MODELLING ENVIRONMENTAL CONSTRAINTS ON THE EFFICIENCY OF MANAGEMENT FORMS FOR PUBLIC SERVICE DELIVERY

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Abstract

This paper presents a new non-parametric methodology in which robust frontiers are used to measure the impact of environmental constraints on efficiency. In this approach, a data panel structure is applied to determine which management forms for the delivery of municipal services – public or private, in cooperation or individual – are best suited to the environment where the services are provided. The study method proposed is then applied to analyse the waste collection service provided in Spanish municipalities during the

period 2002-2014. The results obtained show that of the management forms considered inter-municipal cooperation adapts best to heterogeneous environmental conditions.

Key words: Conditional efficiency, Environmental factors, Data panel, Waste collection.

1. Introduction

There is some controversy as to which management forms of municipal service delivery provide the highest levels of efficiency (Goodspeed, 2017; Srakar et al, 2017; Campos-Alba et al., 2020; Bel et al., 2021). Traditionally, studies of this question have examined whether efficiency is better served by public or private management forms (Dijkgraaf and Gradus, 2003; Bel et al., 2010; Simões and Marques, 2012; Simões et al., 2012a; Simões et al., 2012b; Suárez-Varela et al., 2017). However, with the current proliferation of forms of management, public managers can now choose from many alternatives, including various types of joint service provision (Hefetz and Warner, 2012; Bel, Fageda and Mur, 2014) as a means of reducing costs in the provision of municipal services (Bel and Fageda, 2006, 2008a; Mohr, Deller and Halstead, 2010). This is especially true of smaller municipalities, which are sometimes presented with an array of options that is so complex as to make evaluation of this question very difficult. In response, studies have been undertaken to analyse the alternatives resulting from diverse combinations of the management forms currently available (Bel et al., 2010; Gradus et al., 2017; Perez-López et al., 2016; Pérez-López et al., 2018, among others) and to determine which of them achieve higher levels of efficiency. Apart from technical considerations, the choice of a given alternative may also be influenced by the characteristics of the environment in which the municipality is located and where the service is provided (Mohr et al., 2010; Pérez-López et al., 2016; Pérez-López et al., 2018; Zafra-Gómez and Chica-Olmo, 2019). To properly assess efficiency, it is necessary to take into account certain external environmental factors that cannot be controlled by

municipalities and that may have a significant influence on service efficiency (Badin et al., 2014; Schiltz et al. 2019). Therefore, the main aim of this study is to examine whether the socio-economic and geographical environment has a similar effect on different management forms for the provision of public services, and thus determine whether certain forms of management are better suited to these environmental characteristics than others (Beltrán et al., 2019). To address these questions, we have developed a new methodology to measure long-term efficiency, which we term conditional order-m data panel (CordermDP). This approach enables us to obtain a measure of average efficiency over a broad time horizon, which is an advantage when estimating efficiency because we can take into account the structure of the data panel and the interrelations between different observations over time. Thus, data from different years can be compared, a methodological aspect that is not addressed by traditional methods. Furthermore, a robust non-parametric measure of efficiency is obtained, using bootstrapping estimation (through partial order-m frontiers) but with the methodological novelty that we obtain a frontier that measures the impact of exogenous factors on the efficiency indices obtained for each of the public service delivery forms analysed, i.e. municipal direct (MUD), municipal under contract (MUC), intermunicipal cooperation (IC) and private production with cooperation (PPC), in the management of urban waste, taking into account long-term effects on each of the units evaluated (Surroca et al., 2016; Pérez-López et al., 2018; Prior et al., 2019). Our analysis concludes with a study of the impact produced by each environmental factor on the management forms in question. This second-stage analysis is performed by means of a non-parametric regression. Unlike traditional regressions that derive the average effect produced by independent variables on efficiency, our approach makes it possible to observe the behaviour of independent variables at different levels of

efficiency (Li and Racine, 2007; Haelermans and De Witte, 2012; De Witte and Kortelainen, 2013).

The results obtained show that public forms of service delivery (IC and MUD) are better suited to the characteristics of the environment than private ones. IC obtains particularly good average values. In contrast, PPC is most severely affected by environmental factors. Thus, IC is the most appropriate form of service delivery for environments presenting certain levels of altitude, population density and tourist-industry orientation. On the other hand, when the population density is low, MUC minimises the negative effects of this situation on efficiency. Our results also show that different forms of management obtain better or worse levels of efficiency according to the aggregate population of the municipality.

The rest of this paper is structured as follows. The next section describes the proposed theoretical framework, after which our methodological proposal is presented in detail. Section four explains the variables and data included, and the results obtained, and the final section sets out the main conclusions drawn from this study.

2. Exogenous factors impacting on management forms for public service delivery: a theoretical framework

The relation between efficiency and management forms have previously examined for the waste collection service (Simões et al., 2012; Máñez et al., 2016; Pérez-López et al., 2016; Blaeschke and Haug, 2018; Garrido-Rodríguez et al., 2018; Pérez-López et al., 2018, among others). However, the results are not conclusive and different approaches have been applied, such as the analysis of the conditional efficiency (Blaeschke and Haug, 2018) and the analysis of the long-term efficiency (Garrido-Rodríguez et al., 2018; Pérez-López et al., 2018). However, to date, none of these studies

have combined both analysis: the long-term conditional efficiency so that, it can be analysed for a panel data structure how the environment can influence the efficiency of different management forms of the waste collection service.

The exogenous variables that may impact on levels of long-term efficiency are many and varied, as described by Da Cruz and Marquez (2014), who reported that among such environmental factors, demographic and geographic ones were the most significant with respect to local government efficiency. However, local authorities can choose the management form they prefer for public service delivery and even if the environment in which they operate cannot be modified, public managers can apply the management type that they consider best suited to the practical conditions in which services must be provided.

In relation to these forms of management, research has shown that contracting municipal services is one of the most commonly used (and analysed) options (Bel et al., 2010). This concept has been defined as the provision of a public service by a private company, which thereby obtains residual gains (Vickers and Yarrow, 1991; Warner and Bel, 2008). Diverse theories defending the provision of public services by private operators (Ostrom, 1973; Dahl and Tufte, 1974; Niskanen, 1971; Savas, 1987; Earle, 2006; Donahue, 1989) argue that this approach achieves reduces costs, possibly by stimulating competition in the service delivery (Vickers and Yarrow, 1988; Gérard, 2008) or arising from economies of scale, achieved by providing a similar service in different municipalities (Bel and Costas, 2006; Warner and Hefetz, 2003).

More recently, it has been highlighted a trend to re-municipalization or contracting back (Hefetz and Warner, 2007; Hall et al., 2013; Gradus and Budding, 2020). So that, local government recover the service provision from a for-profit entity (Warner and Aldag, 2019). However, there is no consensus about the factors that justify the re-

municipalization. While, Warner and Aldag (2019: 1) found that, in the US context, re-municipalization is "a pragmatic process of contract management"; the study by Campos-Alba et al. (2020) in Spain reveals that political factors have the greatest influence.

