URBAN PATTERNS, POPULATION DENSITY AND THE COST OF PROVIDING BASIC INFRASTRUCTURE: A FRONTIER APPROACH

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Urban Patterns, Population Density and the Cost of Providing Basic Infrastructure: A Frontier Approach

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Abstract

This study estimates cost inefficiency when providing basic infrastructure within a stochastic frontier analytical framework, and investigates the existence of decreasing average costs resulting from economies of scale, associated with larger population and number of dwellings per area, and economies of density, brought about by urban sprawl reductions, to calculate optimal population densities. The methodology relies on the assumption of a cost minimizing behavior on the part of public officials that is characterized by way of a flexible translog cost function. We study in depth the water sector including water supply as well as sewerage and cleansing of residual waters, and considering data at the municipality level for the Spanish region of *Castilla y Leon*. The results indicate that latent scale and density economies as well as relevant inefficiency levels are present, and that they are result of a general suboptimal urban size, in terms of population densities, and the negative effects of dispersed settlement patterns.

Keywords: Scale and density economies, Translog cost function, Stochastic Frontier Analysis, Urban infrastructure, Urban sprawl.

JEL Classification: C3, D24, H1, H4, R53

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1. Introduction

The search for an optimal population and dwellings urban size when proposing policies toward the rationalization of public expenditure at all provision levels ranging from basic urban infrastructure to social services, has been at the center of many debates and controversies since at least the 19^{th} century –i.e. the consolidationist debate, and the main reason behind early spatial-based theoretical modeling balancing in equilibrium the costs of governmental provision and the utility perceived by users through accessibility, e.g. Bramley (1990; ch. 4), and basic econometric studies providing supporting evidence, e.g. Easton and Thomson (1987). Today, despite the fact that the local provision of goods—infrastructure and services—is complex in nature, and subject to ever-changing preferences and legislations, there seems to be an agreement among urban and fiscal economists that for the case of small and medium size cities, when dealing with basic infrastructure, a greater city dimension reducing urban dispersion is desirable.

Intuitively, the provision of basic physical infrastructure must be characterized by the existence of large economies of scale, density and scope, as it is the production of their service utilities counterparts. However, evidence is almost nonexistent, narrow in terms of methodologies and techniques. Clearly not all infrastructures are equally affected by the spatial distribution patterns of population and dwellings. A clear distinction has to be made between "network" infrastructures as the one we study: water distribution and collection and sewerage collection and cleaning of residual waters. Providing the former carry larger costs than the latter for equal population and number of dwellings (i.e., in *per capita* and *per house* terms) as it is done on a door-by-door basis. Moreover we need to differentiate between urban size measured as the number of inhabitants and dwellings within a jurisdiction or administrative limit—i.e., *scale* in terms of these latter variables, and the *density* of those variables in space, *i.e.* the degree of urban dispersion or sprawl. While the provision costs for local governments of network infrastructure is greatly affected by population and housing dispersion or sprawl, this is not the case for hub infrastructure—see Frank (1989) for an early review of the literature from an urban planning/land use, UP&LU, engineering perspective and Schmalensee (1978), in the context of natural monopoly, for determining the cost of providing permanent physical connections between the plant and the premises of consumer spread over a single urban area.

In the literature we find three strands of studies addressing the production cost of utility services: (i) a majority of studies estimating cost functions to quantify the magnitude of economies of scale, density (customer) and scope; (ii) some studies estimating cost frontiers and focusing almost entirely in the quantification of inefficiency, and that normally do not pursue the study of the technological characteristics of the provision; and, (iii) a handful of studies combining both approaches and estimating the different sources of cost economies for the provision of utility services within a frontier framework. Prieto et al. (2010) review the literature and how it compares to their contribution within the first strand of the literature. Attending to the reasons previously stated on the importance of the provision of physical network infrastructure, the main novelty of their work is to focus on this dimension rather than on the production of the associated utility service. That is, the importance of studying the underlying stock of capital (e.g. mains, pipes, purifying and pumping stations, etc., rather than the distribution and collection of water itself), and the effect that urban dispersion —defined as the number of populations settlements (cluster) and the density of population, e.g. Inhab./Km^2, has on its provision cost.

These authors depart from two noticeable recent exceptions of studies that account for spatial density effects in the production of service utilities and extend it to the underlying infrastructure. These are Torres and Morrison (2006) and Bottasso and Conti (2009), who focus on the water supply sector within a non-frontier framework. The present study extends previous results that consider scale and density economies to the field of stochastic frontier analysis (SFA) within the infrastructure provision setting, thereby introducing and extending the application of the SFA to this new research topic. Nevertheless, from the perspective of the production of utility services within a frontier framework, we also find recent contributions. Examples of these studies are Filippini et al. (2008), Bottasso and Conti (2003), and Abrate et al. (2011). The first authors use a stochastic frontier cost function to estimate cost inefficiency and economies of scale of water utilities operating in Slovenia, concluding the existence of relevant economies of scale and density as well as cost inefficiencies; while the last two studies pay more attention to the evolution and determinants explaining the inefficiency term. Bottasso and Conti (2003) using a heteroskedastic stochastic variable cost frontier found that cost inefficiency decreased in English and Welsh water industry. Abrate et al. (2011) take as reference utilities the Italian water and sewerage industry and estimate different panel data cost frontier models incorporating diverse specifications for inefficiency and unobserved heterogeneity terms. Finally, we note that there are also a few studies measuring allocative inefficiency within a normal cost function framework that does not allow for technical inefficiency, investigating resource misallocation by way of shadow prices. This is the case of Battacharyya et al. (1995) incorporating hedonic prices.

Based on the previous discussion, the present study makes several novel contributions. First, it introduces the definition of economies of scale and density in the provision of basic *infrastructure* using advanced frontier techniques. As our review of previous research on this subject shows, while the estimation of flexible costs function, either average or frontier, in *services* production has been extensively applied when studying utility industries to determine optimal production size, this literature has neglected the provision of the supporting physical infrastructure. Secondly, in extending the scope of analysis we discuss in depth how the existing definitions of economies of scale and density in the econometric literature dealing with service production, must be redefined when taking into account infrastructure provision. This redefinition of existing concepts is done while taking into account several variables reflecting the compact or sprawled pattern of a jurisdiction. This allows us to incorporate the concept of provision density as a proxy of urban dispersion, and control for it when assessing its effect on provision costs. Third, the study extends the research carried out in the field of efficiency measurement from a parametric approach, which is crucial for an effective and rational urban planning and to establish sensible land use and urban planning guidelines.

