy to measure this pattern.

The Mapa Urbanístic de Catalunya (MUC) is a synthetic map that elaborates the Department of Territory and Sustainability of the government of Catalonia with the aim of achieving a continuous picture of how distributed the urban land of the region it is. The map is elaborated at the municipal level. For each unit, they construct a graphic adaptation of the original documentation in a raster format file obtained from the Registre de Planejament Urbanístic de Catalunya (RPUC) over an official topographic base in a 1:5000 scale.

Urban land qualifications are displayed in several categories to determine their main use and sub-use. The urban land uses are divided into housing, economic activity, and other uses (urban reform, conservation and mixed uses). Only the first sub-use of land will give the distribution of the dwellings in each municipality. On it, we can distinguish six sub-levels of residential land: historical population centre, traditional urban centre, closed disposition, open disposition, dwellings in rows, and isolated and semi-detached buildings. Indeed, the last sub-level is also defined as extensive dispositions of *low-density*, isolated and semi-detached housing for single-family residential use. Or even with a garden-city shape. Hence, this sub-level is able to measure the number of hectares that each municipality has with low-density urban use.

Figure 2: Share of low-density areas for each municipality, 2019



Note: The figure plots the share of low-density areas for each municipality for 2019. The concept includes all low-density settlements, from semi-detached and isolated houses to garden city structures.

Figure 2 displays the percentage of low-density areas with respect to the total residential land for the 165 municipalities comprised in the urban area of Barcelona. In Barcelona and its nearest surrounding area, the share of isolated or semi-detached houses does not surpass the 60%. Cornellà de Llobregat (0%), Ripollet (2.4%), and Barcelona (7.3%) are clear on the lower bound of the list with almost no signs of low-density patterns. Conversely, there is some kind of spatial association of closer towns concentrating high values of low-density dwellings across the rest of the urban area of Barcelona. These areas are partly located in valleys, mountainous areas or in peri-urban and rural areas. More than 30 towns show low-density values over 90%, such as Olivella (98.3%), Bigues i Riells (96.9%), and Vallirana (96.9%), among others.

Control variables

The urban area of Barcelona is characterized by its heterogeneity. One of the features is the difference in density values: some areas concentrate the major part of the population, while others tend to show noticeable low-density patterns. Likewise, municipalities characterized by higher housing prices tend to be located in the metropolitan area, in places with good network communications, but also on the coast. To capture all these features, several control variables are defined.

In terms of the geographical controls, I incorporate two variables. Conroy and Milosch (2011) found that the value of housing increases if it is close to the coast. For this reason, I incorporate a dummy variable named *coast* to check for the availability of coast for each municipality with value 1 if it has direct access to the coast and 0 otherwise. Another relevant physical variable is the distance to the CBD. Although the demise of the monocentric model in Barcelona's urban area is a fact (Garcia-López, 2010), the city centre is still exerting a high influence on the territory. Consequently, the model incorporates the natural logarithm of *the distance in kilometers to Barcelona* from each municipality. With this indicator, I am expecting to capture those municipalities that have more difficulties in arriving to Barcelona.

The use of a hedonic price model approximates better the disposition of housing prices, given that the dependent variable incorporates all buying and selling activities of dwellings for the period mentioned (Rosen, 1974). Likewise, the importance of identifying the dwelling characteristics of each municipality is the key for an adequate measurement of the quality of life, in this case through housing prices (Streimikiene, 2015). This is the reason why I incorporate a set of dwelling and building controls that will help in defining the specific particularities of the households' structure for each municipality. First, it is essential to include the *average building area* for each municipality to look for the dimensions of the buildings. I expect a bigger size in the buildings outside Barcelona and its metropolitan area than in the rest of the municipalities. This control is only available for municipalities with more than 5,000 inhabitants from 2013 to 2019. The subsequent variables are only available for 2011 but they are still relevant and time-invariant. I also add the *number of rooms* of each dwelling by calculating the share of dwellings that have, for instance, 1 room with respect to the total number of dwellings of the municipality. The same process was done for all the range of rooms that goes from 1 to 9 or more. The concept of rooms includes bedrooms, living rooms, kitchens and closed terraces of the dwelling, but not bathrooms, halls, corridors or open terraces. Municipalities with a higher number of rooms tend to occupy a bigger share of land than small flats. I also control for the existence of an independent and structurally separated space for a *garage* in the same building, independently of whether it is used by the households or not. Big cities cannot assure a space for parking the car to all households due to the lack of space but in areas with a large number of semi-detached or isolated houses, it is likely that each dwelling has a parking slot. Finally, I gather the construction year for each building in yearly ranges by computing the percentage of buildings with the same *construction year period* in each municipality. The ranges are before 1900, 1900-1920, 1921-1940, 1941-1950, 1951-1960, 1961-1970, 1971-1980, 1981-1990, 1991-2001 and 2002-2011. The expansion of urban sprawl is a recent phenomenon in the urban landscape, so this indicator may allow identifying those new residential areas characterized by low-density patterns. All regressions incorporate yearly fixed effects to avoid disparities in the values.