Nevertheless, it has been observed that in many cases private companies that provide local public services do so in different municipalities with different socioeconomic characteristics, and that they are able to do this because they can readily adapt to heterogeneous socioeconomic environments. Private companies are believed to be more flexible than public corporations, because they are less subject to standards, rules and regulations developed in the political sphere, which often result in excessive bureaucracy and reduced productivity (Boyne, 2002, Alfiero et al., 2017). Accordingly, we hypothesise that private management forms can achieve higher levels of efficiency than public ones in situations presenting differing environmental characteristics.

However, the theoretical framework we consider is not limited to differentiating between public and private management. In addition, it addresses the many, more nuanced, alternatives that exist for the provision of public services, taking into account that a simple two-way choice between public or private may not be sufficiently focused for certain types of local authority (Gradus et al., 2014; Andrews and Entwistle, 2015; Bel et al., 2015). Specifically, privatisation may be less attractive to smaller municipalities, as well as unprofitable for potential suppliers (Warner and Hefetz, 2001; Bel and Fageda, 2006; Warner, 2006). In such a case, inter-municipal cooperation might be an interesting alternative, with cost savings being obtained from the sharing of resources and of service-delivery costs. The main hypothesis underlying this approach is that inter-municipal cooperation can be used to exploit economies of scale, by grouping municipalities and thus increasing the level of production (Warner and Hefetz, 2003; Dijkgraff, Gradus and Melenberg, 2003, 2006a; Warner, 2006b; Zullo, 2009). In short,

inter-municipal cooperation for service delivery, conducted in the socio-economic and geographic environments of different municipalities, can enable each municipality to benefit from economies of scale and, at the same time, is better equipped to adapt to these heterogeneous environments than other forms of public municipal management by which public services are provided by individual authorities.

In addition, when two or more municipalities decide to join forces in the delivery of public services, they can decide whether the service, in these conditions, might advantageously be privatised, once an economically viable operating size has been achieved. This option has been termed private production with cooperation (PPC) (Bel, Fageda and Mur, 2014, Plata-Díaz et al., 2014). This approach overcomes one of the limitations associated with outsourcing, namely the lack of interest among private operators in providing services to a small municipality; with PPC, the scale of the operation is increased, and it becomes more attractive to the private operator (Pérez-López et al., 2016). This form of management combines the benefits of inter-municipal cooperation with those of outright contracting-out, as regards the influence of environmental factors. It may be hypothesised, therefore, that this form of management could obtain the highest possible levels of efficiency, when various municipalities are faced with differing environmental conditions.

In this context, when environmental factors are considered in conjunction with the efficiency obtained in the provision of public services, various hypotheses may be considered. We tested the following, under the above-described theoretical framework, and taking into account the relationship between conditional and unconditional efficiency (discussed in detail in the next section), in order to compare the efficiency levels obtained by individual, public and private forms of service delivery.

H_1: *The average distance between the conditional and the unconditional frontier) will be less when municipal services are provided by private companies (MUC) than when they are provided by public entities (MUD).*

Taking into account that municipalities may opt for a joint-management formula, we propose a second hypothesis, which is divided into two sub-hypotheses. Thus, if the first hypothesis is accepted, we compare the private management form with that of private production with cooperation (PPC), and the first sub-hypothesis is:

H_{2a}: *The average distance between the conditional and the unconditional frontier is less when municipal services are provided through private production with cooperation (PPC) than when they are provided by private companies (MUC).*

However, if hypothesis 1 is rejected, showing that direct service delivery by a single municipality (MUD) produces a smaller difference between the conditional and the unconditional frontiers, we must then consider the possibility that inter-municipal cooperation (IC), with the service being jointly provided by different municipalities, is better suited to varying environmental conditions than the individual public formulas. In this case, the following sub-hypothesis must be tested:

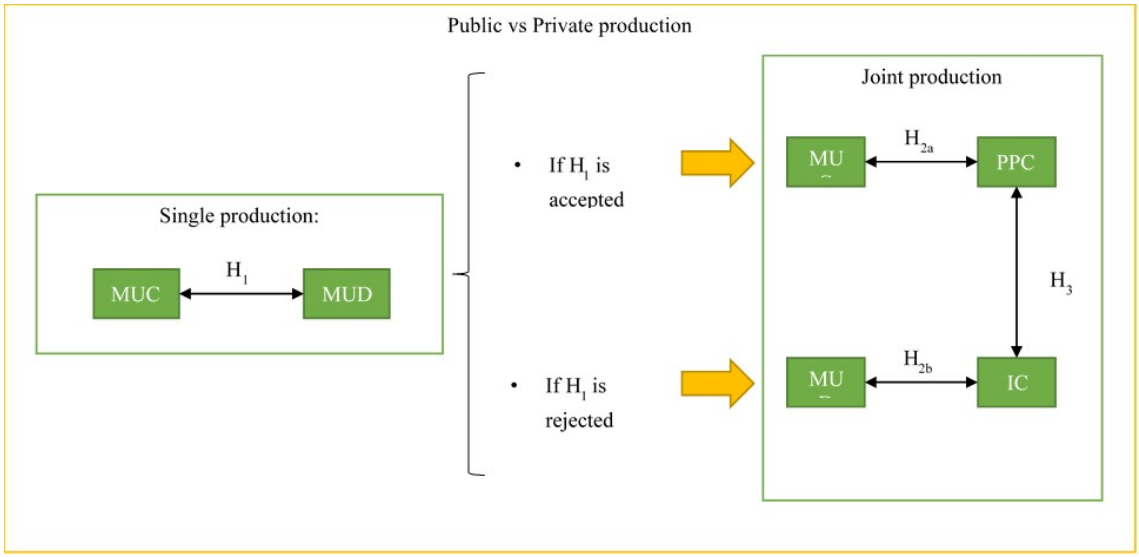
H_{2b}: *The average distance between the conditional and the unconditional frontier is less when public services are provided through inter-municipal cooperation (IC) than when they are provided by each municipality individually (MUD.*

Finally, in the view that the PPC management form can obtain the benefits of contracting-out and also those of cooperation, we consider a third hypothesis:

H_3: *The average distance between the conditional and the unconditional frontier is less when public services are provided through private production with cooperation (PPC) than when they are provided through public inter-municipal cooperation (IC),.*

The study hypotheses are summarised in Fig. 1.

Figure 1. Study hypotheses



Source: Devised by the authors

3. Conditional order-m data panel estimation: a new methodological approach

In recent years, many studies have addressed the question of efficiency in municipal administrations (Narbón-Perpiñá and De Witte, 2018a, 2018b). Most of this research is based on the use of non-parametric techniques, such as data envelopment analysis (DEA) (Charnes et al., 1978) and free disposal hull (FDH) (Deprins et al., 1984). However, given the limitations of these techniques, such as the specific dimensionality of non-parametric estimators, the problems of dealing with extreme values, etc. (Badin et al., 2014), new approaches have been developed, including advanced robust non-parametric efficiency, order-m frontiers (Cazals et al., 2012), order-α quantile frontiers (Daouia and Simar, 2007), DEA-data panel (DEA-DP, Surroca et al., 2016), temporal scale efficiency with DEA-DP (Pérez-López et al., 2018) and order-m data panel (Garrido et al., 2018). All of these make it possible to estimate long-term efficiency while taking into account the data panel structure of the units being evaluated.

