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# Cost assessment of urban sprawl on municipal services using hierarchical regression

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**Abstract**
In Europe, especially in the Valencian Community, Spain, the growth of cities in the last few decades has brought with it a major paradigm change, shifting from a compact to a sprawling urban model. Although it is known about its important environmental, social, and economic effects, there is no clear and unequivocal measurement of the impact of urban sprawl on municipal spending. The impact of the sprawling city on public finances and on the cost of local public services is clearly one of the conditioning factors that should be assessed when making urban development decisions. Based on a measurement of the sprawling city, our aim is to calculate the effect of urban sprawl on the local administration's expenditure and particularly on the cost of basic public municipal services. These are obtained through a statistical model with cost functions that can assess the increase in spending prompted by urban sprawl for municipal current expenditure. The proposed model is novel in the field of urban planning and is based on a Bayesian hierarchical model with the ability to include modeling constraints among the expenditures variables and handle missing values accurately. With this paper, we show that urban sprawl has a significant and positive effect on the unit cost of local public services, which results in an inefficient urban growth model from the economic point of view. The effect is not transferred homogeneously to the budget. There are spending items that are more sensitive to urban sprawl like expenditure on security and public transportation and community wellbeing, which primarily covers waste collection, elimination, and treatment; sanitation, and water supply and distribution; road cleaning; and public lighting.

**Keywords**
Urban sprawl, cost of public services, municipal budget, hierarchical regression

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## Introduction

Urban growth and specifically the urban sprawl model have major environmental, social, and economic effects on a region. The economic effects of urban sprawl can take on a considerable scale at the revenue and expenditure levels. In Spain, over the last few decades, many municipalities have adopted expansive urban models to leverage a source of revenue easy to tap into, provoking very high growth and often even more sprawl (Burriel de Orueta, 2008; EEA, 2006; Gaja i Díaz, 2008; Miralles, 2014). While the last economic cycle and its associated real estate bubble from 1997 to 2006 lasted (Miralles, 2014), the urban sprawl model was a major short-term source of revenue for local Spanish public administrations. However, this expansive growth model was not accompanied by the long-term fiscal balance control it was due.

The economic costs may be private when they refer to the costs of goods or services that the home's user has to assume (like transportation, water, or power) or public when it is the administration that has to assume the costs of providing the goods or services to the home.

These public economic costs are mostly covered by town budgets. If a city grows without major changes in the urban morphology, the population increase will produce an expansion in the budget in the same proportion on the expenditure and on the revenue side, thereby maintaining the same budget balance. If urban growth is done by varying the urban parameters of the city like density, space, demographics, mix of uses, it is unclear whether the budgetary balance would be maintained. This is precisely the central question of this study which aims to determine the direction and magnitude of the changes in municipal public spending produced due to an increase in urban sprawl. There is evidence of the effect of the urban shape on local coffers (Benito et al., 2010; Carruthers and Ulfarsson, 2003; Hortas-Rico, 2014; Hortas-Rico and Solé-Ollé, 2010; Solé-Ollé, 2001; Solé-Ollé and Bosch, 2005), attributing higher costs in the provision of basic public services.

The description of urban sprawl usually focuses on measuring the degree of compactness-sprawl of the entire municipal urban area. There have been several approaches to measuring this index: some use population or housing density (Benito et al., 2010; Carruthers and Ulfarsson, 2003; Hortas-Rico and Solé-Ollé, 2010), the number of hubs and the percentage of the population spread out (Hortas-Rico, 2014; Solé-Ollé, 2001; Hortas-Rico and Solé-Ollé, 2010), and other indexes of fragmentation of urban areas (Sapena and Ruiz, 2015). However, in all of them, the characterization of the urban landscape is only partial.

This article aims to be a study in quantification and analysis of the effect of urban sprawl on spending on basic municipal public services for all of the municipalities in the Autonomous Community of Valencia in Spain. As an index of urban sprawl, we make use of the index calculated in Gielen et al. (2018), which is an urban sprawl index calculated as the latent factor related to a group of 12 characteristics related to the land use in each town, making use of the Bayesian factorial analysis methodology for its calculation. This urban sprawl index covers more aspects and characteristics of the sprawling city than any previous paper.

The relationship between the urban sprawl index and each of the budgetary variables is assessed using the Bayesian regression model adjustment and formula for each of the variables. The hierarchical relationships that exist between the different expenditure variables are modeled so that the different expenditure variables could share information between them and in that way obtain more accurate and reliable estimates. The use of the Bayesian approach to formulate and estimate the regression models has allowed us to take full advantage of the available data set because it takes into consideration the missing data that exist in the data set. The Bayesian approach allows for statistical inference of the missing data simultaneously with the model's inference—a real and efficient way to use the entire database when there are missing data in it. Furthermore, the values equal to zero in the expenditure variables do not usually correspond to a zero cost for a certain variable, but indicate that certain service is not provided by a municipality. The proposed model has the ability to jointly model these values equal to zero and the real expenditure values, and share information among them. The proposed model with all these modeling features is novel in the field of urban planning.

As a result, we were able to determine what municipal expenditure variables were dependent on urban sprawl and obtain a series of cost functions to assess the increase in current municipal spending according to urban sprawl.

## Background

### *Relationship between urban sprawl and municipal expenditure*

Although some authors grant a positive fiscal balance to urban development with less density (Speir and Stephenson, 2002), most suggest a clearly loss-making economic balance. According to Muñiz et al. (2006), the sprawl model is clearly inefficient from the economic perspective: the public and private cost of a house in an apartment building is lower than for a single-family detached or row house.