This article is structured as follows. The next section presents the model specification and the methodology employed. Here we model the behavior of public officials and resource managers when providing urban infrastructure by way of the translog cost frontier. The definitions of economies of population scale and urban density are also introduction in this section. We exemplify our analysis using data on the Spanish region of Castilla y León, portraying a large and diverse typology of jurisdictional sizes and urban patterns, and choose as the exemplifying infrastructure sectors that of water supply and sewerage and cleansing of residual waters. In section 3 we introduce the different databases that we use to construct our series of capital stock in this particular infrastructure. We also comment on a novel database on engineer prices that is used to determine the cost of the provision variables. Section 4 presents the estimation results paying special attention to the values of cost inefficiency and its distribution. Section 5 concludes with the main findings.

2. Model specification and methodology

To allow flexibility in the underlying production function when determining the optimal urban size by way of the scale and density economies, we specify a translog cost frontier that accommodates the case of multi-output production in inhabitants and dwellings. This function was introduced by Christensen et al. (1971, 1973) and we can easily derive from it the alternative sources of these size and spatial economies. Public officials optimizing behavior results in an econometric specification corresponding to a cost frontier including the cost of infrastructure provision (*C*) as the dependent variable, and the following regressors: (i) the infrastructure provision targets—outputs, Y_g allowing for population and number of dwellings (Y_1 and Y_2); (ii) prices of the relevant infrastructure—input—physical variables, denoted by P_i —see Table 1 in the next section for their particular definition, and (iii) the densities within a given jurisdiction, which is captured by the Z_k variables reflecting the compact or dispersed pattern of the urban area. Particularly Z_1 is the number of population and housing clusters within a given jurisdiction, while Z_2 corresponds to the urban area in square kilometers (Km^2).

Following Kumbhakar and Lovell (2000) we specify a cost frontier satisfying the properties of concavity and linear homogeneity in input prices, and assume that it is non-decreasing in input prices and outputs. The translog cost frontier *C* can be written in the following way:

$$\begin{aligned} \ln C^* &= \alpha_0 + \sum_{g=1}^{Y} \alpha_g \ln Y_g + \sum_{i=1}^{P-1} \beta_i \ln P_i^* + \sum_{k=1}^{Z} \delta_k \ln Z_k + \\ &+ \frac{1}{2}\left[\sum_{g=1}^{Y}\sum_{h=1}^{Y} \alpha_{gh} \ln Y_g Y_h + \sum_{i=1}^{P-1}\sum_{j=1}^{P-1} \beta_{ij} \ln P_i^* P_j^* + \sum_{k=1}^{Z}\sum_{l=1}^{Z} \delta_{kl} \ln Z_k \ln Z_l\right] + \\ &+ \sum_{g=1}^{Y}\sum_{i=1}^{P-1} \phi_{gi} \ln Y_g \ln P_i^* + \sum_{g=1}^{Y}\sum_{k=1}^{Z} \theta_{gk} \ln Y_g \ln Z_k + \sum_{i=1}^{P-1}\sum_{k=1}^{Z} \omega_{ik} \ln P_i^* \ln Z_k + v + u \end{aligned} \tag{1}$$

where $C^* = C/P_P$ and $P_i^* = P_i/P_P$ indicate that one of the input prices has been used to normalize the cost and the remaining prices, thereby ensuring linear homogeneity in input prices.[1] Since the focus is on the stochastic frontier, the error term is composed of two parts: a stochastic error, v, capturing the effect of noise, and a one-sided non-negative disturbance capturing the effect of inefficiency ($u \geq 0$). To estimate the model by maximum likelihood method as proposed by Aigner et. al. (1977), the following distributional assumptions are made: $v \sim N(0, \sigma_v^2)$ is independently distributed over the

[1] Linear homogeneity in provision prices together with crossed effects' symmetry requires, respectively, the following restrictions:
$\sum_{i=1}^{P} \beta_i = 1$; $\sum_{i=1}^{P} \beta_{ij} = 0, j = 1,...,P$; $\sum_{i=1}^{P} \varphi_{gi} = 0, g = 1,...,Y$; $\sum_{i=1}^{P} \omega_{ik} = 0, k = 1,...,Z$, and $\alpha_{gh} = \alpha_{hg}, g,h = 1,...,Y$; $\beta_{ij} = \beta_{ji}, i,j = 1,...,P$; $\delta_{kl} = \delta_{lk}, k,l = 1,...,Z$.

observations, while the inefficiency term u is independently distributed with variance σ_u^2.[2]

Cost inefficiency is expressed as the following ratio:

$$CE = \frac{C^*}{C^{*F}} = \exp(\hat{u}_i), \tag{2}$$

where C^* is the observed total cost and C^{*F} is the frontier or minimum cost. Cost inefficiency scores equal to one indicate that an urban area is cost efficient lying on the frontier, while inefficient observations present scores greater than one.

From an empirical perspective, besides the cost inefficiency, it is possible to investigate the existence and magnitude of the economies of scale and density. We propose two measures of scale and density economies that portrait cost behavior when population and housing, as well as density increase in the territory. Either by increasing these former magnitudes while keeping constant the variables representing the dispersed or compact pattern of the urban are (i.e. number of clusters Z_1, and the urban area Z_2), or by *reducing* these latter ones while keeping constant the number of inhabitants and dwellings.

The particular definition that we make of the scale economies allows answering the question relative to the optimal urban size, while informing about the effect that an equal change in the number of inhabitants (Y_1) and dwellings (Y_2) would have on current provision costs holding the urban pattern variables constant. Given the provision variables Y_g, g = 1, 2, scale economies define as:

$$\mathrm{SCE} = \sum_{g=1}^{Y} \frac{\partial \ln C^*}{\partial \ln Y_g} =$$
$$= \left[\sum_{g=1}^{Y} \alpha_g + \sum_{g=1}^{Y} \sum_{h=1}^{g-1} \alpha_{gh} \ln Y_h + \sum_{g=1}^{Y} \alpha_{gg} \ln Y_g + \sum_{g=1}^{Y} \sum_{h=g+1}^{Y} \alpha_{gh} \ln Y_h + \sum_{g=1}^{Y} \sum_{i=1}^{P-1} \varphi_{gi} \ln P_i^* + \sum_{g=1}^{Y} \sum_{k=1}^{Z} \theta_{gk} \ln Z_k \right] \tag{3}$$

When SCE is less, equal to, or greater than one, returns to scale are respectively increasing (scale economies), constant or decreasing (scale diseconomies). Note that the smaller the SCE value, the lower the cost increase when expanding the number of inhabitants and dwellings. In the case that economies of scale existed, this would imply that an equiproportional increase in population and

[2] The inefficiency term is normally modeled according to the following distributions: exponential, half-normal, and truncated normal with mean μ. In the empirical section we test these alternative assumptions.

housing brings lower provision cost increases. Therefore, given equal municipal characteristics relative to the urban patterns, Z_k, increasing the values of Y_g by one percent translates into a lower provision cost in the magnitude signaled by the sum of their elasticities: SCE = $\varepsilon_{C,Y_1} + \varepsilon_{C,Y_2}$.