By applying measures of long-term efficiency, robust long-term estimates can be obtained. Unlike traditional techniques, in which year-on-year observations cannot be compared, these methodological developments facilitate the evaluation of municipal efficiency by taking into account the structure of the data panel and the interrelations between observations over time. However, as it has been previously explained, municipalities provide public services in a variety of complex environments, and any estimation of long-term efficiency must take into account the possible influence of such environmental factors (Da Cruz and Marques, 2014; Blaeschke and Haug, 2018; Cordero et al., 2017; Gearhart and Michieka, 2018).

In order to obtain robust long-term estimates, reflecting the influence of external factors, we first present the unconditional order-m data panel specification, which does not take into account the effects of the environmental variables. We then estimate the conditional model order-m data panel, in which the latter effects are included. Finally, to analyse the effects of the environmental variables on the long-term efficiency of the different forms of management, we calculate the conditional efficiency ratio data panel (CERdp) as the relationship between these two measures.

Unconditional order-m data panel (Uorderm-DP)

For *S* units $s = 1, \dots, S$ assume there are *N* inputs $x^s = x_1^s, \dots, x_n^s, \dots, x_N^s \in \Re_+^N$ that produce *M* outputs $y^s = y_1^s, \dots, y_m^s, \dots, y_M^s \in \Re_+^M$ with a data panel structure. We then define a variable *t* ($t = 1, \dots, T$) that is representative of the corresponding period of time for the inputs and outputs: $x^{s,t} = x_1^{s,t}, \dots, x_n^{s,t}, \dots, x_N^{s,t} \in \Re_+^N$ and $y^{s,t} = y_1^{s,t}, \dots, y_m^{s,t}, \dots, y_M^{s,t} \in \Re_+^M$, . Then, following the data panel methodology proposed by Surroca, Prior and Tribó (2016), for each unit $s = 1, \dots, S$ we can define the mean values of input n and of output m, for the complete period *T*, as $\tilde{x}_n^s = {\sum_{t=1}^{T} x^{s,t}}/{T}$ and $\tilde{y}_m^s =$

$\sum_{t=1}^{T} y_m^{s,t}/_T$, respectively. Hence, the production set (of feasible input-output combinations) Ψ would be defined as:

$$\Psi = \{(\tilde{x}^s, \tilde{y}^s) \in \Re_+^{N+M} | \tilde{x}^s \; can \; produce \; \tilde{y}^s\} \qquad [1]$$

Following Cazals et al. (2002), we describe the production process as a measure of probability in the production space $\Re_+^{N+M}$, based on the probability of dominance of random variables (*X, Y*), which are determined by:

$$H_{XY}(\tilde{x}^s, \tilde{y}^s) = P(X \leq \tilde{x}^s, Y \geq \tilde{y}^s) \qquad [2]$$

where $X \in \Re_+^N$ is the vector of inputs and $Y \in \Re_+^M$ is the vector of outputs of a given production process. Notice that $H_{XY}(\tilde{x}^s, \tilde{y}^s)$, which is monotone non-decreasing in $\tilde{x}^s$ and monotone non-increasing in $\tilde{y}^s$, reflecting the probability that a unit operating at the input-output level $(\tilde{x}^s, \tilde{y}^s)$ will be dominated, i.e. the probability that another unit will produce at least the same level of output while using no more inputs than the unit operating at the level $(\tilde{x}^s, \tilde{y}^s)$.

Then, following an input orientation, [2] can be decomposed into:

$$H_{XY}(\tilde{x}^s, \tilde{y}^s) = P(X \leq \tilde{x}^s | Y \geq \tilde{y}^s) \, P(Y \geq \tilde{y}^s) = F_{X|Y}(\tilde{x}^s | \tilde{y}^s) S_Y(\tilde{y}^s) \quad [3]$$

where $F_{X|Y}(\tilde{x}^s | \tilde{y}^s) = \frac{H_{XY}(\tilde{x}^s, \tilde{y}^s)}{H_{XY}(0, \tilde{y}^s)}$ represents the survival function of X and $S_Y(\tilde{y}^s)$ is the marginal survivor function of Y, for which it is assumed that $S_Y(\tilde{y}^s) > 0$.

The traditional efficiency estimator is deterministic by nature, and therefore all observations are assumed to belong to the production boundary. In other words, $prob\left((\tilde{x}^s, \tilde{y}^s) \in \Psi\right) = 1$ (Kourtesi et al., 2012), which is why the estimation is sensitive to the presence of outliers that may influence the lower boundary of the support of $F_{X|Y}(\tilde{x}^s | \tilde{y}^s)$. The partial order-m frontier approach proposed by Cazals et al. (2002) helps overcome this limitation.

Following the above specification, and taking into account the extension data panel for frontier estimation proposed by Surroca, Prior and Tribó Giné (2016), for a sample $(\tilde{x}_i^s, \tilde{y}_i^s), i = 1, \dots, n$ of the random vector (*X, Y*), the empirical survival function is defined as:

$$\hat{H}_{XY,n}(\tilde{x}^s, \tilde{y}^s) = \frac{\sum_{i=1}^{n} I(\tilde{x}_i^s \geq \tilde{x}^s, \tilde{y}_i^s \geq \tilde{y}^s)}{n} \qquad [4]$$

and the empirical analogue of $F_{X^t|Y^t}(x^{s,t}|y^{s,t})$ is then given by:

$$\hat{F}_{X|Y}(\tilde{x}^s|\tilde{y}^s) = \frac{\hat{H}_{XY,n}(\tilde{x}^s, \tilde{y}^s)}{\hat{H}_{XY,n}(0, \tilde{y}^s)} \qquad [5]$$

For $X^1, \dots, X^m$ random variable vectors generated by the empirical distribution of *X* given $Y \geq \tilde{y}^s$, the survival function of which is [5], the estimator of the unconditional order-m data panel (UOM-DP) efficiency function is defined as:

$$\hat{\theta}_{m,n}(\tilde{y}^s) = \hat{E}\left(min(X^1, \dots, X^m | Y \geq \tilde{y}^s)\right) \qquad [6]$$

which is computed as follows:

$$\hat{\theta}_{m,n}(\tilde{y}^s) = \int_0^{\infty} [\hat{F}_{X|Y,n}(u|\tilde{y}^s)]^m du \qquad [7]$$

where u is a dummy of integration[1]. The algorithm used to estimate the efficiency coefficients of the order-m data panel is computed by resampling techniques, in which the estimation process is repeated *B* times, thus producing *B* efficiency coefficients, from which the efficiency value is obtained as the arithmetic mean of the *B* efficiency coefficients.