The costs far outstretch benefits and although some benefits may exist in isolated cases, this balance appears to be loss-making in general terms (Ewing, 1994, quoted by Pichler, 2007; Miralles and García-Ayllon, 2013). In addition, Brueckner (2001) demonstrates that the promotion of new sprawling residential neighborhoods, far from the city, is artificially less expensive than it is in actuality. According to this author, paying additional taxes does not usually cover the marginal costs of providing new infrastructure (highways, sewage systems, electrical and gas grid, schools, parks, and recreational areas), which creates a net individual benefit for the new owner over the net social benefit.

There is an abundance of international literature which attributes the economic cost overrun of urban sprawl much of which has to do with higher expenses in the provision of public services assumed by municipalities (Burchell and Mukherji, 2003; Carruthers and Ulfarsson, 2003; Real Estate Research Corporation (RERC), 1974; Speir and Stephenson, 2002). The RERC (1974) of the United States in a study called "The Costs of Sprawl" estimated that, in the service exploitation stage, once the city has been built and inhabited, an urban development with less density is twice as expensive as others that are denser (Carruthers and Ulfarsson, 2003, quoting RERC, 1974). In Switzerland, the Office Fédéral du Développement Territorial (2000) indicates three times the costs for public sanitation and water distribution, trash collection, roads, and electricity. Burchell and Mukherji (2003) estimate that the sprawling city generates 10% more deficit in public service costs as well as 10% more highways and 8% in housing costs. Carruthers and Ulfarsson (2003) establish that the type of urban development has an effect on the expenditure associated with transportation infrastructure, trash collection, road cleaning, police, firefighters, public parks, and libraries. The study shows that higher density, which leverages economies of scale, reduces the unit cost of providing public services and that the spatial extension of urban development increases those same costs. The properties of density, distance, and fragmentation that define the sprawl of urban space have a direct effect on higher costs for the services of water sanitation and distribution (Speir and Stephenson, 2002). There are also authors like Ladd (1994), quoted by Carruthers and Ulfarsson (2003) who argue the opposite: higher density produces higher costs for public services and even demonstrate the existence of a nonlinear relationship in which, at first, at very low densities, the costs decrease as density increases, and then, as it approaches higher densities, rise again. In Europe, Guengant et al. (1995), quoted by Garrido et al. (2013), concluded that density had no economic effect on the cost of public services.

In Spain, several authors have studied the relationship between urban sprawl and the cost of public services. According to Muñiz et al. (2006), maintaining certain levels of public services in disperse areas "implies higher costs than for a compact and dense area." Garbiñe (2007) estimates that the maintenance costs for public services per house in a development with row houses (water distribution, sanitation, lighting, cleaning, and development) can cost up to seven times a development in an urban center. The work done by Solé-Ollé (2001) and Solé-Ollé and Bosch (2005) underscores this idea: urban sprawl has a positive and significant impact on the cost of municipal public services. These same results can be found in more recent studies carried out from 2008 to 2014 by Solé-Ollé and Hortas-Rico: a 1% increase in the area built-up per capita increases the current expenditure by 0.11% (Hortas-Rico and Solé-Ollé, 2010); urban sprawl is responsible for a 2.3% growth in the cost of basic public services which is 7% in the infrastructure chapter, 2.3% in goods and services, 2% in housing and police, 2.7% in administrative services, and 3.7% in culture. It also shows that in 4% of the municipalities analyzed, this increase was over 10% (Hortas-Rico and Solé-Ollé, 2010).

## *Variables and methods used in the cost estimate*

The economic impact of urban sprawl has been studied through input–output studies and econometric studies. The first are empirical studies that aim to draw up a prototype that analyzes the influence of urban space's development characteristics on the economic flows involved (Garbiñe, 2007; Moral and Garrido, 2010; Office Fédéral du Développement Territorial, 2000; Paulsen, 2013; RERC, 1974). The second, more recent, uses econometric techniques that due to progress in computer processing, the availability of the amount of economic data, and more knowledge about the variables being used are better equipped to paint a more realistic picture. In Spain, the studies by Solé-Ollé (2001), Solé-Ollé and Bosch (2005), Hortas-Rico and Solé-Ollé (2010), Hortas-Rico (2014), and Benito et al. (2010) were carried out with these kinds of methodologies, attempting to establish the relationship between urban sprawl and municipal expenditure on basic public services. In most of these studies, least squares was used to analyze the determining factors of local spending which was combined in some cases with segmented linear regression techniques (Benito et al., 2010; Hortas-Rico, 2014; Hortas-Rico and Solé-Ollé, 2010; Solé-Ollé and Bosch, 2005), assuming a nonlinear relationship between expenditure and independent variables like population.

Location factors or of urban configuration considered by other authors are developed area per capita (Hortas-Rico, 2014; Solé-Ollé, 2001; Hortas-Rico and Solé-Ollé, 2010), percentage of single-family houses (Hortas-Rico and Solé-Ollé, 2010), number of population centers (Hortas-Rico and Solé-Ollé, 2010), percentage of dispersed population (Hortas-Rico, 2014; Hortas-Rico and Solé-Ollé, 2010), density, land value, and total developed area (Carruthers and Ulfarsson, 2003). There are also other social or demographic variables like population structure or education (Benito et al., 2010; Cabasés et al., 2012; Hortas-Rico, 2014; Solé-Ollé, 2001); economic variables, like income, the weight of tourism or industry (Benito et al., 2010; Carruthers and Ulfarsson, 2003, Hortas-Rico, 2014; Solé-Ollé, 2001); political and institutional variables in Solé-Ollé (2001) and Cabasés et al. (2012); variables related to the financial situation of the administration (Benito et al., 2010; Cabasés et al., 2012; Solé-Ollé, 2001), and territorial variables like the capacity of the centers or grouping of municipalities (Hortas-Rico, 2014). In Spain, the study by Solé-Ollé (2001) covers the most variables.