Next we define economies of urban density as the change that takes place in the provision cost when both variables reflecting urban dispersion are reduced by one percent, Z_k, k = 1, 2. Because we want to study cost behavior when increasing population and housing densities, we interpret the elasticities with reversed sign, so to obtain the magnitude of cost reduction when density is increased by jointly reducing the number of clusters and the surface area. It is expected that increasing population and housing density by *reducing* the number of dispersed urban clusters, Z_1, along with a *reduction* in the square kilometers of urban area, Z_2, would carry lower provision costs—ceteris paribus the number of inhabitants and dwellings. Hence, economies of density coming from urban sprawl reductions at the levels of the provision variables Y_g read as follows:

$$\mathrm{DNE} = -\sum_{k=1}^{Z} \frac{\partial \ln C^*}{\partial \ln Z_k} =$$
$$= -\left[\sum_{k=1}^{Z} \delta_k + \sum_{k=1}^{Z}\sum_{l=1}^{k-1} \delta_{kl} \ln Z_l + \sum_{k=1}^{Z} \delta_{kk} \ln Z_k + \sum_{k=1}^{Z}\sum_{l=k+1}^{Z} \delta_{kl} \ln Z_l + \sum_{g=1}^{Y}\sum_{k=1}^{Z} \theta_{gk} \ln Y_g + \sum_{i=1}^{P-1}\sum^{Z} \omega_{ik} \ln P_i^* \right] \quad (4)$$

If increasing urban density—considering the elasticities of Z_1 and Z_2 with reversed sign—brings a reduction in the provision cost, (4) will be negative, and economies of density exist. In this case negative values smaller than −1, i.e., DNE ∈ (−∞,−1), indicate increasing economies of density (increasing the density reduces the cost in a larger proportion as the sum of the elasticities: DNE = $-\varepsilon_{C,Z_1} - \varepsilon_{C,Z_2}$ is greater than one absolute values), whereas negative values equal or greater than −1, i.e., DNE ∈ (−1, 0], imply that decreasing density economies are observed (increasing the density reduces the cost in a lower proportion as the sum of the elasticities is smaller than one in absolute terms). For DNE = −1, constant economies if density exist. Note that in this case, as opposed to SCE, the largest the DNE value in absolute terms, the highest the cost reduction. Therefore, when density economies exist, reducing the number of population clusters and the extension of the urban area (e.g., promoting densification by means of a single urban area and reducing the number of single houses by favoring apartment buildings with multiple housings units), would reduce the cost of provision of infrastructure. In this way (4) establishes that the provision of infrastructure to population and housing carries lower costs as territorial density increases, e.g., when they locate in one single cluster with high-rise buildings, as opposed to rural zones characterized by single and dispersed housings located in numerous clusters. [3]

2.1 Optimal population density

The final aim of calculating economies of scale and density is the determination of the ideal urban dimension in terms of the actual variables upon which public officials take action when planning urban infrastructure investments. Not surprisingly, from a political perspective, the most relevant variable when allocating intergovernmental grants devoted to infrastructure is urban population, proxy of the number of voters, while from the urban planning perspective that concerns this study, population density is the variable that better captures cost efficiency when providing public infrastructure—low and high densities reflecting extensive and thick settlements respectively. We therefore consider population Y_1 and urban size Z_2 as the key dimension variables whose optimal values minimizing average provision cost should be determined.

We analytically determine the ideal dimension for which average provision cost is minimum by generalizing the approach set out by Mizutani and Urakami (2001) for water utilities, and extend it to the determination of the minimum cost in the case of multiple outputs within our infrastructure provision framework. When particularly referred to population density the expression for the minimum provision cost can be calculated by taking the antilogarithm of (1) and dividing by population Y_1 and by the urban surface Z_2. The first order conditions that jointly minimize average provision cost with respect to these two variables allow us to establish optimal population density by dividing the former by the latter (Inhab./Km^2, i.e. Y_1 / Z_2).

The first step is to take the antilogarithm of (1) and divide by Y_1:

[3] The definitions that we present of economies of scale (4) and density (5) correspond to those originally introduced by Panzar and Willig (1977) and adopted by Torres and Morrison (2006), and they are the inverse of those later suggested by Caves et al. (1984, 1985), that in turn are favored by Botasso and Conti (2009). Nevertheless, whether the scale and density economies are defined as the inverse of the sum of the elasticicities or not does not change any conclusion, but just their numerical interpretation.

$$
\begin{aligned}
AC_{Y_1} &= C^* \big/ Y_1 = \left(1/Y_1\right) \cdot \exp\left(\ln C^*\right) = \\
&= \left(1/Y_1\right) \cdot \exp\Bigg[\alpha_0 + \sum_{g=1}^{Y} \alpha_g \ln Y_g + \sum_{i=1}^{P-1} \beta_i \ln P_i^* + \sum_{k=1}^{Z} \delta \ln Z_k + \\
&+ \frac{1}{2}\left[\sum_{g=1}^{Y}\sum_{h=1}^{Y} \alpha_{gh} \ln Y_g Y_h + \sum_{i=1}^{P-1}\sum_{j=1}^{P-1} \beta_{ij} \ln P_i^* P_j^* + \sum_{k=1}^{Z}\sum_{l=1}^{Z} \delta_{kl} \ln Z_k \ln Z_l \right] + \\
&+ \sum_{g=1}^{Y}\sum_{i=1}^{P-1} \varphi_{gi} \ln Y_g \ln P_i^* + \sum_{g=1}^{Y}\sum_{k=1}^{Z} \theta_{gk} \ln Y_g \ln Z_k + \sum_{i=1}^{P-1}\sum_{k=1}^{Z} \omega_{ik} \ln P_i^* \ln Z_k \Bigg]
\end{aligned}
\tag{5}
$$

Differentiating this average cost function with respect to first provision variable Y_1 and equating it to zero gives us the following first order condition:

$$
\frac{\partial AC_{Y_1}}{\partial Y_1} = \frac{\partial\left(C^* / Y_1\right)}{\partial Y_1} = \left(1/Y_1^2\right) \cdot \left[\begin{array}{l} \exp\left(\ln C^*\right) \cdot \\ \left[\alpha_1 + \alpha_{11} \ln Y_1 + \sum_{h=1}^{Y-1} \alpha_{1h} \ln Y_h + \sum_{i=1}^{P-1} \varphi_{1i} \ln P_i^* + \sum_{k=1}^{Z} \theta_{1k} \ln Z_k \right] \\ - \exp(\ln C^*) \big] \end{array} \right] = 0
\tag{6}
$$