Alternative measures of urban sprawl

The difficulties of measuring sprawl accurately have been evident through previous research. For this reason, I am going to suggest other indicators that may capture low-density patterns in

Barcelona's urban area. The idea is that low-density settlements do not present similar features through the territory: more costly accessibility to big cities or amenities, lower number of amenities or difficulties in coverage signals. Appendix D depicts in a map each of the following indicators proposed. Values in Barcelona and its first ring tend to show similar intensities in the colors despite the fact that all variables have different behaviors over the municipalities. Here are the measures proposed.

Distance to Barcelona in public transportation (time). This variable consists in computing with Google Maps the time needed to arrive to Barcelona from each municipality. Bus, train, railway, and metro are the transportation modes included in the measurement of the variable. Municipalities characterized by scattered or isolated areas will have more difficulties in establishing a fast and continuous connection with the city. Due to the high variability in the values, which are in minutes, I transform this variable to its natural logarithm.

Distance to the closest hospital (km). This variable tries to offer a more polycentric perspective of urban sprawl. The inclusion of the network of public hospitals along the territory allows me to distinguish other important municipalities that are meant to be important or act as sub-centers, as Muñiz et al. (2008) identified with employment. This variable will also be transformed to its natural logarithm for the same reason as the latest. Appendix C displays the hospitals selected in the sanitary network together with the municipality in which they are established.

Distance to the closest hospital in public transportation (time). Apart from knowing the distance in kilometres, it is interesting to see the estimated time to the nearest hospital by public transportation. These modes of transport do usually require more time than private cars, so the adequacy of transportation connections are going to determine whether it is needed more time or not to take the journey. Time is measured in minutes. Again, this indicator will use the natural logarithm to control for disparities in the timing values.

Number of cars per capita. This variable works under the hypothesis that the metropolis and surrounding municipalities do enjoy a good public transportation infrastructure, and individuals do not always need a car to travel, commute or do any other activity. Conversely, municipalities located far away from cities or sub-centers are expected to need a car to exert any of those activities mentioned. Hence, metropolitan municipalities should show a lower number of cars per inhabitant in comparison to the rest. Private cars include all four-wheel vehicles with a maximum capacity of 9 seats.

Number of pharmacies per 1,000 inhabitants. With this proxy, the aim is to look for the number of pharmacies per 1,000 inhabitants per municipality, as an example of shop or business. Areas characterized by low-density patterns should have fewer pharmacies or services in general. This variable was only available for 2001.

Percentage of population in city centre. Municipalities with a large share of low-density areas tend to have the population scattered along the municipal area in the form of urbanizations or isolated residential areas. This may be one of the features to identify urban sprawl. Here, I compute the percentage of the population living in the most populous nucleus with respect to the total number of inhabitants of each municipality. Populous nucleuses are considered the combination of at least ten buildings that form streets, squares, or other urban ways. If this first condition is not fulfilled, the number of inhabitants of this area should not be lower than 50. Cities of the so-called first metropolitan ring are expected to show values close to 1, whereas the value will be lower for those municipalities with distinct populated areas or urbanizations scattered within the limits of the municipality.

Radio signal. Low-density areas tend to be scattered with space and maybe far from its CBD. The coverage of the radio station Catalunya Ràdio will allow us to control for those areas that present radio coverage issues due to its location. Since the whole territory is not flat, I expect lower coverage signal in municipalities characterized by isolated, mountainous, peri-urban, or rural land. Recall that some municipalities that are located above 300 meters above sea level do show low-density patterns. Appendix B explains the extraction process for this indicator.

Mobile signal. This variable works in a similar way than the latter. I expect a strong mobile signal in places located close to the metropolitan area and lower in more scattered places. One of the strengths of this variable is the massive number of observations used to compute it, which is detailed in Appendix B.

5. Results

I first develop a pooled cross-sectional analysis of low-density areas and quality of life for the municipalities of Barcelona's urban area. Based on equation 1, Table 1 shows the primary results for my hypothesis. All regressions are robust to heteroskedasticity and with the standard errors clustered at the municipality level. At the same time, I incorporate year fixed effects to capture any variation in prices over time. I expect that municipalities with a higher share of semi-detached and isolated houses will have a lower price per square meter. Column (1) shows that low-density areas have a significant and negative impact on housing prices: for each additional percentage point increase in the share of semi-detached or isolated housing areas in the municipality, the price per square meter decreases by 3%. This finding goes in line with Ehrlich et al. (2018), in which he found that urban sprawl is negatively associated with real house price growth. From Figure 2, municipalities with higher shares of low-density values are concentrated in less dense and more isolated areas from big cities or counties' capitals, and that is why prices are lower. Column (2) adds a range of controls to check for the variability in the dwellings' features. The coefficient for the main variable of interest drops but remains significant.[7] The inclusion of these controls contributes, to a great extent, in explaining more than the 90% of the variability of housing prices.