## Methodology

### *Conceptual model*

Despite the recognition of the importance of the relationship between public finance and urban form (Burchell and Mukherji, 2003; Carruthers and Ulfarsson, 2003; RERC, 1974; Solé-Ollé, 2001; Solé-Ollé and Bosch, 2005; Speir and Stephenson, 2002), this is, to a large extent, an undeveloped assumption and urban planners do not have yet the assessing tools to evaluate the effect of the urban model they project.

In order to model the expenditures in the public finances of a municipality, several factors have to be taken into consideration. First, the expenditure in a certain budgetary variable is dependent on the amount of services that it includes. Which amount of services included depends on the population size of the municipality, as established in the Spanish Local Regime Basic Law of 1985. In addition, this expenditure also depends on the demand for services, such as the greater the demand for houses or people, the higher the cost. Furthermore, the quality of the services provided also affects their costs. And finally, the cost of providing public services depends on the established urban model, since it governs the characteristics and the dynamics of the supply and capture of the services (Burchell and Mukherji, 2003; Carruthers and Ulfarsson, 2003; Solé-Ollé, 2001; Solé-Ollé and Bosch, 2005; Speir and Stephenson, 2002).

From this evidence, a "cost function" for the municipal expenditures can be expressed in a conceptual form that includes the effects of the different factors. This "cost function" can be represented by some function $f$

$$E = f(s, n, q, u)$$

where $E$ represents the expenditure in a budgetary variable of a municipality, $s$ is the amount of services provided, $n$ is the demand for the services, $q$ is the quality of the services, and $u$ is the established urban model in the municipality.

Assuming that the factors $s$ and $q$ might be constant over time for a municipality, since both the amount of services, which are set for the Spanish Local Regime Basic Law according to the population size and the quality of the services are not expected to change in the short term, the remaining factors in the cost function are the demand for the services $n$ and the urban model $u$. If the municipality expenditures are expressed per unit of service demand, so that $e = E/n$, we obtain a "cost function" for a municipality only as a function of the urban model

$$e = g(u)$$

where $g(u)$ represents a certain "cost function" that depends on the urban model $u$.

This conceptual model can be a framework on which the modeling of a "cost function" for a municipality should be based on. The determination of a "cost function" allows us to estimate the effects a new urban pattern might cause on the expenditures of a municipality.

The "cost function" can give the planners a more active role with a decision-making tool that incorporates spatial characteristics of the urban model.

Further on, the present work is focused on the determination of the "cost function" $g$ as a function mainly of the urban model for all the municipalities of the Valencian Community in Spain. The urban model is characterized by an index, called sprawl index (Gielen et al., 2018).

## Area of study and sample units

The study is of 542 municipalities in the Autonomous Community of Valencia, Spain, on the Mediterranean coast, corresponding to NUTS 2 level of the Nomenclature of Territorial Units for Statistics of the EU (Figure 1). The territory has an area of 23,255 square kilometers with more than five million in population and is divided into three provinces: Castellon, Valencia, and Alicante.

The Autonomous Community of Valencia is known for its particular Valencian urban development model (Burriel de Orueta, 2008; Fortbou, 2005; Gaja i Díaz, 2008; Miralles, 2014), which due to its geographic location and its productive model based on tourism triggered a real estate boom and an expansive urban model (EEA, 2006).

The municipality is the minimum unit of observation and analysis in this study. Until now, there have only been similar studies of samples of few Spanish municipalities (Benito et al., 2010; Hortas-Rico and Solé-Ollé, 2010; Hortas-Rico, 2014) and the province of

