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Efficiency of water service management alternatives in Spain considering environmental factors

Emilio José de la Higuera-Molina *, Cristina María Campos-Alba, Germán López-Pérez, José Luis Zafra-Gómez

University of Granada, Spain

A R T I C L E I N F O

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A B S T R A C T

The main aim of this study is to identify the most efficient forms of management for municipal water supply services, taking into account exogenous factors. The study is based on a sample of 1518 Spanish municipalities, all with 1000 to 50,000 inhabitants, for the year 2019. The study method consists of analysing order-m partial frontiers subjected to environmental factors. The main results obtained indicate that mixed management forms achieve the highest levels of efficiency.

1. Introduction

In the last decade, public administrations have had to face significant economic difficulties caused by financial restrictions (López-Hernández et al., 2018) or health crises such as the COVID-19 pandemic. While the demand for these services has increased, the resources available to local public entities have been constricted. In consequence, public managers have sought to maximise efficiency in the provision of services, and a significant aspect of this is the form of service provision adopted (Benito et al., 2019).

In this respect, many researchers have sought to identify the most appropriate forms of management to provide local public services (Girth et al., 2012; Bauer and Markmann, 2016; Bel and Gradus, 2018; Schoute et al., 2021), often by examining the efficiency achieved by different forms of management (Pérez-López et al., 2016; López-Hernández et al., 2018; Campos-Alba et al., 2020). However, most previous studies have not considered the effect of environmental factors on this efficiency estimation, and among the few that have, the DEA method is often used.

Therefore, the main objective of this study is to determine the efficiency of the domestic water supply service, considering the environmental factors that impact on this calculation. For this purpose, we apply order-m partial frontiers, taking into account environmental factors, in an analysis of 1518 Spanish municipalities with between 1000 and 50,000 inhabitants, using data for 2019.

The rest of this paper is structured as follows: in Section 2 we review the literature on service delivery forms, continuing in Section 3 with a review of the exogenous factors that may influence the efficiency achieved in each case. Section 4 then describes the methods applied to address this research question, after which we present the data analysed and the variables employed. The results thus obtained are discussed in Section 6. Finally, Section 7 summarises the main conclusions drawn.

2. Delivery forms of public services: the case of water supply

2.1. Water service efficiency

Efficiency can be defined as the optimal use of resources to maximise the production of goods or services – or to minimise the use of resources (Karlaftis and Tsamboulas, 2012). Thus, local entities seek to respond to the needs of citizens by optimising the quantity of resources employed in providing the service. Studies have aimed to help public managers reach appropriate decisions by analysing the efficiency achieved, both at the global level of local entities (Kalb et al., 2012; Balaguer-Coll et al., 2013; da Cruz and Marques, 2014; Narbón-Perpiñá and De Witte, 2017), and for the specific provision of public services, for example for waste collection services (Pérez-López et al., 2021; Campos-Alba et al., 2019; Zafra-Gómez et al., 2015; Plata-Díaz et al., 2014; Rogge and De Jaeger, 2013), street cleaning (Benito et al., 2021), urban public transport (Campos-Alba et al., 2020; Daraio et al., 2016; Karlaftis and Tsamboulas, 2012; Odeck, 2008), street lighting (Lorenzo and Sánchez, 2007), fire protection (Donahue, 2004; Church and Li, 2016) and water supply (Coelho and Andrade-Campos, 2014).

* Corresponding author.
E-mail address: edelahiguera@ugr.es (E.J. de la Higuera-Molina).

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Municipal water supply is one of the most studied public services, due to the evident importance it has for the population. According to the UN World Report (2021), there is growing concern about water supply due to the increasing scarcity of drinking water worldwide. Therefore, the UN framed this concern within the SDGs of the 2030 Agenda (Goal 6), to "ensure availability and sustainable management of water and sanitation for all" (Pereira and Marques, 2021). Achieving the MDGs and SDGs related to water supply is a major objective for nations around the world (Pereira and Marques, 2021, 2022a), in view of its essential nature, meeting a basic need and being of mandatory provision for local governments in many countries (Benito et al., 2019; López-Hernández et al., 2018). Therefore, this is one of the public services on which special emphasis should be placed when studying the efficiency of management forms (Zafra-Gómez et al., 2020).

Provision of this service involves the collection, treatment and distribution of water, and requires significant infrastructure for this purpose (Coelho and Andrade-Campos, 2014). The substantial initial investment necessary, in addition to the costs of maintenance and normal operation, make the control of these costs essential, as they impact directly on the final tariff charged to customers (Guerrini et al., 2017). However, cost control cannot be at the expense of upholding quality and performing the necessary maintenance of the network. Among other considerations, sufficient investment in sanitation and drinking water helps avoid the risk of waterborne disease, which is as important as guaranteeing access to drinking water (Ferreira et al., 2021).