[7] The buildings' floor area control is positive and significant and increases the price for any extra unit of floor area. The hypothesis is fulfilled with the share of dwellings with garage, which increases in those areas with low price per square meter, so the ones that are characterized by low-density patterns.

Table 1: Pooled cross-section OLS with low-density areas' variable

	OLS			
Price per square meter	(1)	(2)	(3)	(4)
Low-density area	-2.919***	-1.100***	-1.039***	-0.768**
	(0.798)	(0.331)	(0.327)	(0.303)
Ln Dist. to Barcelona (km)			-0.294**	-0.672***
			(0.139)	(0.216)
Coast			0.172	0.321
			(0.204)	(0.213)
Constant	6.305***	0.543*	1.707***	2.929***
	(0.496)	(0.325)	(0.641)	(0.885)
Observations	1,155	1,155	1,155	1,155
R-squared	0.066	0.931	0.932	0.938
Dwelling Controls	No	Yes	Yes	Yes
County FE	No	No	No	Yes

Note: The dependent variable only includes values for the municipalities over 5,000 inhabitants. Column (2) includes dwelling controls: average building area, garage availability, number of rooms and building construction in 10-year range periods. Column (3) adds geographical controls and Column (4) adds county fixed effects. Robust standard errors (in parentheses) are clustered at the municipal level. *** p<0.01, ** p<0.05, * p<0.1

Once we control for geographical features in Column (3), the coefficient keeps similar values, which means that a one standard deviation increase in low-density areas is associated with a reduction of the price by 32%. The closeness of some low-density areas to the core of the urban area could be behind this plunge in prices. Similarly, it also turns relevant the distance to Barcelona. An increase of 1% in the distance to Barcelona means almost a 0.3% decline in the price per square meter. The dummy for the coast suggests that it is not a relevant indicator to determine housing prices in this model. When I control for county fixed effects (Column (4)), I see that it does not imply much changes, and it barely increases the goodness of fit. The main explanatory variable drops but continues to be significant. Therefore, the results of the next stages will be reported without county fixed effects.

In practice, I could exemplify these results evaluating the effects of an individual moving from one municipality to another. I will take Column (3) as the reference. For instance, Cardedeu has 18,357 inhabitants (2019) and it is located in Baix Montseny county. The mean income per capita before taxes in this municipality is €18,512. A second municipality, Sant Joan Despí, has 34,123 inhabitants and it is placed in Baix Llobregat county. The income per capita here is €18,718. Both municipalities are inland and are close to the capital of the county (Granollers and Sant Feliu de Llobregat respectively), but they are 42 km and 17 km far from Barcelona, respectively. Low-density areas occupy the 55% of the territory in Cardedeu, whereas only the 1% in Sant Joan Despí. If I live in Cardedeu and I want to move to Sant Joan Despí, I will face higher housing prices. According to our model, the predicted price per square meter in Cardedeu will be equal to €1,565.64, whereas in Sant Joan Despí will be €1,720/m^2. Considering housing prices a proxy for quality of life, this shift in municipalities will raise my wellbeing by 9.8%. Although some municipalities with the highest rent per capita in the urban area show low-density patterns and are not located close to Barcelona, the overall effect is stronger to think that these isolated and semi-detached housing patterns are linked with lower housing prices. Within the urban area of Barcelona, a higher share of low-density areas is associated with an increase in the municipality income before taxes. But the rent dimension is not studied in this paper and may be left to another project.

Table 2 may strengthen the primary results obtained. The metropolitan transportation authority of Barcelona (ATM) divides the municipalities in different tariff rings for all transportation modes with the center located in Barcelona city. I am going to split the municipalities to see if the effect on housing prices varies depending on the transportation ring. Appendix D shows how the metropolitan transportation institution distributes the municipalities in different rings. I use the same econometric method as in Table 1. All regressions are robust to heteroskedasticity and with the standard errors clustered at the municipal level. Column (1) includes the municipalities that belong to the first ring for the period 2013-2019. One standard deviation increase in the percentage of low-density areas is associated with an increase in housing prices of 28%. There is a range of municipalities in this ring that show high patterns of isolated and semi-detached houses, but its proximity to Barcelona makes them to show higher prices per square meter. Some of these municipalities are located in the county Baix Llobregat, either in valleys or scattered in the mountains.

Column (2) projects the regression for the second ring composed of 71 municipalities. Once we get far from Barcelona, the coefficient for low-density areas keep significant but changes to a negative sign. This coefficient is similar to the baseline results considered from Column (3) in Table 1. The negative effect of low-density areas with respect to housing prices is accentuated in Column (3) when I only use the 45 municipalities of the third ring. The more distant to Barcelona, the more negative the impact. The distance to Barcelona behaves in an inverse way in comparison to the main variable of interest, from lower to higher. It is only significant for the first ring of municipalities. Muñoz et al. (2011) reported that semi-detached dwellings in the first ring tended to lose space, whereas in the second and third ring the dwellings constructed occupied more space. Direct coastal access does not either contribute to explain housing prices under the transportation rings set-up, although all the dwelling controls added in Table 1 remain relevant here.