Conditional order-m data panel (Corderm-DP)

To evaluate the effect produced by environmental variables, we consider the vector of the exogenous environmental variables $Z \in \Re^k$ which may influence the

[1] The frontiers in an order-m data panel represent the efficiency values of each unit by comparison with a sub-sample of *m* units, such that for an average input of $(\tilde{x}^0)$ and an average output of $(\tilde{y}^0)$, we consider m production units, chosen randomly, with output variables $(Y_1, \dots, Ys, \dots, Y_m)$, which are derived from the distribution of the output matrix *Y* that meets the condition $Y_s \geq \tilde{y}^0$.

probabilistic production process. In this case, we focus on the conditional distribution of (*X, Y*) for a given value of *Z*, and therefore expressions [2] and [3] can be specified as follows:

$$H_{XY\,|Z}\,(\tilde{x}^s, \tilde{y}^s|\tilde{z}^s) = P(X \leq \tilde{x}^s, Y \geq \tilde{y}^s|\, Z = \tilde{z}^s) = F_{X,Y\,|Z}(\tilde{x}^s|\tilde{y}^s, \tilde{z}^s) S_{Y\,|Z}(\tilde{y}^s|\tilde{z}^s) \qquad [8]$$

where $F_{X,Y\,|Z}(\tilde{x}^s|\tilde{y}^s, \tilde{z}^s) = \frac{\partial_Z H_{XY\,|Z}\,(\tilde{x}^s, \tilde{y}^s|\tilde{z}^s)}{\partial_Z H_{XY\,|Z}\,(0, \tilde{y}^s|\tilde{z}^s\,)}$, and where ∂_Z is the operator of the order-k derivative with respect to all the components of $\tilde{z}^s$.

Accordingly, the conditional order-m data panel efficiency is defined as:

$$\hat{\theta}_{m,n}(\,\tilde{y}^s, \tilde{z}^s) = \int_0^\infty [\hat{F}_{X,Y\,|Z}\,(u|\tilde{y}^s;\, \tilde{z}^s)]^m du \qquad [9]$$

where $\hat{F}_{X,Y\,|Z}\,(u|\tilde{y}^s;\, \tilde{z}^s) = \frac{\sum_{i=1}^n I(\tilde{x}_i^s \geq u, \tilde{y}_i^s \geq \tilde{y}^s) K(\tilde{z}^s - \tilde{z}_i^s / h_n)\,/_n}{\sum_{i=1}^n I(\tilde{y}_i^s \geq \tilde{y}^s) K(\tilde{z}^s - \tilde{z}_i^s / h_n)\,/_n}$, and where $K\,(.)$ is the kernel density and h_n the smoothing bandwidth.

Conditional efficiency ratio data panel (CERdp)

When the long-term conditional and unconditional efficiencies have been estimated, we then calculate the efficiency ratio, in order to measure the distance between the two frontiers and to evaluate the effects of environmental variables on the efficiency of each form of local public service management. The conditional efficiency ratio is calculated as follows:

$$CERdp\;(Efficiency\;ratio) = \frac{UOMDP}{COMDP} = \frac{\hat{\theta}_{m,n}(\,\tilde{y}^s)}{\hat{\theta}_{m,n}(\,\tilde{y}^s, \tilde{z}^s)} \qquad [10]$$

For values close to one, the conditional and unconditional order-m data panel estimations are similar, and therefore there is scant distance between the two frontiers. However, for values that differ considerably from 1, there is a noticeable distance between

these frontiers, indicating that environmental factors have a significant impact on long-run municipal efficiency.

A non-parametric bootstrapped regression was performed to determine how well each management form adapts to differing environments. Although the influence of the determinants of efficiency has been analysed via approaches such as Tobit regression or bootstrap truncated regression (Simar and Wilson, 2007; Da Cruz and Marques, 2014; Li and Racine, 2007), we opted for the non-parametric bootstrap procedure, as used previously by Haelermans and De Witte (2012) and De Witte and Kortelainen (2013), based on local linear regression estimation using non-parametric tests and a non-parametric naïve bootstrap. This approach obtains standard errors and p-values for the influence of environmental variables on average efficiency values.

4. Application of the CordermDP to the waste collection service in Spain

Variables

To determine the relationship between long-term conditional efficiency and different management forms for public services, we evaluated the waste collection and treatment service provided during the period 2002-2014 by 306 Spanish municipalities with populations ranging from 1,000 to 50,000 inhabitants[2]. This public service is of great importance to local governments, among other aspects due to the significant weight it represents in the budget (Bel et al., 2010; Plata-Díaz et al., 2014; Zafra-Gómez et al., 2016; González-González and García-Fénix, 2020) and its provision is strongly influenced by the socioeconomic factors prevalent in the area where the service is

[2] This sample represents the 10% of Spanish municipalities with a population ranging from 1,000 to 50,000 inhabitants. Regarding the different size of Spanish local governments, the sample represents the 23% of total municipalities with a population ranging from 5,000 to 20,000 inhabitants and 16% of local governments with a population between 20,000 and 50,000 residents. So, a huge range of local government is represented by the sample. Finally, the sample only includes 1% of municipalities with a population ranging from 1,000 to 5,000 inhabitants which ensures the data reliability.

provided. In consequence, many studies have analysed the efficiency of the waste management service with respect to possible alternative forms of management (Bel and Mur, 2009; Bel and Fageda, 2010; Dijkgraaf and Gradus, 2013; Zafra-Gómez et al., 2013; Bel et al., 2014; Plata-Díaz et al., 2014; Pérez-López et al., 2016; Pérez-López et al., 2018). In Spain, waste collection is a public service that is of obligatory provision in all municipalities. However, each local authority can choose the form of service provision it prefers; the most common options in this respect are public management, intermunicipal cooperation and outsourcing (Warner and Bel, 2008).

Table 1 shows the definitions and sources of the output variables, together with the cost of the waste collection service and information for the environmental variables considered in the CordermDP estimate. Table S1 (in online supplementary annex) contains the descriptive statistics for all these variables.

Table 1. Output variables, service costs and environmental variables included in the efficiency calculation

Variable	Definition	Source
Total cost	The total cost of the waste collection service, including capital and operational costs.	Virtual Office of Local Government Financial Coordination, within the Ministry of Public Administration and Treasury
Tonnes of waste	Annual production of waste, in tonnes/year.	Survey of Local Infrastructure and Equipment (EIEL), published on the Ministry of Public Administration website
Tonnes of waste * quality	Annual production of waste, in tonnes/year, corrected by the index of service quality. This index is an internal measure representing the adequacy/inadequacy of the service provided, in terms of the availability and cleanliness of the containers, and of the periodicity of the waste collection performed.	
Containers	Number of containers available on public streets in the municipality, for each type of waste collection.	
Population size	Total population of the municipality (logarithm).	National Institute of Statistics
Population density	Number of inhabitants of the municipality divided	National Institute of Statistics

	by its surface area (square kilometres).	
Altitude	The height of the municipality above sea level.	National Institute of Statistics
Urban agglomeration	Number of population centres within the municipal area.	National Institute of Statistics
Tourist activity	Index of tourism-oriented activities.	Spanish Economic and Social Yearbook: La Caixa
Industrial activity	Index of industry-oriented activities.	Spanish Economic and Social Yearbook: La Caixa
Commercial activity	Index of commerce-oriented activities.	Spanish Economic and Social Yearbook: La Caixa

Source: Devised by the authors

Among the environmental variables considered in most previous analyses of the efficiency of the waste collection service are the size and density of the population (Rogge and De Jaeger, 2013; Blaeschke and Haug, 2018). Large and more density municipalities are more likely to be more cost efficient regarding the economies of scale (Narbón-Perpiñá and De Witte, 2018b). Research has shown, unambiguously, that efficiency is positively related to the population size (García-Sánchez, 2008). However, the findings are less clear for population density; some studies have reported a negative association with efficiency (De Jaeger et al., 2011; Benito-López et al., 2011) while others have observed a positive relationship (Hirsch, 1965; García-Sánchez, 2008; Blaeschke and Haug, 2018).