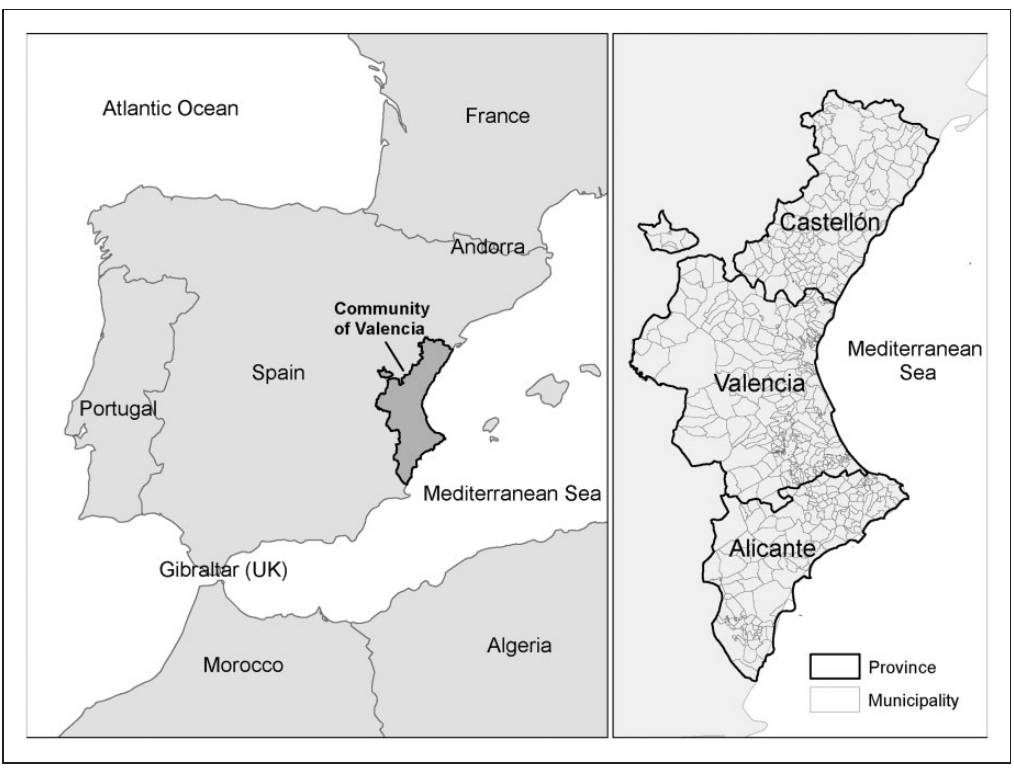


**Figure 1.** Area of study.

Barcelona (Solé-Ollé, 2001). The sample chosen has several advantages when compared to these studies: (1) the Community of Valencia has its own regulatory framework in urban development, (2) it is a large and diverse enough sample to run the statistical analysis in its territorial characteristics which vary considerably if the town is inland or on the coast, (3) there are full and standard data on land use and public finance, and (4) the previous paper by Gielen et al. (2018) offers a synthetic index of sprawl already calculated for all of the municipalities in the study's scope.

### *Budget expenditure variables*

The expenditure variables were obtained from budget settlement data for local institutions published by the Virtual Offices for Financial Coordination with the Local Institutions of the Secretariat-General of Autonomous and Local Coordination of the Ministry of Finance and Public Administrations. The concept of expenditure used in this study is current expenditure. Capital and financial transactions are not included since they are the result of more volatile and complex decisions, with longer timeframes than current expenditure (Solé-Ollé, 2001). Expenditure variables were defined in euros per house and at the municipal level.

In comparison with other studies carried out in Spain, a more complete budget data set is analyzed: several budgetary fiscal years are used, specifically from 2010 to 2013, and the authors work with a new organization of the data that corresponds to the structure of the budgets of the local institutions in effect since 2008. In that way, more detailed budgetary data are included, up to a third hierarchical level (expenditure program groups). The effect on the different basic public municipal services can be differentiated and individualized results obtained for sanitation, supply and distribution of water; collection, elimination, and treatment of waste; road cleaning; and public lighting.

Table 1 shows the different expenditure variables. They respond to a hierarchical structure with four levels in line with the classification of municipal budgets in Spain. In this case; only expenditure variables that might, a priori, be affected, were considered (Garbiñe, 2007; Muñiz et al., 2006; Solé-Ollé, 2001; Solé-Ollé and Bosch, 2005).

**Table 1.** Dependent variables.

| Variable | Level | Type of expenditure |
|---|---|---|
| *Etot* | 1 | Total current |
| *E1* | 2 | Basic public services |
| *E13* | 3 | Security and public transportation |
| *E132* | 4 | Security and public order |
| *E15* | 3 | Housing and urban development |
| *E151* | 4 | Urban development |
| *E155* | 4 | Public roads |
| *E16* | 3 | Community wellbeing |
| *E161* | 4 | Sanitation and water supply |
| *E162* | 4 | Waste collection, elimination and treatment |
| *E163* | 4 | Road cleaning |
| *E165* | 4 | Public lighting |
| *E17* | 3 | Environment |
| *E171* | 4 | Parks and gardens |

## *Explanatory variables*

The explanatory variables in the regression model are those that supposedly have an explanatory effect on the response variable or budgetary expenditure variable (Table 2). Naturally, the most important explanatory variable whose effect we are interested in is the urban sprawl index. This is a one-dimensional variable that acts as a synthesis of the multi-dimensional phenomenon of urban sprawl and was proposed in the research done by Gielen et al. (2018). This sprawl index was based on computing the underlying common factor to a wide set of input variables concerning density, land occupation, form and structure of the urban patches, by means of using Bayesian factor analysis. It is a continuous variable, of an approximately normal distribution, dimensionless, and with an approximate range of $-2.5$ to $+2.5$, indicating less or more sprawl according to the value of the index.

There are other explanatory factors that can have an effect on municipal expenditure. They are taken as secondary variables because, in principle, they are not the direct subject of this study, but they have been included since we suspect they might affect the cause–effect relationship between sprawl and expenditure. These variables are related to the municipal size (set by the municipal authorities), the specialization in land use, and the existence of budgetary conditioning factors like income from fiscal pressure and other expenditure for payment of certain services through transfers to other administrations.

In Solé-Ollé and Bosch (2005) and Hortas-Rico (2014), the authors have studied the relationship between municipal expenditure and municipal size. Both publications show a nonlinear relationship with inflection points in 1000 and 5000 inhabitants. In the present work, we adopted that criterion and categorized the population size in three classes.

**Table 2.** Explanatory variables.

| Explanatory variables | Definition | Data calculation and source |
|---|---|---|
| *Sprawl* | Sprawl index | Gielen et al. (2018) |
| *tpop* | Population size. Categorical variable defined in three classes:<br>• <1000 inhabitants (*tpop1*)<br>• 1000–5000 inhabitants (*tpop2*)<br>• >5000 inhabitants (*tpop3*) | Population data (2011 census) |
| *IndTer* | Proportion of industrial/tertiary area to residential population area | SIOSE 2011 data |
| *SecHom* | Importance of second home in overall housing | SIOSE 2011 data |
| *SNE* | Weight of undeveloped area in residential and industrial developments | SIOSE 2011 data |
| *ExpTransf* | Expenditure in transfers to other public administrations | Data on budgetary settlements of local institutions of the Secretariat-General of Autonomous and Local Coordination |
| *Pressure* | Revenue from fiscal pressure | Data on budgetary settlements of local institutions of the Secretariat-General of Autonomous and Local Coordination |

SIOSE: System of Information on Spain's Land Use.