Table 2: Pooled cross-section OLS - Split Sample

		OLS	
Price per square meter	(1)	(2)	(3)
Low-density area	0.889*	-1.200***	-1.743**
	(0.496)	(0.361)	(0.734)
Ln Dist. to Barcelona (km)	-1.273***	0.527	1.101
	(0.179)	(0.354)	(1.205)
Coast	0.115	0.285	-0.0234
	(0.164)	(0.202)	(0.418)
Constant	-58.24***	-10.28	3.077
	(10.25)	(6.780)	(9.382)
Observations	252	497	315
R-squared	0.936	0.950	0.943
Dwelling Controls	Yes	Yes	Yes

Note: The dependent variable only includes values for the municipalities over 5,000 inhabitants. Column (1) includes the 36 municipalities of the first tariff ring in public transportation for the period 2013-2019, Column (2) adds the 71 municipalities of the second ring also for each year, and Column (3) works with the 45 municipalities of the third ring for each year. All regressions incorporate the dwelling controls: average building area, garage availability, number of rooms and building construction in 10-year range periods, as well as the geographical controls for distance to Barcelona and direct coastal access. Robust standard errors (in parentheses) are clustered at the municipal level. *** p<0.01, ** p<0.05, * p<0.1

Next, I investigate the use of other alternative variables to measure urban sprawl unrelated to urban land. Due to the difficulty of establishing an adequate measure of sprawl, I suggest several indicators. Table 3 displays the proposed measures together with the suitable controls used before. All regressions are using a pooled cross-section OLS for the period between 2013 and 2019. They are also using robust standard errors and are clustered at the municipal level. The model in Column (3) of Table 1 turns to the baseline specification since the inclusion of fixed effects through the different counties does not add new information. Each of the columns in Table 3 corresponds to a different indicator. In Column (1) it turns out that the distance to Barcelona with public transportation is not significant to determine housing prices. It is the same case for the logarithm of the distance in kilometers to Barcelona, which acts as a control but has lost its significance. The reason is that the correlation between both is 0.8554, and I should drop the second to consider it as a proxy of sprawl since then it would be significant. Column (2) uses the distance from each municipality to its nearest hospital in kilometers. It is significant and shows the expected sign: an increase of 1% in the distance to the hospital implies a decrease in the price of 0.3%. Municipalities with a predominant scattered housing structure become cheaper once we are more distant to the closest hospital. As I commented before these hospitals could act as sub-centers to proxy polycentrism in the territory. This distance could also be analyzed in time and with public transportation (Column (3)). The coefficient slightly diminishes but preserves the sign for this indicator. Apart from being far from Barcelona, municipalities with low-density structures tend to need more time or traverse more distance to reach essential services like hospitals. Nonetheless, it could also be the case that urban sprawl in this urban area is not concentrated along highways or good transportation networks but rather in peri-urban, rural or mountainous areas. These hospitals are generally located either in big cities in terms of population or in the capital of the different counties that may be settled in strategic areas.

Column (4) adds the number of pharmacies per 1,000 inhabitants. Although it has the expected positive impact, a greater amount of pharmacies increase housing prices, and it is not statistically relevant. It seems that some municipalities showing low-density patterns with a low amount of population do have pharmacies and others not; and some big cities have a low rate of chemists because of their high density. Interestingly, the number of cars per capita in Column (5) is significant and positive: any increase in the number of cars per capita will result in higher housing prices. The initial hypothesis is those dense areas do have better public transportation infrastructure, and not all workers need a private car to commute, there is also less space for parking cars in the streets, and parking slots are more expensive. I interpret that individuals who live in expensive areas have high income and possess more than one car, but it may also be the case for metropolitan municipalities. Column (6) adds the percentage of inhabitants living in the most populous area of each municipality. It is interesting to see how municipalities in the first metropolitan ring concentrate their population in only one nucleus, as Appendix E shows. Despite obtaining the positive expected sign, it is not statistically significant in this set up.

The final columns include two novel components. Column (7) introduces the coverage of radio station Catalunya Ràdio in the territory. It is clearly significant, meaning that a one percentage unit increase in the radio signal is associated with a 1.6% change in the logarithm of the price per square meter. The radio coverage signal is already high in all municipalities – reaching values above 90% -, except for some specific areas that may be characterized by semi-detached houses. The other indicator is mobile signal (Column (8)). Although the effect is not as strong as before, it is positive and relevant for those areas with higher housing prices. Appendix E projects all these measures, one by one, in maps. Municipalities in the first ring tend to show similar values that progressively decrease or increase as long as we look outwards. The range of controls continues to be significant in general, except for the coastal dummy: within the urban area of Barcelona, the price per square meter is not influenced by direct coastal access. This argument could be subject to one limitation: the lack of available housing data for those municipalities below 5,000 inhabitants that are predominantly inland located. Those municipalities, which some of them show low-density patterns if I take into consideration the first variable low-density, may be cheaper for buyers who want to install there.