The urban agglomeration variable was included as a proxy of the complexity in the service provision because the collection of waste from widely-separated urban areas can have a negative effect on efficiency; clearly, greater proximity between pick-up points reduces the cost of the service (Domberger et al., 1986). A similar reasoning is applied to the topography of the area (represented by the altitude of the municipality). According to Da Cruz and Marques (2014), greater topographic difficulty constrains service efficiency due to the greater technical difficulties imposed. Indeed, the urban distribution in Spain is highly variable, and in some cases, municipalities are composed of various widely-

separated population centres or districts. Furthermore, the country has many mountainous areas, creating physical difficulties to providing the waste collection service. Each of these "natural condition" variables represents a service constraint (Da Cruz and Marques, 2014).

Finally, indices of tourism and of industrial and commercial activity were obtained, to measure the level and type of economic activity in the municipality. Touristic areas face seasonal increases of population (Benito et al., 2019) that could affect to investments and a greater demand for higher quality service (Narbón-Perpiñá and De Witte, 2018b). Industrial municipalities will attract companies that may necessitate particular infrastructures or a higher frequency of waste collection, demanding a greater level of efficiency (Narbón-Perpiñá and De Witte, 2018b). At the same time, it is expected that the economic level of the municipality positively affects the local government efficiency because of the greater control exercised by traders (Narbón-Perpiñá and De Witte, 2018b). However, research findings in this respect are somewhat contradictory (Benito et al., 2011; Da Cruz and Marques, 2014).

Results

First Stage. Application of CordermDP and analysis of CERdp

Tables 2 and 3 show the effects of environmental factors on long-term efficiency. Table 2 shows, according to the management form adopted, the descriptive statistics for the CERdp, which measures the distance between the conditional and unconditional efficiency values determined by order-m data panel estimation. Table 3 shows the density functions for the conditional and unconditional estimates, according to the management form adopted, determined by the Li test (1996), following the proposal by Zelenyuk

(2006). Figures S2 and S3 (in online supplementary annex) presents the density graphs for these estimates, according to the management form.

Table 2. Descriptive statistics: efficiency ratio (CERdp), conditional and unconditional efficiency, by management form

Management Form/Variable	N	Mean	Median	Min.	Max.	Std. Dev.
MUD *Municipal Direct*						
CERdp	56	0.2801349	0.2020642	0.1225993	0.9683605	0.18059
Unconditional efficiency (UcordermDP)		0.1556911	0.1469825	0.0520987	0.3684572	0.0754984
Conditional efficiency (CordermDP)		0.6117169	0.6269287	0.2211366	0.9030533	0.1923723
MUC *Municipal under contract*						
CERdp	108	0.2269246	0.169507	0.1206495	0.9544021	0.16492
Unconditional efficiency (UcordermDP)		0.0857054	0.0746953	0.0276452	0.2253988	0.0453279
Conditional efficiency (CordermDP)		0.4427363	0.4261568	0.1002076	0.8558541	0.2188207
IC *Intermunicipal Cooperation*						
CERdp	107	0.3197558	0.2231839	0.1287848	1	0.2113533
Unconditional efficiency (UcordermDP)		0.1799163	0.1557901	0.0445049	1	0.1242675
Conditional efficiency (CordermDP)		0.6037226	0.5953881	0.192636	1	0.2114647
PPC *Private Production with Cooperation*						
CERdp	35	0.2089762	0.1760878	0.0990175	0.6313192	0.1086621
Unconditional efficiency (UcordermDP)		0.1325236	0.1217797	0.0590555	0.3036283	0.0575667
Conditional efficiency (CordermDP)		0.6599805	0.7259037	0.3649756	0.9162404	0.1752245

MUD: Municipal Direct; MUC: Municipal under Contract; IC: Intermunicipal Cooperation; PPC: Private Production with Cooperation;

$Efficiency\ ratio = {}^{Unconditional\ efficiency}/_{Conditional\ efficiency}$

Table 3. Comparison of hypotheses by the Li test: conditional and unconditional efficiency, by management form

Null hypothesis (H_0)		10% significance	5% significance	1% significance
Municipal Direct	*Corderm-DP= Ucorderm-DP*	H_0 rejected	H_0 rejected	H_0 rejected
Municipal under contract	*Corderm-DP= Ucorderm-DP*	H_0 rejected	H_0 rejected	H_0 rejected
Intermunicipal Cooperation	*Corderm-DP= Ucorderm-DP*	H_0 rejected	H_0 rejected	H_0 rejected
Private Production with Cooperation	*Corderm-DP= Ucorderm-DP*	H_0 rejected	H_0 rejected	H_0 rejected

CordermDP= Conditional efficiency *UcordermDP= Unconditional efficiency*

The results presented in Table 2 clearly show that, in general, for all forms of management, the relationships between conditional and unconditional efficiency values differ widely. These values are greater for all forms of management when environmental variables (conditional efficiency) are included in the estimation than when they are not (unconditional efficiency), which leads us to conclude that the socioeconomic environment considered has a strong impact on the form of service management adopted[3]. These differences between conditional and unconditional density functions are significant for each of the management forms analysed, as shown in Table 3, which highlights the importance of including these factors in the estimation of efficiency, because their omission could lead to efficiency levels being over or underestimated.

In general, private production with cooperation (PPC) obtained the lowest efficiency ratio (20.9%), which means that this form of management is most strongly affected by the variables of the socioeconomic environment in which the service is provided. The highest efficiency ratio (31.96%) was obtained for intermunicipal cooperation (IC), which on average was the management form least affected by the variables of the socioeconomic environment (Table 2). This finding suggests that, in

[3] If the relationship between the two efficiencies were close to one, the two estimates would be closer, reflecting a weaker impact of environmental variables on the management form adopted.

general, the IC formula is better suited to the municipal environment. However, further analysis is needed to determine whether the density functions of the CERdp are significantly different between management forms, and to test whether our study hypotheses are met.

Accordingly, taking into account the average values shown in Table 2, we compared the efficiency ratios (density functions) obtained, according to management form, using the Li test (Li, 1996; Zelenyuk, 2006). Table 4 presents the results of this analysis, which is complemented with the density graphs included in Figure S3.

The first hypothesis considered is that the efficiency of municipal services managed by private companies is less affected by environmental factors than when the service delivery is provided by public management (H_1). The null hypothesis addressed by the Li test[4], namely that the CERdp is equally distributed between the MUD and MUC formulas (public vs. private management), is rejected (Table 4). Therefore, we conclude that environmental variables impact on the efficiency of service delivery in different ways according to the management form adopted. Specifically, the results presented in Table 2 show that the average CERdp with private service delivery (MUC: 22.69%) is lower than that with direct management (MUD: 28.01%). These values conflict with Hypothesis 1. Therefore, since there are significant differences between the density functions (and as the mean value with MUD is higher than with MUC), we find no evidence that private management forms are less influenced by environmental variables than public forms, and so H_1 is rejected. This result is in line with the study of Blaeschke and Haug (2018) who found that the efficiency advantage of contracting municipalities over the in-house production disappears when the conditional efficiency is estimated.