In the last 100 years, water consumption has increased by six percentage points (Wada et al., 2016), and by 2050 demand is forecast to be 55% higher than in 2000 (OECD, 2012). This trend, together with the need to maintain service quality standards, has caused growing concern among public managers, generating pressures to ensure the sustainability of the service (Suárez-Varela et al., 2017), especially at the financial level. Thus, efficiency is a major concern in the management of this service. Authors such as Molinos-Senante et al. (2020) and Zafra-Gómez et al. (2020) have shown that the inappropriate use of resources raises costs, and that attention should be paid not only to technical efficiency but also to allocative efficiency in managing water services. Numerous studies have analysed the efficiency of municipal water services. Cetrulo et al. (2019) conducted a review of these studies with respect to the situation in developing countries, observing that an output orientation should be used, because water consumption is in fact to be encouraged in these countries, in contrast to developed countries, where the common practice is to adopt an input orientation towards service efficiency. This review also addresses the variety of study methods employed in the analysis of service efficiency, finding that Stochastic Frontier Analysis (SFA) is the most commonly used parametric method, while Data Envelopment Analysis (DEA) is the most common non-parametric method. Similar studies of service efficiency have been carried out for developed countries, such as Abbott and Cohen (2009) and Worthington (2014). DEA has been used, in studies conducted in developed countries, by Molinos-Senante et al. (2020), analysing technical efficiency in water utilities in England and Wales, by Liu and Fukushige (2020) in Japan, by Woodbury and Dollery (2004) in Australia, and by Benito et al. (2019), in Spain, among many others. Although DEA is the most common approach in this context, other non-parametric models have also been used in the study of efficiency, such as Directional Distance Function (DDF), the Total Production Factor (TPF) or Partial Frontier Analysis (order-m; order-a) (Cetrulo et al., 2019). Fundamentally, the method employed is determined by the aim of the study.

Pinto et al. (2017) and Molinos-Senante and Maziotis (2018) showed that exogenous variables and service quality are relevant to any assessment of water service performance, but few studies have included these aspects in an analysis of efficiency. Nevertheless, it is important to select an appropriate study method to analyse service efficiency, taking into account the environment where it is provided. The ownership of the service is another question that has attracted research attention in studies of efficiency. In this respect, many authors have argued that private operators are more efficient than the public alternative, due to their greater expertise, innovation, and flexibility in response to change (Saal and Parker, 2001; García-Sánchez, 2006; Correia and Marques, 2011).

Research papers that have studied the relationship between efficiency and the choice of management methods to provide public services include Bel et al. (2021), Campos-Alba et al. (2021), Cuadrado-Ballesteros et al. (2012), Ferro et al. (2014), González-Gómez et al. (2014), Pérez-López et al. (2021), Zafra-Gómez et al. (2020), Mohr et al. (2010), Gradus et al. (2016) and Petkovšek et al. (2021).

2.2. Management forms

Management forms for public services can be classified as follows: private management, direct public management, mixed management or intermunicipal cooperation (Albalate et al., 2021; Benito et al., 2019; Cuadrado-Ballesteros et al., 2012; Pérez-López et al., 2021; Petkovšek et al., 2021; Zafra-Gómez et al., 2020).

Private management is the provision of a public service by a private company. Here, we distinguish between strict privatisation, in which the ownership of the service becomes private, and private management in which the service is outsourced to a private provider, while ownership and control of the service remain in the public sector (López-Hernández et al., 2018; Plata-Díaz et al., 2019). This form of management has been widely used as an alternative to direct public management. Proponents argue that direct management suffers from greater rigidity due to the considerable bureaucracy present in the public sector. Moreover, it presents high maintenance costs and requires significant economic investment by the local corporation (Prior et al., 2019; Zafra-Gómez et al., 2020). In this context, furthermore, González-Gómez et al. (2014) argue that private management provides higher service quality, due to its more efficient resource management.

An alternative to the above is the use of mixed forms of management, using entities linked to both the public and the private sectors. The most common formula in this respect is that of Public-Private Partnership (De la Higuera-Molina et al., 2022).

However, not all local entities have access to private operators for the provision of public services (Zafra-Gómez et al., 2020); this is the case of many smaller municipalities. The private sector will not be interested in managing public services where the size of the municipality is insufficient for them to operate profitably and amortise their investments (Zafra-Gómez et al., 2020). On the other hand, when the characteristics of the service allow its simultaneous provision in more than one municipality, economies of scale can be generated, which may attract private operators for its provision. This operating mode is termed private management with cooperation (Pérez-López et al., 2016).