Table 3: Alternative measures of urban sprawl

	OLS							
Price per square meter	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Ln Dist. Barcelona pub.trans. (time)	0.081							
	(0.265)							
Ln Dist. hospital (km)		-0.346***						
		(0.088)						
Ln Dist. hospital pub.trans. (time)			-0.259***					
			(0.056)					
Pharmacies per 1,000 inhab.				0.378				
				(0.416)				
Cars per capita					0.155*			
					(0.08)			
Pop city centre						0.0732		
						(0.324)		
Radio signal							1.654***	
							(0.354)	
Mobile signal								0.097**
								(0.046)
Constant	1.289**	2.213***	2.224***	1.413**	1.299**	1.379**	0.503	0.0917
	(0.603)	(0.655)	(0.687)	(0.595)	(0.601)	(0.597)	(0.537)	(0.840)
Observations	1,155	1,155	1,155	1,155	1,155	1,155	1,155	1,155
R-squared	0.928	0.932	0.934	0.928	0.928	0.928	0.934	0.930

Note: The dependent variable only includes values for the municipalities over 5,000 inhabitants. All regressions incorporate the dwelling controls: average building area, garage availability, number of rooms and building construction in 10-year range periods, as well as the geographical controls for distance to Barcelona and direct coastal access. Robust standard errors (in parentheses) are clustered at the municipal level. *** p<0.01, ** p<0.05, * p<0.1

6. Conclusion

This paper studies the effects of urban sprawl on quality of life in the urban area of Barcelona. Given the difficulties of measuring individuals' quality of life properly, I proxy this concept with a pure socioeconomic variable, housing prices (Krupka and Noonan, 2009). To the best of my knowledge, this is the first study that establishes a link between sprawl and quality of life. Besides, the context of Barcelona is particularly interesting as the morphology of the urban area of Barcelona is quite heterogeneous, and urban sprawl is very present in a large number of municipalities outside the urban core.

To carry out this empirical analysis, I use a pooled cross-section OLS to measure how urban sprawl patterns affect individuals' quality of life. The main result states that areas characterized by semi-detached and isolated houses are associated with lower prices per square meter and thus, to lower quality of life. This is the general trend for the 165 municipalities that form the urban area of Barcelona. If I consider only the first metropolitan ring composed of 36 municipalities, then low-density patterns increase housing prices. The appearance of urban sprawl and the suggestion of a polycentric scheme for the urban area of Barcelona - mentioned in previous literature - do not imply that the distance to Barcelona does not affect housing prices. Barcelona and its metropolitan area show significant and higher values for housing prices that progressively decline once you get far from the core.

This thesis also presents alternative measures of sprawl. I introduce an indicator to simulate subcenters, given the polycentric structure of the area of Barcelona (Muñiz et al., 2008). This indicator consists of the distance in kilometers and in time from each municipality to the closest hospital. Municipalities that are distant (in kilometers or time) to the nearest hospital show lower housing prices. Both variables result feasible and, together with mobile and radio coverage signals, they are the best proxies of sprawl, given the low-density pattern in housing prices and the morphology of the urban area of Barcelona. The buildings' features, such as the average building area and the garage availability, remain key factors to explain the major part of the variability of housing prices. Conversely, it seems that those municipalities with direct access to the coast do not have strong relevance to determine prices in the model. Geographical controls or fixed effects are not able to capture spatial patterns clearly, except for the distance from each municipality to Barcelona.

In line with the current results, it would be interesting to analyze the relationship between urban sprawl and income per capita. Some of the municipalities that show low-density patterns share the similarity of having high levels of income. Perhaps, a segment of the rich population prefers to live in big semi-detached houses outside the urban core with larger housing units, and they do not matter if they have to commute larger distances. Or, it could be the case that these individuals use these houses only in summer and they do not live there during the major part of the year.