The data on land use are taken from the SIOSE database (System of Information on Spain's Land Use) at the Spanish National Geographic Institute, with a scale of 1:25,000. The budgets come from the Ministry of Finance and Public Administrations. Population and housing data were obtained from the year's Housing and Population census by the National Institute of Statistics.

With the aim to check possible collinearity issues between the continuous explanatory variables including the sprawl index, a pre-analysis using principal components analysis was conducted and nonsignificant correlations were recognized. On the other hand, it is known that there might be some correlation between the sprawl index and the population categories, which were handled in the modeling by including the interaction effects between those variables.

## Regression model

A statistical regression model is proposed to estimate the effects of urban sprawl on municipal expenditure and investigate the existence of a certain correlation between current expenditure on public goods and services and the type of urban model.

The model estimates the relative cost, equal to the marginal increase in expenditure in a certain budgetary variable when the index of urban sprawl increases by one unit

$$r = \frac{E^{S+1}}{E^S}$$

where $r$ is the increase of relative cost, $E^{S+1}$ is the current expenditure on a certain expenditure variable of a municipality with a sprawl index $S+1$, and $E^S$ is the municipality's current expenditure with an $S$ sprawl index.

A *Bernoulli–Gamma* regression model is developed (Paradinas et al., 2015), with a Bayesian focus (Ntzoufras, 2009). The *Bernoulli–Gamma* model is characterized by modeling the expenditure variables through mixing two distributions: a *Bernoulli* distribution that models whether a value is zero or not and a *Gamma* distribution that models the values not equal to zero.

The values equal to zero in the database are not usually zero cost for a certain item; instead they usually indicate a municipality's lack of power to provide a certain service, so the results of the *Bernoulli* model will mainly reflect the effect of those budgetary powers and not the real zero expenditure on providing a certain service.

The results of this investigation will be mainly those that come from the *Gamma* model, i.e. the modeling of values not equal to zero. The formulation of this mixed model allows for a compact and complete modeling of the observed expenditure data and to analyze the distribution of the values not equal to zero, real expenditure values, and values equal to zero together, and detect and estimate the possible driving factors in both cases.

The Bernoulli model represents the observations 0 or 1 for each municipality where 1 indicates that a municipality has an expenditure not equal to zero. The model depends on the probability $p(i)$ (probability of being 0 or 1)

$$f\big(p(i)\big) = Ber\big(u(i)|p(i)\big)$$

where $u(i)$ is the 0 or 1 value observed for a municipality $i$ ($i = 1, \ldots, n =$ number of municipalities), $p(i)$ is the probability that value 1 for municipality $i$, where $(1 - p(i))$ would be the probability of the value 0.

Expenditure values $y$ not equal to zero are modeled using the Gamma model since the expenditure values not equal to zero are strictly positive values and have asymmetrical distribution

$$\begin{aligned} f\big(a(i), b(i)\big) &= G_A\big(y(i)|a(i), b\big), \\ a(i) &= \ \mu(i) \cdot b \end{aligned}$$

where $a(i)$ and $b$ are, respectively, the form and ratio parameters of the Gamma distribution, and $\mu(i)$ is the measurement of the Gamma distribution. Note that the $b$ ratio parameter has been considered to be equal for all the municipalities $i$.

To combine the Bernoulli and Gamma models in order to form a mixed model, the $\mu(i)$ measurement of the Gamma model must be conditioned by the $u(i)$ value of the Bernoulli model by the expression in equation (1), so that if the observed value $u(i)$ is equal to 1, the functional regression's entire expression is shown in the parameter $\mu'(i)$. If $u(i)$ is equal to 0, the measurement $\mu(i)$ of the Gamma distribution is equal to 0

$$\mu(i) = u(i) \cdot \mu'(i) \tag{1}$$

With that, the overall likelihood function of the Bernoulli–Gamma model takes the form

$$f\big(p(i), a(i), b\big) = Ber\big(u(i)|p(i)\big) \cdot G_A\big(y(i)|a(i), b\big) \tag{2}$$

The linear regression (3) is defined on the logarithm of the average $\mu'(i)$ and includes the explanatory quantitative factors Sprawl, IndTer, ExpTransf, Pressure, SecHom, SNE, and the categorical covariable of the type of population $tpop(i)$. Coefficients $\beta_k$ measure the effect of the quantitative covariables on the logarithm of the average $log(\mu'(i))$. Coefficient $\beta_0$ is the global average of the model and factor $P(tpop(i))$ measures the effect on $log(\mu'(i))$ of belonging to a certain $tpop(i)$ population group. Coefficient $\beta_1$ is differentiated by population groups $tpop(i)$. The possible correlation between the population type variable $tpop(i)$ and the sprawl index has been minimized by including their interaction, allowing the effect of the $\beta_1$ on the sprawl to be different in each population group $tpop(i)$

$$\begin{aligned} log\big(\mu'(i)\big) = \beta_0 + P\big(tpob(i)\big) + \beta_1\big(tpop(i) \cdot Sprawl(i)\big) + \beta_2 \cdot IndTer(i) \\ + \beta_3 \cdot ExpTransf(i) + \beta_4 \cdot Pressure(i) + \beta_5 \cdot SecHom(i) + \beta_6 \cdot SNE(i) \end{aligned} \tag{3}$$