Since $Y_1 \neq 0$ and $\exp(\ln(C^*) \neq 0$, the minimum of the average cost function requires the following equality:

$$
\alpha_1 + \alpha_{11} \ln Y_1 + \sum_{h=1}^{Y-1} \alpha_{1h} \ln Y_h + \sum_{i=1}^{P-1} \phi_{1i} \ln P_i^* + \sum_{k=1}^{Z} \theta_{1k} \ln Z_k - 1 = 0
\tag{7}
$$

Following the same procedure we can obtain the expression for the optimal value of the density variable Z_2 that minimizes average costs. The counterpart to equation (7) corresponding to the first order condition of $\partial AC_{Z_2} / \partial Z_2 = \partial(C^* / Z_2) / \partial Z_2$ is:

$$
\delta_2 + \delta_{22} \ln Z_2 + \sum_{l=1}^{Z-1} \delta_{2l} \ln Z_l + \sum_{g=1}^{Y} \theta_{g2} \ln Y_g + \sum_{i=1}^{P-1} \omega_{i2} \ln P_i^* - 1 = 0
\tag{8}
$$

We can use equations (7) and (8) to jointly determine the optimal values for the provision and density variables that allow us to establish the optimal population density ratio Y_1/Z_2 (Inhab./Km^2).

3. Databases: LIES and cost based engineering prices

3.1. Physical variables, prices and the cost urban infrastructure stock

The physical variables X_i that we have used to construct our novel database in urban infrastructure stock come from the Spanish Local Infrastructure and Equipment Survey, *Encuesta de Infraestructura y Equipamientos Locales*, performed in 2005. This inventory was designed by the Ministry of Public Administration (MAP, 2005) and local governments at the provincial level–*Diputaciones*–are responsible for executing it. The inventory lists all infrastructure and equipment that has to be provided in each jurisdiction according to the legal framework represented by the Spanish law, 7/85 *Ley de Bases de Régimen Local*. [4]

For this study we have also produced a second database using engineering cost prices of the different provision variables as technically defined in the inventory. We calculate unit provision prices—e.g., 1 m of sewage collection, which are the result of weighing each input price: labor, capital, intermediate consumptions,…— by its cost share in the production of that particular provision variable. Additionally, the unit provision price also incorporates other costs regarding single unit inputs (pipelines, street chests and wells, drains, etc.), as well as other auxiliary input units (sand, mortar, concrete, trench refilling, etc.).[5] This methodology takes into account best practice technological characteristics and incorporates all those elements that are part of each of the representative tasks that are necessary to produce one unit of infrastructure.[6] As an example, Table 1 shows how to calculate the cost of one linear meter of sewage collection network.

[4] As provision levels and conditions may change with time as services deteriorate or are improved, the inventory is periodically updated. Its importance resides in the fact that it constitutes a dynamic statistical source that can be used to evaluate local provision levels and conditions to allocate the intergovernment grants funds. We remark however that our analysis solely relies on the quantity variables of the *LIES* survey and therefore does not take account the characteristics related to quality of the infrastructure (whether it is in good, mediocre or bad condition). Therefore, in the context of this limitation, we can explain the reduction in cost due only to quantity (physical) related improvements in the provision of basic infrastructure.

[5] These and other individual task prices that we have used to determine unit prices for the remaining provision variables can be looked up in the Castilla y León database of construction prices, *Instituto de la Construcción de Castilla y León*: www.iccl.es, BPCCL (2004).

[6] For this purpose we have gathered information from the technical engineering staff of the provincial governments whose expert opinion on the components and prices of the different civil works —provision variables— is critical. These public works' supervisors plan, organize, oversee, coordinate and review a comprehensive program of public works construction, maintenance and repair of urban infrastructure, which includes water supply, sewerage collection and paving and lighting.

Table 1. Individual tasks comprised in the sewage collection network price (euros)

Activity	Task	Units.	Nº units	Length	Width	Height	Weight	Price	**Total**
Sewer: Network of pipes for collection and disposal of sewage LIES – 2005	Pavement breaking...	m^2	1	1	0.9		0.45	3.76	**1.69**
	Trench digging …	m^3	1	1	0.8	1.0	0.8	8.16	**6.53**
	Sand and materials…	m^3	1	1	0.7	0.2	0.14	11.23	**1.57**
	Sewer pipeline…	M	1	1			1.00	40.24	**40.24**
	Sewer manhole…	Unit	0.033	1			0.033	240.46	**8.93**
	House connection…	Unit	0.1	1			0.1	120.20	**12.02**
	Trench refilling……	Unit	1	1	0.8	0.8	0.64	0.88	**0.56**
	Concrete HM/25N/…	m^3	0.50	1	0.9	0.2	0.09	109.21	**9.83**
								Total unit price (1 m.)	**81.37**

Source: Own elaboration and provincial governments engineer guidelines for the parametric price database.
2005 prices. Best practice technique.

Once the parametric price for each provision variable is calculated, it is in turn weighted by its relevant geo-structural variables characterizing the particular urban location in which the civil work takes place: lithology/geology, altitude and distance to the closest commercial hub—as a proxy to transportation costs and normally overlapping with the province's capital city.[7] All these ancillary variables allow us to establish an "urban area factor" that renders the single provision price more accurate as this weight allows us to modify it taking into account the characteristics of a particular geographic location. [8]

The cost of provision that we obtain by multiplying the prices P_i by the existing physical infrastructure X_i can be considered as the provision stock of urban infrastructure. Given that the year in which a particular infrastructure was constructed is unknown, as well as the fact that their current condition or quality level (note that repairs are timely programmed and budgeted), we are forced to value the existing stock at current provision prices. This corresponds to the usual definition of gross capital stock in wealth national accounts, which prices assets at their current acquisition value.[9]

[7] The weight capturing the lithological and geological characteristics of a municipality reflects soil hardness when executing a work. The information provided by the lithological map of Castilla y León, SIEMCALSA (1997) allows us to classify urban areas in thirteen distinctive categories and six levels of soil hardness. As for the altitude, we have considered four levels taking as reference for a particular urban area that of its largest population cluster. Finally, when the closest city head of a commercial area coincides with the administrative capital city, the distance can be found in the 1993 Nomenclator produced by the Spanish National Statistical Office, INE (2003), while the distances to alternative commercial cities have been calculated using the information database given by the National Center of Geographical Research, CNIG (2001) and the Commercial Atlas of Spain published by the Spanish savings bank, laCaixa (2000).

[8] These weights are commonly used in studies on production of urban utilities, e.g. Coelli and Walding (2005) for water supply, Rubiera (2007) in studies testing central place, hierarchy, and location theories, Deller et al. (1988) for rural low-volume roads, all of which obtain provision prices by means of engineering costs analyses.