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Appendix

Appendix A. Descriptive Statistics and Source

Table A.1: Descriptive Statistics and Source

	Mean	Descriptive SD	Statistics Min	Max	Data Sources and Period
Panel A: Main Variables					
% Low-density areas	0.579	0.314	0	1	Dades Obertes, 2013-19
Ln Price per square meter	4.654	3.587	0	8.376	Habitatge Gencat, 2013-19
Panel B: Control variables					
Ln Dist. Barcelona (km)	3.575	0.562	0	4.394	Google Maps, 2020
Coast	0.164	0.370	0	1	Dades Obertes, 2020
Average building area (m^2)	72.60	62.27	0	242.9	INE, 2011
% Buildings with Garage	0.490	0.199	0	0.913	INE, 2011
% Buildings with 1 Room	0.005	0.007	0	0.037	INE, 2011
% Buildings with 2 Rooms	0.029	0.018	0	0.089	INE, 2011
% Buildings with 3 Rooms	0.120	0.047	0	0.237	INE, 2011
% Buildings with 4 Rooms	0.200	0.052	0	0.297	INE, 2011
% Buildings with 5 Rooms	0.291	0.069	0	0.478	INE, 2011
% Buildings with 6 Rooms	0.202	0.057	0	0.325	INE, 2011
% Buildings with 7 Rooms	0.074	0.045	0	0.212	INE, 2011
% Buildings with 8 Rooms	0.033	0.026	0	0.111	INE, 2011
% Buildings with 9 or more Rooms	0.028	0.028	0	0.171	INE, 2011
% Buildings with Cons. before 1900	0.047	0.061	0	0.308	INE, 2011
% Buildings with Cons. 1900-1920	0.025	0.036	0	0.241	INE, 2011
% Buildings with Cons. 1921-1940	0.018	0.018	0	0.120	INE, 2011
% Buildings with Cons. 1941-1950	0.019	0.020	0	0.118	INE, 2011
% Buildings with Cons. 1951-1960	0.048	0.039	0	0.234	INE, 2011
% Buildings with Cons. 1961-1970	0.118	0.083	0	0.389	INE, 2011
% Buildings with Cons. 1971-1980	0.193	0.095	0	0.854	INE, 2011
% Buildings with Cons. 1981-1990	0.135	0.079	0	0.433	INE, 2011
% Buildings with Cons. 1991-2001	0.191	0.092	0	0.509	INE, 2011
% Buildings with Cons. 2002-2011	0.162	0.100	0	0.587	INE, 2011
Panel C: Alternative measures					
Ln Dist. Barcelona pub. trans. (time)	4.279	0.535	0	5.881	Google Maps, 2020
Ln Hospital (km)	2.107	0.762	-1.050	3.640	Google Maps, 2020
Ln Hospital in pub. trans. (time)	3.183	1.225	0.693	6.928	Google Maps, 2020
% Pop. in city center	0.701	0.287	0.114	1.119	Prog. HERMES, 2013-19
Cars per capita	0.453	0.408	0	11.90	Progr. HERMES, 2013-18
Pharmacies per 1,000 inhab.	0.368	0.253	0	1.608	Progr. HERMES, 2002
% Radio signal	0.828	0.208	0	1	Dades Obertes, 2019
Mobile Signal	12.34	1.918	6.039	16.97	Dades Obertes, 2015-17

Note: The data sources mentioned in the table but not in the text are the following: Dades Obertes, which corresponds to an open database of the regional government of Catalonia; Habitatge Gencat that stands for the Housing Department of the regional government of Catalonia; and Programa Hermes, which was a program created by Diputació de Barcelona in 1998 in which they display a database with the socioeconomic characteristics of the municipalities of the province of Barcelona until today.

Appendix B. Data

The process of collecting the data for radio and mobile coverage signals is described below. The first variable is the coverage of the radio station Catalunya Ràdio, 102.8 in the FM broadcasting, for all populated areas that belong to each municipality. For municipalities with only one population center, such as Barcelona, only one signal of coverage was collected as a reference. However, in towns with more than one populated area, I computed the average of coverage for all areas. Although each populated area may receive the coverage signal from different telecommunication towers, only the tower with the highest value of coverage was collected. The list of emission towers covering the whole urban area – or outside it, but at least receiving any signal from a municipality of the urban area– is the following: Arbúcies, Arenys de Munt, Cabrils-Mataró, Calella, Collserola, Collsuspina, Igualada, Lloret, Montcaro, Montserrat, Mussara, Pujal, Rocacorba, Sant Celoni, Sant Hilari Sacalm, Sant Pere de Ribes and Vendrell.

The second variable is encompassed in the application Cobertura Mòbil directed by the Department of Polítiques Digitals i Administració Pública. The project tries to map the mobile network of the region and deal with those areas that suffer coverage difficulties. One of the aims is to improve the coverage of the emergency services number, 112. More than 6,000 individuals have downloaded the application and have proportionate more than 7.4 million observations of coverage signals between 2015 and 2017. Among these observations, 6.4 million correspond to the municipalities of the urban area of Barcelona. This coverage signal is basically organized in the so-called Arbitrary Strength Unit (ASU), which measures the signal strength received by the mobile phone. Values range from 6 (weaker signal strength) to 17 (stronger signal strength). I uniformed all signals received by computing the mean strength signal for each municipality across all observations and all days of the period mentioned. It is important to clarify that the number of observations received by the municipality is similar to the number of inhabitants that each municipality has, but there are not any criteria behind defined.