[4] The Li test compares the complete density functions of two distributions, to determine whether the distributions are equal or different.

From this result, we then considered hypothesis H_{2b}, according to which management formulas based on public-private cooperation are less affected by environmental factors than are individual formulas of public management. However, the results obtained (Table 4) did not reflect any significant differences between the density functions of the CERdp for individual public management (MUD) and intermunicipal cooperation (IC); thus, the null hypothesis of equality of distribution of the CERdp was not rejected. In other words, there were no statistically significant differences in the effects of the socioeconomic environment on MUD and IC, and so H_{2b} cannot be accepted.

Finally, we analysed the third hypothesis, under which the formula of private production with cooperation (PPC) is less influenced by environmental variables than inter-municipal cooperation (IC). The results obtained led us to reject the null hypothesis of equality of distribution of the CERdp. Specifically, the mean CERdp results (Table 2) showed that PPC obtained a lower efficiency ratio (20.9%) than IC (31.98%). Therefore, IC is more adaptable than PPC, being less subject to environmental factors, and so hypothesis 3 cannot be accepted.

Table 4. Evaluation of study hypotheses by the Li test: CERdp by management form

Study hypothesis	Null hypothesis (H_0)	10% significance	5% significance	1% significance
H_1	CERdp (MUD) = CERdp (MUC)	H_0 rejected	H_0 rejected	H_0 rejected
H_{2b}[5]	CERdp (MUD) = CERdp (IC)	H_0 not rejected	H_0 not rejected	H_0 not rejected
H_3	CERdp (IC) = CERdp (PPC)	H_0 rejected	H_0 rejected	H_0 rejected

MUD: Municipal Direct; MUC: Municipal under Contract; IC: Intermunicipal Cooperation; PPC: Private Production with Cooperation
H_1: Private vs. public management; H_{2b}: Intermunicipal cooperation vs. public management; H_3: Privatised intermunicipal cooperation vs. Intermunicipal cooperation.

[5] Although private management forms are more strongly affected by environmental conditions (hypothesis 1), hypothesis H_{2a} was also tested.

From the above, we conclude that the efficiency of private management forms, both individually and in cooperation, is more strongly influenced by environmental factors than are public management forms. So, public management is more appropriate in presence of heterogenous environments. This result gives support to the most current trend of re-municipalization of local public services, through which local governments recover the control of services that were previously provided by a private operator (Warner and Aldag, 2019; Campos-Alba et al., 2020).

Second Stage. Measuring the impact of environmental factors, using non-parametric regression

We now analyse the factors that may influence management forms for the waste collection service and examine the strength of the effects produced. To do this, we apply non-parametric regression to the efficiency ratio[6] (Badin et al., 2010; De Witte and Kortelainen, 2013; Cordero et al., 2017). The main advantage of this approach is that it enables us to analyse the effect produced by environmental variables on CERdp, according to the values taken by the variable in each case. To illustrate this, Table 5 shows the influence and level of significance of each of the variables included in the estimation of conditional efficiency. Figures 2 and 3 represent, for each management form, the behaviour of each of the environmental variables estimated by non-parametric regression (the solid line shows the estimated levels according to the regression and the vertical segments indicate the confidence interval for the different levels of the independent variable).

Table 5. Descriptive statistics for the influence of environmental variables, by management form

[6] The dependent variable of these regressions is a ratio of efficiencies, calculated as the quotient of the unconditional and conditional efficiencies (UC/C). The independent variables are the environmental factors considered.

Variable	Mean	p25	p50	p75
MUD (Public: municipal direct provision)				
Lnpopulation	1.232482***	1.065	1.115	1.4
Density	11732.19	0.0406	0.0456	0.067
Altitude	1804541	967	998	1030
Agglomeration	3778581	7.365	9.9	11
Tourism	0.0010569	0.000939	0.00103	0.00109
Industrial	1078.576	0.003375	0.00361	0.003925
Commercial	117.3587	0.0015	0.0016	0.001635
MUC (Private)				
Lnpopulation	1.548611***	1.13	1.645	1.945
Density	0.0432454**	0.03725	0.0392	0.0451
Altitude	971.5741	932	959	1000
Agglomeration	12.86065*	9.765	12.25	18.8
Tourism	0.0010361	0.000995	0.00105	0.00107
Industrial	0.0034241	0.003175	0.00331	0.0036
Commercial	0.0015939	0.001565	0.00162	0.00164
IC (Public: intermunicipal cooperation)				
Lnpopulation	1.263308**	1.07	1.16	1.53
Density	8650.525	0.0393	0.0447	0.0713
Altitude	2290667**	961	983	1030
Agglomeration	4478514**	6.61	9.86	14.3
Tourism	77.11322*	0.000952	0.00105	0.00113
Industrial	1057.023	0.00333	0.00359	0.00391
Commercial	92.52485	0.00153	0.00161	0.00164
PPC (Public-Private intermunicipal cooperation)				
Lnpopulation	1.244*	1.08	1.14	1.5
Density	11965.76	0.0408	0.0441	0.0709
Altitude	6372393	968	996	1040
Agglomeration	5771438	8.6	9.85	10.4
Tourism	0.0013459*	0.000934	0.00104	0.00113
Industrial	1671.433	0.00336	0.00366	0.00403
Commercial	19.71584	0.00151	0.0016	0.00163

Significance: * $p<0.05$; ** $p<0.01$; *** $p<0.001$

As can be seen in Table 5, the variables that have a significant influence are population, urban agglomeration, tourism index, altitude and population density, although the influence in each case varies according to the management form adopted.

The results show that the size of the municipality does not affect the efficiency of the management forms in the same way. While this variable has a positive effect on the CERdp in every case, MUC responds best to conditions in which different population

sizes may be encountered (the regressor corresponding to the average is 1.54). In the case of IC, Figure 3 must be analysed carefully, because the behaviour of the CERdp is significant but varies according to the circumstances. Thus, for the first population tranche, the CERdp has a decreasing concave function; in other words, the CERdp falls when the population increases, until it reaches a turning point, at which the relationship changes to become an increasing one; this form of management is progressively better suited to the (population) environment. This result suggests that, in smaller municipalities, the environmental condition of limited population size impairs the provision of the waste collection service through the formula of public intermunicipal cooperation (IC) (see Fig. 3, *Lnpopulation* tranche, from 7.5 to 8.5).

For the urban agglomeration variable, the effect produced varies according to the management form adopted, although a significant positive influence was only detected for MUC and IC, with the latter having the most significant value (see Table 5). For IC (Fig. 3), it can be seen that, for municipalities with fewer population centres, the CERdp increases; while for PPC, the CERdp decreases as the number of population centres increases (Fig. 3, centres 1-20 approximately). This means that the IC management form is the most suitable for municipalities with fewer population centres (Fig. 3, centres 1-100 approximately).