[9] A methodological discussion summarizing the conclusions of the Camberra group on capital stock measurement, with regard to the concepts of gross, net and productive capital stocks can be found in OECD (2001).

With regard to the target provision variables (outputs) for which infrastructure investment is planned: population Y_1 and dwellings Y_2, we have considered a population figure that considers both permanent residents as well as temporary visitors –e.g. seasonal students, workers officially residing in other places, etc... The reason behind this choice is that urban infrastructure levels must be planned according to its potential number of users at any moment in time. This means for example that urban areas with a high degree of second residences will experience unused infrastructure capacity, but it is clear that basic urban infrastructure –*e.g.* sewerage collection and disposal, must be provided on a door-by-door basis regardless of the intensity of use. Both variables gathered and listed by municipalities, which is the benchmark jurisdictional level, come from the LIES-2005 (2004 Spanish Census of Population and Dwellings, INE 2004). As reflected by INE, this concept of population "is believed to reflect a more accurate estimation of the real level of population to whom the municipality must provide infrastructure".

3.2. Data description

The number of municipalities included in the estimation of the cost function corresponding to the entire water cycle: including Water supply and sewerage and cleansing of residual waters, as well as the principal descriptive statistics relative to provision costs, population and dwellings and provision prices are shown in Table 2. With regard to provision costs, both sectors reach a cost on average of €773,001. Also, given the similarities in the engineering prices between the water supply and sewerage infrastructures, regarding high capacity and low capacity pipelines for both flows of water, as well as tanks for drinkable water and its purifications after use (treated flow), we consider the average price of these two pair-wise infrastructures as presented in Table 2. In relation to the prices, the price for water tanks and treated flow has the biggest unit value. With regard to the variables related to density, as anticipated we consider the number of clusters in each municipality Z_1 whose average ranges among 1 and 24, whereas the effect of urban area in square kilometers, explicitly introduced as a dwellings to area ratio Z_2, ranges from 1 to 291.

Table 2. Descriptive statistics by provision sectors of Water Supply and Sewerage and cleansing of residual waters (n = 999)

Variables	Average	Std. Deviat.	Minimum	Maximum
C_i - Cost (Stock)	773,001	929,149	36,729	1.06e+07
Y_1 - Population (nº)	426	495	17	4,829
Y_2 - Housing (nº)	276	349	11	4,450
P_1 - High cap. water supply pipelines (€/m) High cap. water disposal pipel. (€/m)	56	6	45	71
P_2 - Water tanks (€/m3) Treated flow (€/m3)	222	4	207	230
P_3 - Water distribution network (€/m) Sewerage distribution network (€/m)	89	6	82	113
Z_1 - Population clusters (nº)	2.14	2.57	1	24
Z_2 - Urban Area (Km^2)	17.91	26.09	0.72	291.38

Our estimate refers to municipalities up to 5,000 inhabitants, known in Spain as strictly rural. We have only found good estimates for 995 municipalities in this group of rural municipalities. Its population is 67.3% out of 1,356,000 inhabitants and 45% out of 2,238 municipalities belonging to EIEL-2005.
Source: Own elaboration from LIES and Price Databases.

4. Empirical Analysis

4.1. Significance of the stochastic cost frontier and alternative efficiency distributions.

The estimation results of the translog cost frontier function obtained for Water supply and Sewerage and cleansing of residual waters sector in *Castilla y León* are presented in Table 3.[10] Since all data are mean corrected, the expansion point of the translog stochastic frontier cost function specified in eq. (1) is chosen to be the sample mean. Moreover, given the total cost and all the explanatory variables are in logarithms, the estimated first-order coefficients can be interpreted as cost elasticities.

The cost efficiency estimation has been performed using the alternative exponential, half normal and truncated normal distributions. In general, we observe a reasonable goodness of fit when considering the test for joint significance of the parameters. The variances of the two error components are significant and the ratio of the standard deviation of the inefficiency component to the standard deviation of the random component (λ) is more than 50. Accordingly, the variance of the random component explains more than the variance of inefficiency in the error term. Finally, the generalized log-likelihood test for the presence of inefficiency term allows rejecting the null hypothesis, which refers to the inexistence of inefficiency.

[10] The stochastic frontiers are estimated using Stata V.11

Table 3. Cost determinants of urban infrastructure.
Water Supply and Sewerage and cleansing of residual waters (999 observations)

		Exponential Distribution		Half Normal Distribution		Truncated Normal Distribution	
Variables	Parameters	Coefficients	T-Student	Coefficients	T-Student	Coefficients	T-Student
Constant	α_0	-0.066	-4.318**	-0.128	-7.836**	-0.129	-2.596**
$\ln Y_1$	α_1	0.508	16.343**	0.511	16.278**	0.511	16.257**
$\ln Y_2$	α_2	0.091	3.539**	0.088	3.425**	0.088	3.422**
$\ln P_1^*$	β_1	0.300	2.643**	0.290	2.600**	0.290	2.590**
$\ln P_2^*$	β_2	0.385	2.760**	0.434	3.091**	0.435	3.022**
$\ln Z_1$	δ_1	0.319	13.622**	0.324	13.858**	0.324	13.741**
$\ln Z_2$	δ_2	0.063	5.348**	0.061	5.163**	0.061	5.058**
$(\ln Y_1)^2$	α_{11}	0.341	3.747**	0.337	3.747**	0.337	3.749**
$(\ln Y_2)^2$	α_{22}	-0.050	-0.983	-0.053	-0.994	-0.053	-0.982
$\ln Y_1$	α_{12}	0.130	1.061	0.136	1.106	0.136	1.104
$(\ln P_1^*)^2$	β_{11}	2.996	1.841**	2.852	1.767**	2.852	1.767**
$(\ln P_2^*)^2$	β_{22}	-2.390	-1.168	-1.726	-0.832	-1.719	-0.820
$\ln P_1^*$	β_{12}	-4.140	-1.564*	-3.927	-1.501*	-3.926	-1.501*
$(\ln Z_1)^2$	δ_{11}	0.264	4.747**	0.276	5.003**	0.276	4.926**
$(\ln Z_2)^2$	δ_{22}	-0.018	-0.710	-0.015	-0.603	-0.015	-0.601
$\ln Z_1$	δ_{12}	0.126	2.667**	0.124	2.633**	0.124	2.624**
$\ln Y_1$	ϕ_{11}	-0.481	-1.584*	-0.439	-1.432*	-0,440	-1,432
$\ln Y_1$	ϕ_{12}	0.397	1.254	0.379	1.195	0.379	1.195
$\ln Y_2$	ϕ_{21}	-0.089	-0.304	-0.117	-0.388	-0.116	-0.383
$\ln Y_2$	ϕ_{22}	0.014	0.045	0.020	0.065	0.020	0.064
$\ln Y_1$	θ_{11}	-0.386	-6.558**	-0.387	-6.548**	-0.387	-6.508**
$\ln Y_1$	θ_{12}	-0.038	-1.030	-0.049	-1.324*	-0.049	-1.316*
$\ln Y_2$	θ_{21}	0.040	0.797	0.036	0.687	0.036	0.687
$\ln Y_2$	θ_{22}	-0.017	-0.512	-0.009	-0.266	-0.009	-0.263
$\ln P_1^* \ln Z_1$	ω_{11}	0.280	1.269	0.332	1.515*	0.332	1.509*
$\ln P_2^* \ln Z_1$	ω_{21}	-0.238	-1.089	-0.227	-1.065	-0.227	-1.064
$\ln P_1^* \ln Z_2$	ω_{12}	0.174	1.281*	0.133	0.999	0.132	0.963
$\ln P_2^* \ln Z_2$	ω_{22}	-0.149	-1.052	-0.133	-0.921	-0.133	-0.921
σ_v		0,117	18,631**	0,093	11,036**	0.095	2.288**
σ_u		0,096	9,528**	0,198	14,160**	0.197	2.220**
σ^2		0,023	18,218**	0,048	11,058**	0.219	2.316**
$\lambda = \sigma_u / \sigma_v$ (1)		0,823	53,295**	2,133	99,047**	0.905	17.803**
Test σ_u=0		$\chi^2(1)$=29.660		$\chi^2(1)$=31.750		$\chi^2(1)$=5.526	
Test Wald Sig.		$\chi^2(27)$=27,204.850		$\chi^2(27)$=27,762.980		$\chi^2(27)$=26,900.890	
Vuong's Test. H_0: Truncated normal is equivalent to Exponential or Half normal.		1.999**		2.485**		BM	