Appendix C. Hospitals criteria selection

The regional health department of Generalitat de Catalunya (Departament de Salut) provides a list with the main public hospitals throughout the province of Barcelona with its corresponding address and municipality.[8] Table A.2 in the Appendix shows the list of hospitals selected with its corresponding municipality and county. For bigger cities with more than one hospital, such as Barcelona, Badalona, l'Hospitalet de Llobregat, Sabadell, and Terrassa, I only took one for simplicity. Nonetheless, there are some municipalities in which the closest hospital is outside the urban area of Barcelona. These medical centers are also taken in the study for these towns and they are basically the ones located in Blanes and Vic, all in the northeast of the urban area. The work consists of checking manually, with Google Maps, municipality by municipality, which the closest hospital is. Both the distance in kilometers and in time by public transportation corresponds to the best route suggested by the platform. The latter include distinct means of transport such as bus, railway, train and metro.

Table A.2: Selected hospitals

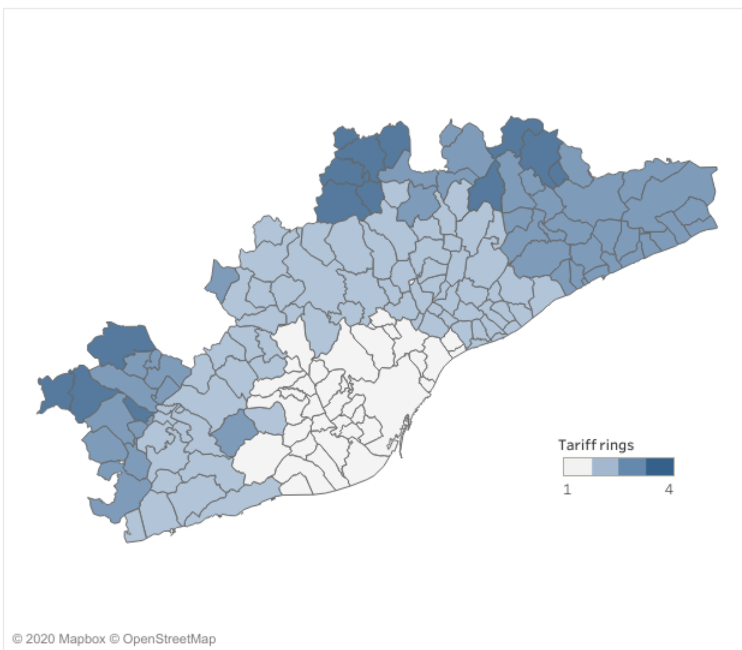
Name	Municipality	County
Panel A: Urban Area of Barcelona		
Hospital Comarcal de l'Alt Penedès	Vilafranca del Penedès	Alt Penedès
Hospital General. Parc Sanitari Sant Joan de Déu	Sant Boi de Llobregat	Baix Llobregat
Hospital de Viladecans	Viladecans	Baix Llobregat
Hospital Sant Joan de Déu	Esplugues de Llobregat	Baix Llobregat
Hospital de Sant Joan Despí Moisès Broggi	Sant Joan Despí	Baix Llobregat
Hospital Sant Joan de Déu	Martorell	Baix Llobregat Nord
Hospital de Mataró	Mataró	Baix Maresme
Hospital de Sant Celoni	Sant Celoni	Baix Montseny
Hospital Clínic i Provincial de Barcelona	Barcelona	Barcelonès
Hospital Universitari de Bellvitge	Hospitalet de Llobregat	Barcelonès
Hospital Universitari Germans Trias i Pujol	Badalona	Barcelonès
Fundació Hospital Comarcal Sant Antoni Abat	Vilanova i la Geltrú	Garraf
Fundació Hospital Residència Sant Camil	Sant Pere de Ribes	Garraf
Hospital Comarcal Sant Jaume de Calella	Calella	Selva Marítima
Hospital de Sabadell	Sabadell	Vallès Occidental
Hospital Mútua Terrassa	Terrassa	Vallès Occidental
Fundació Privada Hospital de Mollet	Mollet del Vallès	Vallès Oriental
Hospital General de Granollers	Granollers	Vallès Oriental
Panel B: Outside Urban Area of Barcelona		
Hospital Comarcal de Blanes	Blanes	Selva Marítima
Hospital General de Vic	Vic	Osona

[8] Departament de Salut. Llistat d'hospitals per regió sanitària (2017): https://salutweb.gencat.cat/ca/el_departament/organitzacio/adreces_i_telefons/hospitals/

Appendix D. ATM rings

The ATM (Autoritat del Transport Metropolità) is the institution in charge of the management, planning and funding of the public transport of the metropolitan area of Barcelona. This organism divides the transportation system area into six rings and different tariff areas that contain 296 municipalities in total. Although our available data only covers the first three rings, we can consider that the whole urban area is almost included as these rings represent 92% of the entire sample. Nonetheless, the few municipalities that belong to the fourth ring are also represented in Figure A.1 even though that there is no available information in housing prices and, thus, they are not used in the regressions. The first ring is formed by 36 municipalities that belong to Barcelonès (5), Baix Llobregat (21), Baix Llobregat Nord (1), Baix Maresme (2) and Vallès Occidental (7). The second ring is formed by 71 municipalities in Alt Penedès (10), Baix Llobregat (1), Baix Llobregat Nord (6), Baix Maresme (12), Baix Montseny (1), Garraf (6), Vallès Occidental (14) and Vallès Oriental (21). The third ring is composed by 45 municipalities in the following counties: Alt Maresme (6), Alt Penedès (13), Baix Llobregat Nord (1), Baix Maresme (4), Baix Montseny (9), Moianès (1), Selva Marítima (7) and Vallès Oriental (4).