The tourism index only has a significant impact with IC (see Table 5). With MUD, for the municipalities with the lowest tourism index the slope of the CERdp is slightly positive for the lowest values of this index, and so this management form reduces the impact of the tourist index on the waste collection service when it presents a low level (Fig. 2). With MUC, no significant effect was observed, either positive or negative (Fig. 2). On the contrary, Figure 3, on the impact of the tourist index, present a positive slope for IC and PPC. Thus, the greater the tourist activity in the municipality, the greater its

CERdp, although IC is affected more strongly in this respect when the tourist index presents low values.

Finally, IC presents a positive slope for the altitude variable. Thus, the effect of altitude on the CERdp is less at values of 400-500 m above sea level (Fig. 3). When the population density is low, the private form of service delivery (MUC) reduces the effect of this environmental variable (Fig. 2, section 0.01 - 0.05).

So similarly, to the results of Blaeschke and Haug (2018) and Cordero et al. (2017), we find that controlling for the environmental factors has an effect on the local government efficiency. But, in contrast to the previous empirical literature, our main contribution is that the diverse management forms of waste collection service face this environment differently. In this sense, our results show that public forms of service delivery (IC and MUD) are better suited to the characteristics of the environment than private ones. Concretely, IC is best suited for environments presenting certain levels of altitude, urban agglomeration and tourist-industry orientation, while MUC minimises the negative effects of population density.

Figure 2. Non-parametric regression for MUD (left figure) and Non-parametric regression for MUC (right figure)

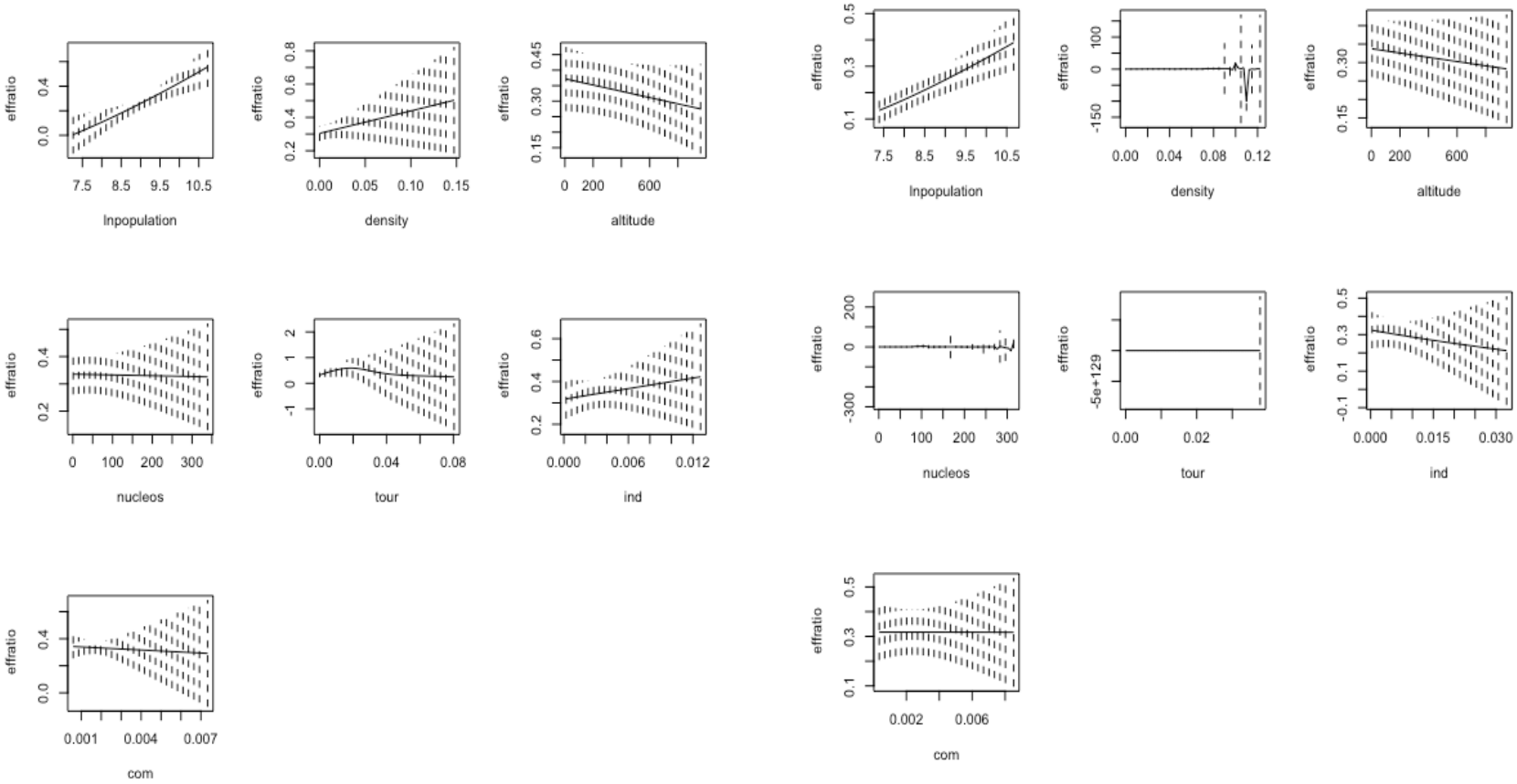
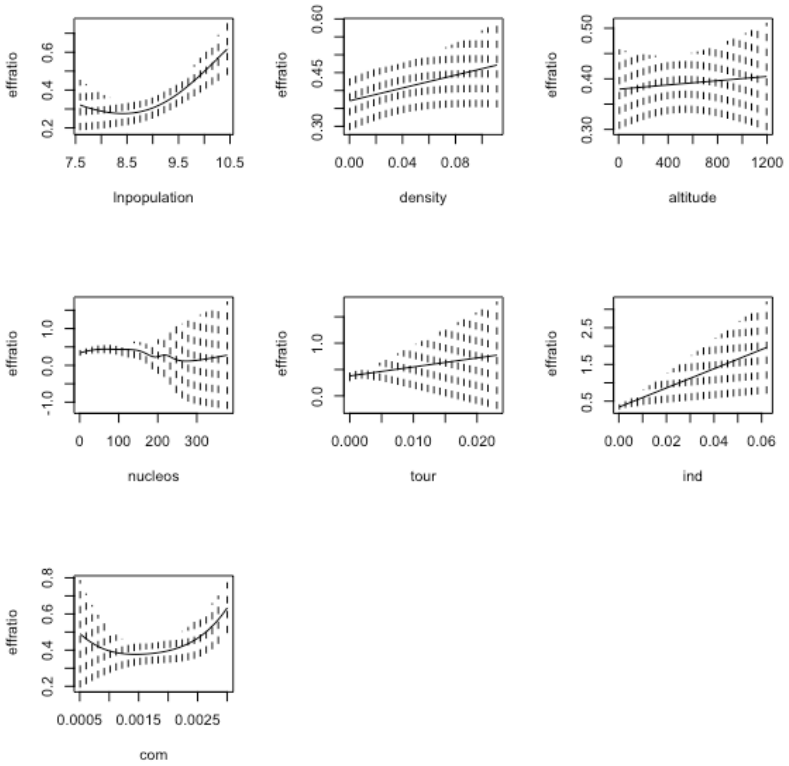
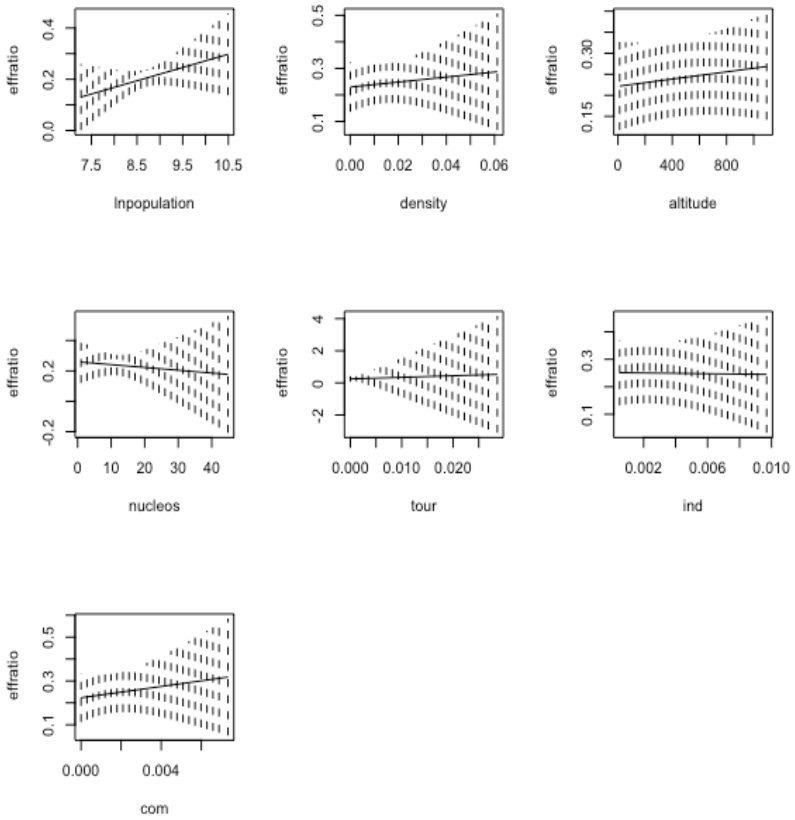