Notes: * Parameter significant at 90%; **Parameter significant at 95%; (1) In the truncated-normal distribution the specification is $\gamma = \sigma_u^2 / \sigma_v^2$.
Vuong's (1989) Test, which has been obtained from Lai and Huang (2010), follows a N(0,1) distribution.
P_i^* indicate that prices are normalized by P_3.
Source: own elaboration

Focusing specifically on the comparison of the inefficiency distributions, although the parameters estimated are similar for the different assumption, Vuong's (1989) test allows us to discriminate between them.[11] The Vuong test rejects at a 10% or lower significance level the null hypothesis that all specifications are equivalent, suggesting that the truncated normal model fits best the stochastic frontier specification. Based on this result that identifies the truncated normal model as the benchmark for the analysis, we nevertheless make a pairwise comparison of the efficiency levels obtained under the correct assumption and the other two possibilities, and graph it against the estimated cost frontier values, so as to determine the possible biases that considering the incorrect distributions might cause.

Figure 1 shows the ratio of efficiencies plotted (vertical axes) against the ratio of estimated (predicted) cost frontier values (horizontal axes). Considering the definition of the cost inefficiency in (2), both comparisons suggest that assuming the wrong distributions for the efficiency term results in the underestimation and overestimation of the cost frontier values with respect to the truncated normal results (for the exponential,

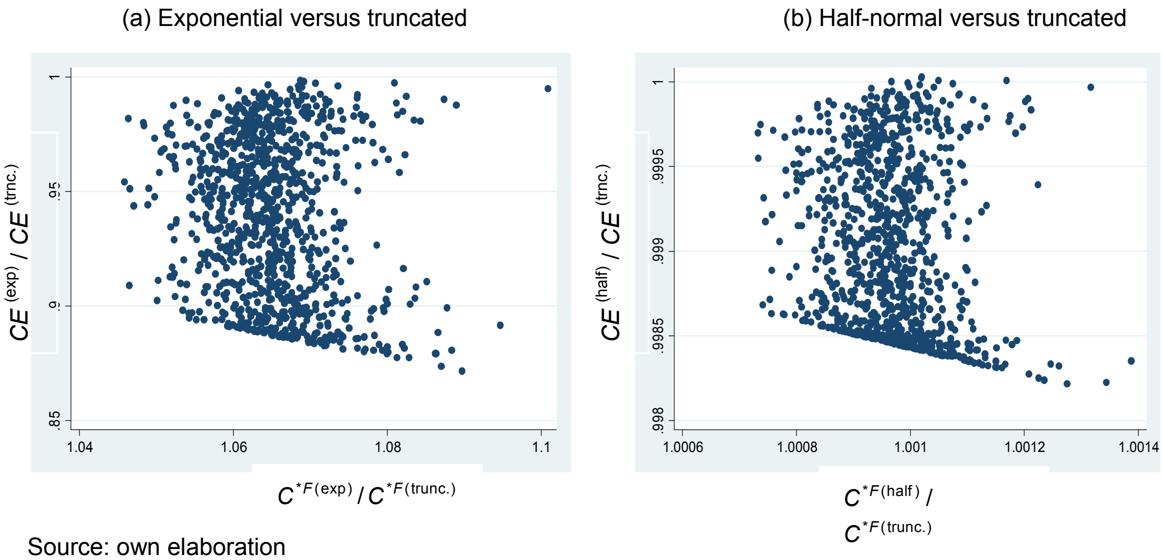
[11] Lai and Huang (2010) extend the likelihood ratio (LR) test of Vuong (1989) model selection criterion to the SF models. This test compares a parametric family of the SF model: $F_{\theta_f} := \left\{ f(y \mid s;\theta_f) : \theta_f \in \Theta_f \subset R^{d_f} \right\}$, with an alternative parametric family of the SF model $G_{\theta_g} := \left\{ g(y \mid s;\theta_g) : \theta_g \in \Theta_g \subset R^{d_g} \right\}$, where $f(y \mid s;\theta_f)$ and $g(y \mid s;\theta_g)$ represent the conditional probability densities of both models, respectively, d_f and d_g are the dimension of the parameters, θ_f and θ_g are the vector of parameters and Θ_f and Θ_g are the parameter spaces of the SF models. In our empirical approximation, also is programmed in the Stata V.11 software, we contrast the convenience of the truncated normal distribution model (F_{θ_f}), which represents the Baseline Model (BM) in Vuong´s test statistic, in comparison with exponential and half-normal distribution, denoted by G_{θ_g}. With this propose, we consider the following two hypothesis: (i) H_0: F_{θ_f} and G_{θ_g} are equivalent and (ii) H_f: F_{θ_f} is better than G_{θ_g}. In order to contrast both hypothesis, Vuong (1989) has proposed a LR test of the hypothesis Ho defined as:

$$T_{LR}^V = n^{-1/2} LR(\hat{\theta}_f, \hat{\theta}_g) / \hat{\theta}_{LR} = n^{-1/2} \left[\ln L_n^f\left(\hat{\theta}_f\right) - \ln L_n^g\left(\hat{\theta}_g\right) \right] / \hat{\theta}_{LR} = n^{-1/2} \left[\sum_{i=1}^{n} \ln \frac{f(y_i \mid s_i;\hat{\theta}_f)}{g(y_i \mid s_g;\hat{\theta}_g)} \right] / \hat{\theta}_{LR},$$

where, $\ln L_n^f\left(\hat{\theta}_f\right)$ and $\ln L_n^g\left(\hat{\theta}_g\right)$ are the conditional log-likelihood functions and $\hat{\theta}_{LR}^2 = \frac{1}{n}\sum_{i=1}^{n}\left[\ln \frac{f(y_i \mid s_i;\hat{\theta}_f)}{g(y_i \mid s_i;\hat{\theta}_g)} \right]^2 - \left[\frac{1}{n}\sum_{i=1}^{n} \ln \frac{f(y_i \mid s_i;\hat{\theta}_f)}{g(y_i \mid s_i;\hat{\theta}_g)} \right]^2$. Under some regular conditions (assumptions A1–A6 in Vuong (1989)), $T_{LR}^V \xrightarrow{d} N(0,1)$ under H_0.

$C^{*F(\exp)} > C^{*F(\text{trunc.})}$, and for the half-normal, $C^{*F(\text{half})} > C^{*F(\text{trunc.})}$), causing the corresponding overestimation or underestimation of the inefficiency values, respectively (i.e., $CE^{(\exp)} < CE^{(\text{trunc.})}$ and $CE^{(\text{half})} < CE^{(\text{trunc.})}$). Additionally, in both comparisons the correlation between the ratios is slightly negative, i.e., as the difference between the predicted values reduces, the upward or downward bias in the corresponding efficiency value also reduces. For these reasons and based on the results obtained with Vuong's test, we take the truncated normal model as the benchmark (base model) for the analysis of cost inefficiency as well as the scale and density economies resulting in the optimal population density.

Figure 1. Frontier and efficiency for different distributions



Source: own elaboration

4.2. Cost efficiency, economies of scale and density, and optimal population density

The results show that the output coefficients are positive and highly significant. The value resulting from the addition of the elasticities corresponding to the number of inhabitants (Y_1) and dwellings (Y_2) are systematically smaller than one, showing that a joint increase of these two target provision variables would increase the provision cost to a lower extent, reflecting the existence of economies of scale. As expected, the values of the variables representing population density (Z_k) are also positive and significant. As a result, when interpreted with reverse sign, reducing the number of clusters (Z_1) and the urban area (Z_2) reduces provision cost, and when taken together, also reveal the existence of relevant density economies.

The particular estimates of economies of scale (SCE) and density (DNE) as defined in (3) and (4) can be found in Table 4.With regard to the scale economies, the larger their value the lower the increase in provision costs when the number of inhabitants and dwellings are expanded—i.e. the smaller the value of the elasticities included in the denominator. SCE shows that jointly increasing the number of inhabitants and dwellings by 1% increases costs of infrastructure provision by 0.599%. The existence of these remarkable scale economies suggests important average cost savings in terms of urban scale population and housing. Regarding density economies, whose interpretation is the opposite to that for SCE since the smaller their value the larger the provision costs savings when *reducing*—hence the negative sign—both the number of cluster Z_1 and the urban surface Z_2, we observe that a one percent reduction in the number of clusters Z_1, simultaneous to the same proportional reduction in the extension of urban areas, Z_2, brings a cost reduction equal to – 0.385% (DNE = $-\varepsilon_{C,Z_1} - \varepsilon_{C,Z_2}$ = – 0.324 – 0.061). This result is indicative of the existence of decreasing economies of density, since even if increasing urban density reduces costs, the reduction is to a lower extent.

From these results we learn that when following an strategy to reduce provision costs by exploiting the existing economies of scale and/or density, it is more convenient to focus on achieving a larger number of inhabitants and dwellings given the urban pattern configuration of the jurisdictions, since scale economies are larger than their density counterparts. Table 4 also shows that when comparing the two sources of urban density increases, respectively associated to reducing the number of clusters Z_1, and the urban surface, Z_2, the former carry higher cost reductions than the latter since $\varepsilon_{C,Z_1} > \varepsilon_{C,Z_2}$ —the weights associated to each elasticity are calculated as $\varepsilon_{C,Z_k} / (\varepsilon_{C,Z_1} + \varepsilon_{C,Z_2})$. These results suggests that horizontal or space density economies reflecting network length savings between clusters by promoting compact urban forms are larger than those that could be obtained by increasing population and dwellings density within the exiting clusters, i.e. vertical network economies. This means that land use/urban planning guidelines should prevent disperse ("leap-frog") urban developments in favor of single urban areas within a given jurisdiction, together with housing units accommodating a larger number of people, e.g. high-rise buildings or apartment complexes, since they bring larger costs reductions than trying to reduce the area of the existing clusters.

As for the optimal population density ratios (Inhab./Km^2, Y_1 / Z_2) obtained by solving the system of equations corresponding to (7) and (8). The optimal population density is 3,405.6 Inhab./Km^2, situating in the upper part of the distribution of observed densities in the region of *Castilla y León* and showing that a majority of the currently observed densities are well below the minimum average cost benchmark. In fact, as many as 682 jurisdictions representing 68.3% of the data set are below the optimal value. Recalculating the scale and density economies for the two mutually exclusive subsets of observations divided according the optimal density values we learn that for jurisdictions presenting a population density ration greater than the optimal value, the value of scale economies approach zero while density economies approach ones, when compared to the values for the whole data set. Since the jurisdictions with low density ratios are of a rural nature, where the number of dispersed cluster is high and inhabitants low, it comes as no surprise that the extent of the scale and density economies is so large. This implies relevant cost reductions as both the number of cluster and the size of the urban areas reduces. Moreover, despite the relatively limited number of observations these values are statistically significant.

Table 4. Scale and density economies by population densities.

Size	Scale Economies, SCE	Density Economies, DNE	Weights in DNE	
			Z_1	Z_2
All obs (nº = 999)	0.599 (0.041)*	-0.385 (0.026)*	0.158	0.842
$Y_1 / Z_2 \leq$ 3,405.6 (nº = 682)	0.523 (0.0.056)*	-0.445 (0.043)*	0.126	0.874
$Y_1 / Z_2 >$ 3,405.6 (nº = 317)	0.737 (0.212)*	-0.254 (0.189)*	0.210	0.789

Notes: Standard errors in parenthesis (see Bohrnstedt y Goldberger (1969) for calculation details).
* Significant at the 5% level.
Source: own elaboration.