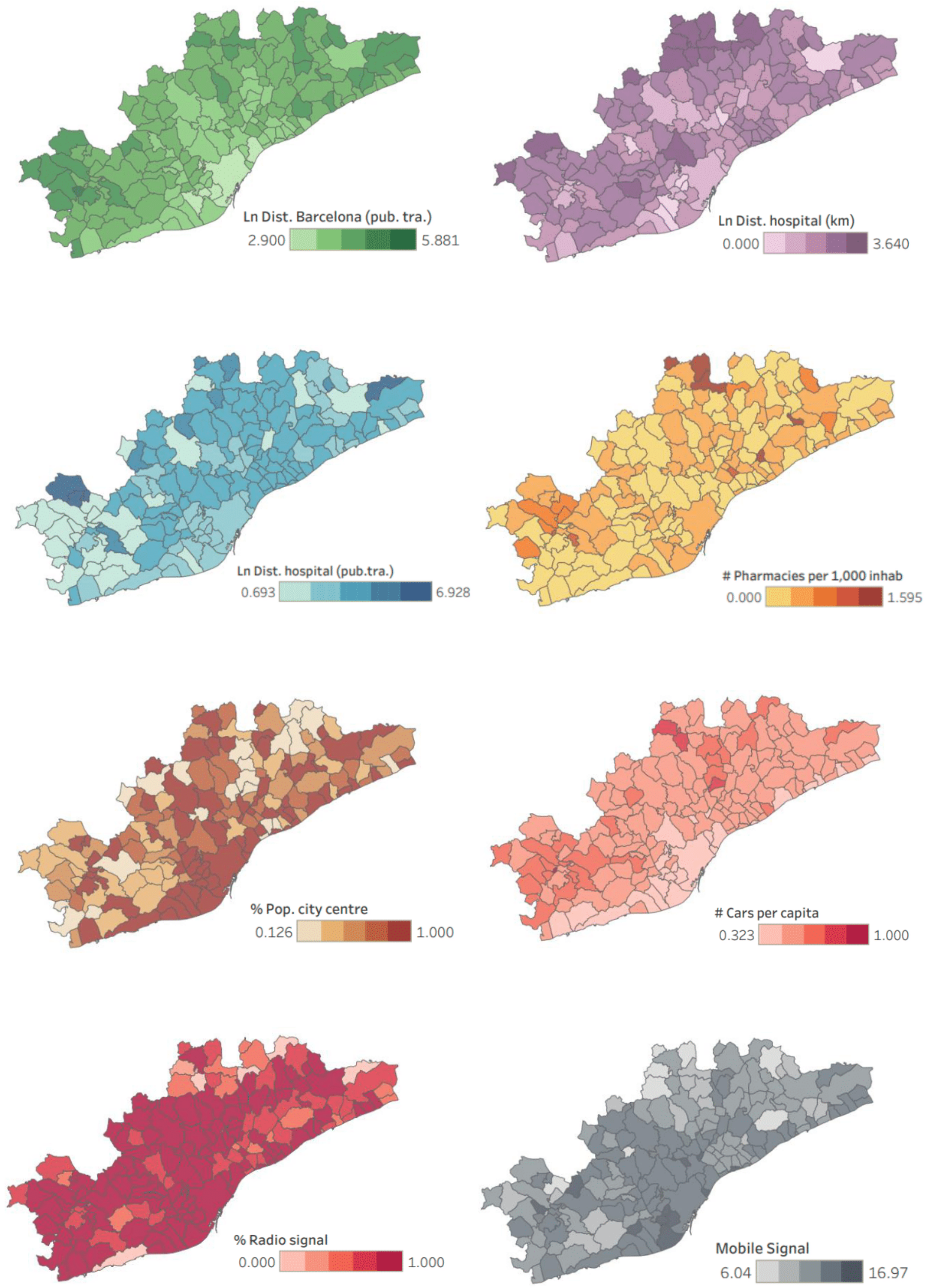
Figure A.1: Tariff rings, 2019



Note: The figure plots the map of transportation rings in the urban area of Barcelona.

Appendix E. Alternative measures of sprawl

Figure A.2: Alternative measures of sprawl



Note: The figure plots the different subfigures of the different sprawl measures for each municipality: distance (ln) to Barcelona in public transportation, distance (ln) to the closest hospital (km), distance (ln) to the closest hospital in public transportation, number of pharmacies per 1,000 inhabitants, share of population living in the city centre, number of cars per capita, share of radio signal and mobile signal.