Generalizing the previous model for different expenditure variables $j$ and observed in different periods $t$, so that the expenditure data for different years are included, you have

$$\begin{aligned} u(i,j,t) &\sim Bernoulli(p(i,j,t)) \\ Y(i,j,t) &\sim Gamma\big(a(i,j,t), b(j)\big) \\ a(i,j,t) &= \mu(i,j,t,) \cdot b(j) \\ \mu(i,j,t) &= u(i,j,t) \cdot \mu\text{'}(i,j,t) \end{aligned}$$

$$\begin{aligned} log(\mu'(i,j,t)) = \beta_0(j,t) + P(tpop(i),j) + \beta_1(tpop(i),j) \cdot Sprawl(i) + \beta_2(j) \cdot IndTer(i) \\ + \beta_3(j) \cdot ExpTransf(i) + \beta_4(j) \cdot Pressure(i) + \beta_5(j) \cdot SecHom(i) \\ + \beta_6(j) \cdot SNE(i) \end{aligned}$$

The meaning and interpretation of parameters $\beta$ and $P$ is done in terms of relative risk according to expressions (4) and (5), where the exponential of $\beta_k(j)$ represents the unit increase of relative expenditure in variable $j$ due to the increase of a unit in the measurement of the covariable $k$, and the exponential of $P(tpob(i), j)$ represents the increase of relative expenditure in variable $j$ due to a change in the categorical variable of population type $tpop(i)$

$$\exp(\beta_k(j)) = \frac{\mu(i, j, t)|Cov_k = x}{\mu(i, j, t)|Cov_k = x + 1} \tag{4}$$

$$\exp(P(tpob(i), j)) = \frac{\mu(i, j, t)|tpop(i) = a}{\mu(i, j, t)|tpop(i) = b} \tag{5}$$

In the previous expressions (4) and (5), $x$ represents a certain value of any quantitative covariable $Cov_k$, and $a$ and $b$ represent two categories of the population type variable $tpop(i)$.

The hierarchical relationships between the budgetary variables are as shown in equation (6). Taking into account these relationships in the modeling improves the estimations of the parameters and the inference of the missing data

$$G1 = G13 + G15 + G16 + G17 \tag{6}$$

Bayesian inference is done over the posterior marginal joint distribution of parameters given the data, which are proportional to the likelihood and priors

$$f(b, \beta, P, p|y) = f(y|b, \beta, P, p) \cdot f(b, \beta, P, p)$$

where $f(y|b, \beta, P, p)$ is the likelihood of the model (2) and $f(b, \beta, P, p)$ is the joint prior of the hyperparameters.

We set weak prior distributions $f(b) = G_A(2, 50)$, $f(\beta) = N(0, 10)$, $f(P(tpop = 2)) = N(0, 10)$, $f(P(tpop = 3)) = N(0, 10)$, $f(P(tpop = 0)) = 0$, $f(p) = U(0, 1)$ for the hyperparameters $b$, $\beta$, $P$, and $p$, respectively, based on prior knowledge about the magnitude of the parameters. So, the marginal posterior joint distribution that results is

$$f(b, \beta, P, p|y) = G_A(b, \beta, P) \cdot Ber(u|p) \cdot G_A(2, 50) \cdot N(0, 10) \cdot N(0, 10) \cdot U(0, 1)$$

To estimate the parameters of the posterior distribution for this model, simulation methods can be used. Simulating methods based on Markov Chain Monte Carlo (MCMC) (Brooks et al., 2011) are general sampling methods based on drawing values of the parameters from approximate distributions and then correcting those draws to better approximate the target posterior distribution. We used MCMC using Gibbs sampling (Geman and Geman, 1984) and the WinBUGS software (Lunn et al., 2000) to estimate the model (Ntzoufras, 2009). Three simulation chains were launched with different initial values.

## Results

The estimate of the effects of the explanatory factors was undertaken based on parameters $\beta$ of the statistical model mentioned in the section above and are expressed in terms of relative expenditure increase. Our interest focuses on the results of the *Gamma* model that gathers and models the distribution of the real expenditure values.

The distribution of later probability estimated for each of the parameters $\beta$ allows inferring the following results: the credible interval, the average, and the typical deviation. The credible intervals and the typical deviation are a measurement of the accuracy of the parameters' estimate. Based on the later probability distribution, a measurement of the significance of the parameter can be estimated, where significance is the probability that the parameter is not void or equal to zero. The meaning and interpretation of parameter $\beta$ is done in terms of relative risk, where the exponential of $\beta_k(j)$ represents the increase of relative expenditure in variable $j$ due to the increase of one unit in the measurement of the covariable $k$

$$\exp(\beta_k(j)) = \frac{\mu(i,j)|Cov_k = x}{\mu(i,j)|Cov_k = x+1}$$

where $x$ represents a certain value of any quantitative covariable $Cov_k$.

If the covariable $k$ is the sprawl index, then we can calculate the effect on the cost of the expenditure variable $j$; the increase of relative expenditure in expenditure $j$, like the logarithm of $\beta(j)$.

The precision of the estimate of the effect is determined by the width of the credible interval or the standard deviation of the parameter's variability.

The lower (low) and upper (up) limits of credible interval at 95%, the average (av) and the typical deviation (dev) are the values presented in Tables 3 to 5 which contain the results of the estimate of parameter $\beta_1$, a parameter associated with the effect of the sprawl index explanatory variable. Parameter $\beta_1$ is differentiated by the type of population (*tpop*).