Figure 3. Non-parametric regression for IC (left figure) and Non-parametric regression for PPC (right figure)





5. Conclusions

Many studies have been undertaken to determine which management forms for the provision of public services provide the highest levels of efficiency. It has been shown that certain forms are more likely to obtain good results than others (Pérez-López et al., 2016; Peréz-López et al., 2018, among others). However, a fundamental aspect that must be evaluated is the impact made by environmental conditions on the provision of these public services. In this paper, we analyse the impact of the socioeconomic and geographic environment on efficiency levels, assuming that this influence varies according to the management form considered, i.e., whether it is public or private, and whether it is based on joint provision or on a single provider. Our initial hypothesis is that delivery by a private supplier will be more adaptable to diverse environmental conditions (as has been suggested in previous research). To address this question, we developed and applied a new methodology; unlike traditional techniques in which year-on-year observations cannot be compared, the approach we present derives an estimation of conditional efficiency. Thus, by extending our evaluation of municipal efficiency, taking into account both the structure of the panel data and also the interrelations among temporal observations (Garrido et al., 2018), and by applying robust order-m estimates based on bootstrapping (Cazals et al., 2002), we calculate a conditional frontier that reflects how the characteristics of the socioeconomic environment influence efficiency, in a model that we term conditional order-m data panel (CordermDP). Then, by calculating the conditional efficiency ratio data panel (CERdp) we can determine which management forms for the provision of public services are better suited, given environmental constraints. The method we propose was applied to the practical case of the waste collection service in Spanish municipalities, for the period 2002-2014, an area of research

that has been the object of numerous previous investigations (Bel et al., 2010; Pérez-López et al., 2016; Pérez-López et al., 2018).

The results obtained show that, in general, environmental conditions exert a strong influence on long-term efficiency in the public service considered. Specifically, our results show that public forms of service delivery (IC and MUD) are better suited to the characteristics of the environment than private ones. IC obtains particularly good average values. In contrast, PPC is most severely affected by environmental factors. Thus, IC is the most appropriate form of service delivery for environments presenting certain levels of altitude, population density and tourist-industry orientation. On the other hand, when the population density is low, MUC minimises the negative effects of this situation on efficiency. Our results also show that different forms of management obtain better or worse levels of efficiency according to the aggregate population of the municipality.

In relation to our study hypotheses, we find that the provision of the service by private entities is not the optimum management form as regards adaptability to heterogeneous environmental conditions, and that the form known as public-private intermunicipal cooperation (PPC) is the worst in this respect. In contrast, public forms of service management are usually least subject to these environmental constraints; in particular, public intermunicipal cooperation (IC) maximises the value of CERdp and best adapts to varying environmental characteristics. These contrasting results suggest that although the private sector might be expected to be more flexible in response to changing environmental circumstances, in fact the two forms of service delivery by private concerns (MUC and PPC) are more severely affected by environmental characteristics than are the public management forms.

This finding represents a new contribution to our understanding of the theoretical framework regarding the contracting-out of public services. Accordingly, planners should

evaluate the performance of service providers taking into account the socioeconomic environment in which the service is provided, and should be aware of the possibility, as in the cases we describe, that privately-managed services may be ill-suited to a particular environmental context. In conclusion, the MUD and IC formulas, especially the latter, for the provision of municipal services obtain the best results when environmental constraints are taken into account. This result is important for the planning and implementation of services where the environment may exert a significant influence on their provision, because when this occurs (for example, with certain levels of population, degrees of agglomeration and dependence on tourism), managers are advised to opt for public forms of management, especially IC.

The selection of the adequate management form in the provision of local public services is an important issue, especially considering saving costs (Zafra-Gómez et al., 2013; Plata-Díaz et al., 2014). In this context, several studies have been conducted to determine which management form is the most cost-efficient from very diverse perspectives, such us through the application of the metafrontier analysis enabling to analyse the specific efficiency for each management form (Pérez-López et al., 2016; Garrido et al., 2018) or considering the scale effect (Pérez-López et al., 2018). The novelty of the present work is to consider the effect of the environmental variables in the efficiency of the different management forms of public services, since to date previous studies that considered the effect of the environment did not analysed this question (Blaeschke and Haug, 2018; Cordero et al., 2017). So, the model we present is a valuable contribution to the research field considered, facilitating the analysis of public policies and enabling public managers to be better informed of the impact made by environmental factors on different forms of public service provision. By adopting the one best suited to

the environmental characteristics in which the service is to be provided, planners can improve municipal efficiency reducing costs.

However, this model should be validated in other local public services such as water supply and public transport, in which the environmental constraints could affect the efficiency of the different service delivery forms. Additionally, future research should extend the analysis of the conditional data panel efficiency to the study of scale efficiency, considering that diverse service delivery forms offer the opportunity to expand the demand for local public services.

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