Cooperation in service provision can also take place between local entities, an approach that is especially common among small municipalities (Bel et al., 2010). In order to ensure this type of shared service provision is efficient, it is necessary to save costs, share resources, achieve optimal production, increase the volume of service provision and generate economies of scale (Soukopová and Klimovský, 2016; Zafra-Gómez et al., 2020). In relation to the latter, studies have shown that national/regional-level entities providing water and sanitation services can achieve higher levels of efficiency via economies of scale (Pereira and Marques, 2022b). It is in this context that the concept of intermunicipal cooperation appears (Pérez-López et al., 2021; Soukopová and Klimovský, 2016). According to Luca and Modrego (2020), intermunicipal cooperation is a governance structure whereby two or more municipalities collaborate to provide public goods/services jointly. One of the main reasons for adopting this form of governance is to achieve cost savings (Niaounakis and Blank, 2017), usually through economies of scale (Aldag et al., 2019; Blank and Niaounakis, 2021; Soukopová and Klimovský, 2016), decreased fiscal stress, increased technical capabilities and more efficient management (Kim and Warner, 2016; Zafra-Gómez et al., 2020).

After several decades during which many public services were privatised, there has been a recent trend towards their remunicipalisation (Albalate et al., 2021). Proponents argue that, in order to guarantee universal access to primary needs and avoid the creation of monopolies by private companies, public management is the most appropriate form of service provision (González-Gómez et al., 2014). Moreover, according to authors such as Bel et al. (2010) and Soukopová and Klimovský (2016), public production is, in general, cheaper than private production.

The domestic drinking water supply service has traditionally been managed publicly, either through the local entity itself or through municipal companies (Thomas et al., 2012; Zafra-Gómez et al., 2020). However, the provision of the service through this form of management has been subjected to numerous criticisms, such as the inability of local governments to expand service coverage, their difficulties in coping with high maintenance costs (Lo Storto, 2014; Prior et al., 2019) and a lack of investment in infrastructure. In consequence, the quality of service provision is considered poorer (Anwandter and Ozuna, 2002), and the private sector has presented itself as a valuable option for improving service quality and achieving cost savings (Prasad, 2006).

As reflected in the above considerations, there are conflicting positions as to which form of management is the most efficient (Zafra-Gómez et al., 2020). Some authors hold that privatisation is the best alternative, as it is capable of providing a higher quality service (González-González et al., 2014; Prior et al., 2019), while others believe this form of management is not very profitable or attractive for municipalities, especially smaller ones (Soukopová and Klimovský, 2016; Pérez-López et al., 2021; Zafra-Gómez et al., 2020). Other authors claim that direct management is the most efficient form of service provision, either directly, via Public-Private Partnership or through intermunicipal cooperation (Luca and Modrego, 2020; Pérez-López et al., 2021; Soukopová and Klimovský, 2016).

Zafra-Gómez et al. (2020) analysed the service efficiency achieved in small municipalities through direct management and intermunicipal cooperation, finding that while both forms of management are efficient, direct management obtains somewhat better results. Benito et al. (2019) compared direct and private management, and reported that the direct public management of drinking water services improves service efficiency. These studies highlight the importance of considering population size in determining the most appropriate form of service management.

But population size is not the only aspect to consider when analysing service efficiency. There are numerous aspects exogenous to the service itself that also influence service provision and efficiency, and many of these cannot be controlled by the service provider. Accordingly, one or other management model should be selected according to the environment in which the service is provided (Da Cruz and Marques, 2014; Pérez-López et al., 2018; Zafra-Gómez and Chica-Olmo, 2019).

3. How do exogenous factors affect to provision of water supply service?

3.1. Exogenous factors

The provision of municipal water services can be subject to exogenous factors that are not directly related to the service, but which could impact on the technology employed and the efficiency achieved (Conti, 2005). Carvalho and Marques (2011) reported that very few studies incorporate these variables into the analysis of water service efficiency. Nevertheless, operational factors such as type of consumer, local topography and climate, peak factor or water source could influence service performance. Marques et al. (2014) performed a similar analysis, but included not only operational and technical variables, but also institutional ones.

Other authors consider demographic, geographic (Pérez-López et al., 2021; da Cruz and Marques, 2014), socioeconomic and political (Campos-Alba et al., 2020) factors as exogenous variables. Among potentially relevant demographic factors, the local population size can determine how the service is managed (as discussed above) and affect service costs. Both questions may impact on service efficiency (Benito et al., 2019). Population density should also be taken into account; for example, a high level of population density could generate economies of scale (Blaeschke and Haug, 2018), while a low one would make service provision more complex, given the significant infrastructure required for its distribution.