The results are consistent with expectations: (1) the data show significant effects in many of the expenditure variables, with magnitudes and directions similar to those expected; (2) the credible intervals are relatively consistent, showing little variability in the parameters, confirming an accurate estimate in the magnitude of the effects, particularly in the expenditure variables on which urban sprawl was expected to have an effect. This demonstrates

**Table 3.** Results of parameter $\beta_1$ for *Etot* and *E1*.

| | *Etot* | | | | *E1* | | | |
|---|---|---|---|---|---|---|---|---|
| Parameter | Av. | dev. | [low | up] | Av. | dev. | [low | up] |
| $\beta_1(tpop=1)$ | 0.20 | 0.02 | 0.16 | 0.23 | 0.32 | 0.03 | 0.26 | 0.37 |
| $\beta_1(tpop=2)$ | 0.18 | 0.02 | 0.15 | 0.22 | 0.23 | 0.03 | 0.18 | 0.28 |
| $\beta_1(tpop=3)$ | 0.19 | 0.01 | 0.16 | 0.22 | 0.25 | 0.02 | 0.20 | 0.29 |

**Table 4.** Results of parameter $\beta_1$ for *E13*, *E15*, *E16*, and *E17*.

| | *E13* | | | | *E15* | | | | *E16* | | | | *E17* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Av. | dev. | [low | up] | Av. | dev. | [low | up] | Av. | dev. | [low | up] | Av. | dev. | [low | up] |
| $\beta_1(tpop=1)$ | 0.32 | 0.06 | 0.21 | 0.42 | 0.28 | 0.04 | 0.21 | 0.36 | 0.25 | 0.03 | 0.19 | 0.31 | 0.19 | 0.06 | 0.08 | 0.31 |
| $\beta_1(tpop=2)$ | 0.18 | 0.04 | 0.10 | 0.27 | 0.08 | 0.04 | -0.02 | 0.16 | 0.23 | 0.03 | 0.17 | 0.29 | 0.14 | 0.05 | 0.05 | 0.25 |
| $\beta_1(tpop=3)$ | 0.19 | 0.03 | 0.14 | 0.25 | 0.13 | 0.04 | 0.07 | 0.20 | 0.32 | 0.03 | 0.26 | 0.37 | 0.18 | 0.05 | 0.10 | 0.27 |

**Table 5.** Results of parameter $\beta_1$ for *E132*, *E151*, *E155*, *E171*, *E161*, *E162*, *E163*, and *E165*.

| | *E132* | | | | *E151* | | | | *E155* | | | | *E171* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Av. | dev. | [low | up] | Av. | dev. | [low | up] | Av. | dev. | [low | up] | Av. | dev. | [low | up] |
| $\beta_1(tpop=1)$ | 0.37 | 0.17 | 0.06 | 0.72 | 0.28 | 0.11 | 0.04 | 0.49 | −0.14 | 0.16 | −0.43 | 0.17 | 0.25 | 0.18 | −0.10 | 0.64 |
| $\beta_1(tpop=2)$ | 0.21 | 0.04 | 0.13 | 0.29 | 0.07 | 0.08 | −0.09 | 0.22 | 0.23 | 0.08 | 0.07 | 0.37 | 0.21 | 0.09 | 0.03 | 0.39 |
| $\beta_1(tpop=3)$ | 0.11 | 0.02 | 0.06 | 0.15 | 0.14 | 0.05 | 0.04 | 0.24 | 0.14 | 0.06 | 0.05 | 0.26 | 0.18 | 0.05 | 0.07 | 0.27 |
| | *E161* | | | | *E162* | | | | *E163* | | | | *E165* | | | |
| | Av. | dev. | [low | up] | Av. | dev. | [low | up] | Av. | dev. | [low | up] | Av. | dev. | [low | up] |
| $\beta_1(tpop=1)$ | 0.37 | 0.16 | 0.08 | 0.73 | −0.04 | 0.06 | −0.15 | 0.07 | 0.80 | 0.28 | 0.13 | 1.18 | 0.10 | 0.07 | −0.06 | 0.22 |
| $\beta_1(tpop=2)$ | 0.11 | 0.09 | −0.07 | 0.28 | 0.19 | 0.05 | 0.09 | 0.27 | 0.01 | 0.12 | −0.23 | 0.26 | 0.05 | 0.06 | −0.08 | 0.15 |
| $\beta_1(tpop=3)$ | 0.21 | 0.06 | 0.10 | 0.33 | 0.39 | 0.03 | 0.33 | 0.46 | 0.15 | 0.07 | 0.01 | 0.28 | 0.15 | 0.04 | 0.08 | 0.24 |

that the model is able to predict the effects in a fairly precise way, converging toward a solution with limited variability.

## Discussion

The results of the model show a positive effect of urban sprawl on the municipal budget at the total current expenditure level and on most of the expenditure variables analyzed. This demonstrates a correlation between the municipal expenditure and the factors of the town's location or the urban fabric.

The results are more precise in estimating the effect for *Etot* and *E1*. The credible variables grow wider as the expenditure variables are more disaggregated because fewer data are available. However, although they are less accurate, the effects are more verified between the different variables. This can be explained by the specialization of expenditure or by an excessive generalization of the expenditure variable *E1* and *Etot*. Finally, the model estimates the effect on municipalities with more than 5000 inhabitants more accurately because the data are more complete in large municipalities.

The effect of the sprawl index on the *total current expenditure* (*Etot*) is significant and positive, slightly higher in municipalities with more than 5000 inhabitants and less than 1000 inhabitants. The accuracy of the estimate is high. According to the results obtained, for each increase of one unit in the sprawl (the value for the sprawl index proposed by Gielen et al. (2018) has an approximate range of $-2.5$ to $+2.5$), the total current expenditure increases 19% in municipalities with 1000–5000 inhabitants, and 21% in the case of the other municipalities. These results coincide with numerous authors who conclude that the location guidelines are especially relevant in total current expenditure (Benito et al., 2010; Carruthers and Ulfarsson, 2003; Hortas-Rico, 2014; Hortas-Rico and Solé-Ollé, 2010; Solé-Ollé, 2001).