Additionally, as a result of the cost frontier estimation we obtain cost efficiency values in the provision of basic public infrastructure, whose main descriptive statistics for the whole data set and the two previous subsets classified according to the same optimal density criteria is presented in Table 5. The cost efficiency values, obtained from the exponential model as proposed by Simar (1992) and Coelli and Battese (1996), show that the mean cost inefficiency is about 18% for the data set including all observations, similar to the value found by Filippini et.al. (2004, 2008) for a sample of Slovenian companies in the water and electricity utility supply sectors. Moreover, we learn that for the subset of jurisdictions with a suboptimal urban size in terms of the population density, cost inefficiency is larger than in the subset where the optimal population density is observed. In fact, the group of observations below the optimal values exhibit high inefficiency levels to the tune of 20%. This average inefficiency value drops to 17%, for the observations meeting the optimal density value. As previously noted the jurisdictions with low density ratios are of a rural nature, where the existence of dispersed clusters is common and the number of inhabitants is quite low, while those with high population density values are normally urban areas presenting compact urban patterns and a large number of inhabitants. So, when the municipalities reach an optimal scale and population density the cost inefficiencies are practically inexistent and there is not a significant inefficiency dispersion. This suggests that when deciding of the provision of infrastructure in the former, the inexistence of capable managers allocating budgets, or the lack of command and control strategies devoted to ensure efficiency is more likely. These and other reasons allow several researchers contributing to Blank (2000), as well as Kalb (2010), to identify as one stylized conclusion regarding the performance of public agents that smaller jurisdictions present higher inefficiency levels than larger counterparts.

Table 5. Optimal size and cost inefficiency scores by population densities.

	Water Supply Sewerage and cleansing of residual waters
All obs.	999 (100%)
Average	1.181
St. Deviation	0.124
Rank	0.992
	$Y_1/Z_2 \leq 3{,}405.6$
Obs.	682 (68.3%)
Average	1.189
St. Deviation	0.135
Rank	0.992
	$Y_1/Z_2 > 3{,}405.6$
Obs.	317 (31.7%)
Average	1.165
St. Deviation	0.093
Rank	0.436

Source: own elaboration

We conclude from these results that the large scale and density economies are very robust indications that the existing urban areas in *Castilla y León* are noticeably smaller than the optimal size obtained when estimating our cost frontier functions, and that the cost excess associated to these diseconomies is worsened by the large cost inefficiency levels that they exhibit. As a result we believe that there are relevant policy implications that can be drawn in terms of land use and urban planning so as to prescribe appropriate guidelines. In fact, it is noticeable that there exists an opportunity for important costs savings when providing basic infrastructure. This can be achieved in a two stage strategy, with a first action increasing urban size in terms of population and housing so as to exploit latent scale economies, while favoring denser urban pattern implying less disperse population and housing clusters, and resulting in relatively smaller urban areas. This increase in urban size and density should result, posteriorly, in higher efficiency levels as those found in larger urban areas. All these results converge into our single measure of optimal urban size defined in terms of population density, whose value is consistent with our findings since it leaves almost two thirds of all jurisdictions, 68.3%, below it. For all these measures having such important impact on provision costs, we find that segmenting the dataset according to our key variable of optimal population density reinforces our findings, since the scale and density magnitudes are statically significant both below and above that optimal threshold. However, the effect of population density on cost scale and density economies as well as cost efficiency is asymmetric with respect to size. From our results we learn that urban areas below these optimal density values incur in much higher provision costs than their larger counterparts due to these economies and a larger inefficiency, but also that these sources of economies tend to fade away as the urban areas increase their population density.[12] In fact, additional calculations carried out for urban areas with population density higher that the 3,405.6 inhab./Km^2 show that both scale and density economies are negligible and statistically insignificant, as well as the inefficiency levels.

5. Conclusions

In this study we have used the existing stochastic frontier methods to estimate a cost function for a dataset of Spanish urban areas situated in region of *Castilla y Leon* and explore the magnitude of scale and density economies, efficiency levels, and determine optimal urban size in terms of population density. In doing so we adopt a cost minimizing behavior on the part of public officials, which is modeled by way of a flexible functional form. Particularly, we make use of the translog specification and estimate the elasticities conforming our definitions of economies of scale and density, as well as cost inefficiency, in the provision of the infrastructure related to the watter supply and sewerage and cleansing of residual waters; sectors particularly suited for the measurement of these magnitudes given their network nature and thoughtfully studied. We adopt a standard but relatively unexploited approach where the target provision outputs are inhabitants and dwellings (Eberts and McMillen, 1999), to quantify the scale economies, and two variables that allow us to control for the patterns of urbanization, i.e. the number of population clusters and the extension of the urban

[12] Similar conclusions can be found in Filippini et al. (2008), and the literature dealing with service—and not infrastructure—utility production.

area, both proxies of horizontal and vertical economies of scale *a la* Torres and Morrison (2006) and Bottasso and Conti (2009), respectively.

We find consistent evidence of relevant of economies of scale and density for the dataset, which are larger for the data subset of urban areas below the optimal urban size, which situates around 3,405.6 inhab./Km^2. Our main findings show that the cost savings resulting from density economies, and particularly from reductions in urban dispersion (sprawl) associated with a decreasing number of clusters, i.e. horizontal or space density economies reflecting network length savings between clusters by promoting compact urban forms, are larger than those that could be obtained by increasing dwellings density within clusters, i.e. vertical network economies. Density economies are slightly lower in magnitude to the scale economies deriving from larger urban sizes in terms of the number of inhabitants and dwellings, confirming that increasing population and housing density in this alternative way also brings important costs savings. However, when differentiating between jurisdictions whose density is below the optimal density value we find that density economies are much more relevant that scale economies, while the opposite takes place for the dataset of jurisdictions above the optimal density value. On the other hand, public officials incur in relevant cost inefficiency when managing the resources devoted to build physical infrastructure, situating in an average cost excess around 14%. In general we conclude that the explanation for these cost savings based on scale and density economies as well as inefficiency reductions, lays in the widespread suboptimal urban size of population and housing settlements in the region of *Castilla y León*, since as many as 63.8% of all urban areas situate below the optimal population density threshold.

Finally, the main policy implication of our results is that in order to reap the benefits of the existing scale and density economies as well as improve cost efficient levels, public officials designing new urban developments and allocating infrastructure investment funds should promote larger and denser urban sizes in terms of population and housing; so as to realize all these economies and efficiencies. Out results suggest that the first step to rationalize urban growth should be preventing isolated developments that would increase the number of clusters within the existing jurisdictions, while favoring an increase the number of dwellings per square kilometer of urban area. As a result, “smart growth” urban planning policies should strongly discourage urban sprawl in the form of disperse and disconnected (skipped-over) population clusters, while promoting higher population and housing densities.

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