The results for the expenditure variable in *Basic public services* (*E1*) demonstrate an even greater effect, being significantly very positive. The credible interval indicates high pressure on the estimate of the effect's magnitude. The effect varies according to the type of town and is greater in municipalities with fewer than 1000 inhabitants. In this case, the increase of one unit of the sprawl index increases the expenditure on basic public services by 38%. In municipalities with 1000–5000 inhabitants, that percentage is 26% and in municipalities with more than 5000 it is 28%. This result is relatively new in the case of Spain since there is no recent research on data with the current budgetary structure. Even so, it coincides with bibliographic references that note a greater cost for the sprawled city in community wellbeing policies (Carruthers and Ulfarsson, 2003; Hortas-Rico, 2014; Solé-Ollé, 2001), that mostly coincide with the variable *E1*.

Differentiating between basic public services, the model demonstrates a significantly positive effect on expenditure in *Security and public transportation* (*E13*). The increased expenditure from the increase of one unit in the sprawl index is 19% in municipalities with 1000–5000 inhabitants and 21% in municipalities with more than 5000 inhabitants. The effect is even greater in municipalities with fewer than 1000 inhabitants but less accurate. The expenditure subvariable in *Security and public order* (*E132*) presents very similar results in the case of municipalities with more than 1000 inhabitants. These conclusions coincide to a large extent with other authors: Solé-Ollé (2001) and Hortas-Rico and Solé-Ollé (2010) demonstrate a similar effect of density; Carruthers and Ulfarsson (2003) obtain a positive effect of sprawl on spending on the police; Ewing (2008) also establishes a positive effect, attributing it to the distance and fragmentation more than density.

In the expenditure variable in *Housing and urban development* (*E15*), the result obtained shows a positive effect, greater in municipalities with fewer than 1000 inhabitants and more than 5000 inhabitants. The increase in the sprawl index of a unit means a 37% increase in expenditure in municipalities with fewer than 1000 inhabitants and 14% in municipalities with more than 5000 inhabitants. In municipalities with 1000–5000 inhabitants, that increase is lower and cannot be predicted with enough reliability. The results partially coincide with Carruthers and Ulfarsson (2003). In terms of the expenditure subvariables in *Urban development* (*E151*) and *Public roads* (*E155*), the previous statements are reaffirmed although with less accuracy especially in municipalities with fewer than 1000 inhabitants.

In the expenditure variable in *Community wellbeing* (*E16*), urban sprawl has a very positive and significant effect, slightly greater than in municipalities with more than 5000 inhabitants. The increase of expenditure that corresponds to an increase of one unit in the sprawl index is 29% in municipalities with fewer than 1000 inhabitants, 26% in municipalities with 1000–5000 inhabitants, and 38% in municipalities with more than 5000 inhabitants. These results are similar to the conclusions reached by Solé-Ollé (2001) and Hortas-Rico and Solé-Ollé (2010).

Within expenditure subvariables of *E16*, Community wellbeing is examined:

- In spending on *Sanitation and water supply* (*E161*), the effect of urban sprawl is very positive and significant in the municipalities of more than 5000 inhabitants, with an increase of spending of 23%.
- In the spending on *Waste collection, elimination and treatment* (*E162*), the effect differs according to the town's size. There is a significant and very positive effect in municipalities with more than 5000 inhabitants which means a 48% increase in spending. The effect is lower although significant in municipalities with 1000–5000 inhabitants (an increase of 20%) while it is not significant in municipalities with fewer than 1000 inhabitants.
- In expenditure on *Road cleaning* (*E163*), the effect is positive and significant only in municipalities with more than 5000 inhabitants.
- In expenditure on *Public lighting* (*E165*), a significant positive effect was only demonstrated in the case of municipalities with more than 5000 inhabitants, with an increase of 17% in expenditure on public lighting.

In the expenditure variable in *Environment* (*E17*), the effect of urban sprawl was significantly positive even when it was with a worse estimate and without relevant differences in town size. In the expenditure subvariable in *Parks and gardens* (*E171*), there is a positive and significant effect in the case of municipalities with more than 1000 inhabitants. This result coincides with the conclusions in Carruthers and Ulfarsson (2003) who attribute higher spending on parks to the need for more parks to provide equal access to the facilities.

## Conclusions

The regression formula model reveals a *significant effect of urban sprawl on current expenditure* of municipalities, especially in municipalities with more than 5000 inhabitants.

The effect *does not transfer in a homogeneous way to all of the municipal budget*. Urban sprawl generates very different effects according to the expenditure variables. This shows how certain expenditure variables in municipal budgets are more sensitive to urban sprawl. The location or distribution of the population in the territory plays a major role in the expenditure variables associated with providing basic public services. Its effect is greatest on security and public transportation and community wellbeing, which primarily covers waste collection, elimination, and treatment; sanitation, and water supply and distribution; road cleaning; and public lighting.

The effects calculated in the expenditure are not linear and *depend on the town's size*. Independently of the quality of the data added to the model, it reveals significant effects according to the town's size in a same expenditure variable. This is consistent with the obligations and powers of the Town Councils which vary depending on the size of the municipality, and with previous studies on the importance of the size of the town and of the economies of scale in the local administration's expenditure (Hortas-Rico, 2014; Solé-Ollé, 2001).

In relation to other studies, where the characterization of the urban space is partial and mainly uses density (Benito et al., 2010; Carruthers and Ulfarsson, 2003; Hortas-Rico and Solé-Ollé, 2010; Hortas-Rico, 2014; Solé-Ollé, 2001), this methodology suggests a more complete characterization of the urban sprawl phenomenon. The model proposed and the effects calculated will be able to generate cost functions to build a model able to assess the increase in municipal expenditure in the different spending variables based on the projected urban development model. This model will constitute a valuable tool for urban planning decision-making and assessment of the economic sustainability of new urban growth.

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