Given the importance of the infrastructure necessary for service provision, the geographic characteristics of the municipality will also play a fundamental role. These include the surface area of the municipality where the service is to be supplied, the altitude of the municipality and its proximity or otherwise to the coast. Specifically, the surface area of the municipality may have an impact on efficiency because a larger area will usually increase the cost of the service (Antonioli and Filippini, 2001). The spatial situation of the municipality, such as being located near the coast, may also influence service efficiency; for example, most coastal municipalities present a seasonal demand, which complicates service provision. On the other hand, these municipalities usually have higher levels of economic development, which facilitates their achieving more investment to improve service quality (Cordero et al., 2017). Finally, the altitude of the municipality is relevant to the nature of the systems installed to distribute water, which must provide adequate pressure. The latter factor is directly associated with the operating and maintenance costs of the service, and hence its efficiency (Coelho and Andrade-Campos, 2014).

Potentially important socioeconomic conditions include the local rate of unemployment (Balaguer-Coll et al., 2019). In this respect, Geys et al. (2010) argue that when there is a high level of unemployment, the demand for quality in public services is lower, which could reduce service costs, and hence increase efficiency. Another aspect is that of the nature of the municipality; one that is dependent on tourism will be exposed to seasonal fluctuations in water demand, which will hinder the provision of the service (Picazo-Tadeo et al., 2009).

Finally, the political factors of the municipality will also affect the service efficiency achieved. A government with a progressive ideology is more likely to seek the direct management of services, a choice that in turn may impact on service efficiency (Revelli and Tovmo, 2007). Similarly, political strength will condition efficiency, as decision making will be more complicated if there is little consensus within the local government (Borge et al., 2008).

In short, all those factors that configure the environment in which the service is provided can influence the efficiency of the service. Proof of this is that various studies have been undertaken to identify the forms of management that can best adapt to certain environments, and thus provide higher levels of efficiency (Pérez-López et al., 2018, 2021; Beltrán-Esteve et al., 2019).

These considerations show that the efficiency achieved through the different forms of management cannot be properly analysed without considering the environment in which the service is provided. Accordingly, in this study our aim is to determine which form of management is most appropriate for the provision of water services, comparing not only public and private management, but also public-private partnership and intermunicipal cooperation in the analysis, an approach that, to our knowledge, has not been taken previously with respect to municipal water services. In this study, exogenous variables were included in the efficiency estimation to clarify which management forms are better adapted to the environment in question. In fact, the way in which the environment can determine the success or otherwise of a given form of service management in achieving optimum efficiency has received little research attention. The present study employs a robust methodology based on partial frontier models, through conditional order-m partial frontier models (see Guerrini et al., 2017; Pérez-López et al., 2021). The overall study aim is to obtain useful information about the suitability of each delivery form for the environment in which the service is to be provided, and thus help public managers decide whether or not to incorporate the private sector into the management of the municipal water service. Our analysis pays special attention to the size of the municipalities analysed, in order to counteract the limited access to private suppliers that is often experienced by small municipalities, a factor that is often overlooked in studies of efficiency.

4. Methods

The efficiency of water supply services has traditionally been studied using non-parametric methods, such as Free Disposal Hull (FDH) or Data Envelopment Analysis (DEA) (Suárez-Varela et al., 2017; Zafra-Gómez et al., 2020), the latter being the most common. However, this traditional method presents some limitations. For example, the production boundary is shaped by taking into account all the observations, which means the estimation is sensitive to the presence of outliers or extreme values, potentially affecting the evaluation of other decision-making units (DMUs) (Campos-Alba et al., 2020; Henriques et al., 2022). The deterministic nature of this method has led researchers to search for new techniques that allow them to address values beyond the estimated efficiency frontier without considering them inefficient by default (De Witte and Marques, 2010). To overcome this limitation, partial or robust frontiers, such as order-m or order-α methods have been proposed (Daraio & Simar, 2007; Pérez-López et al., 2016; Henriques et al., 2022).

The order-m partial frontier model is an extension of traditional DEA models that compare the behaviour of similar production units and estimate which units produce the highest level of output with a given level of input (output orientation) or which need the lowest level of input for a given level of output (input orientation), through the application of bootstrap techniques, where the efficiency values of each unit in the sample are calculated by comparing with a subsample of *m* pairs. The present study uses order-m partial frontiers to analyse service efficiency (Cazals et al., 2002).

As discussed above, the type of environment in which the service is provided can determine the most appropriate form of service management. The failure to consider factors exogenous to the service, when estimating efficiency, can lead to significant biases in the results obtained, for example if municipalities with different production technologies are compared (Aldag et al., 2019). Therefore, the efficiency estimation described in this study takes into consideration such environmental factors, through conditional order-m partial frontier models (see Guerrini et al., 2017; Pérez-López et al., 2021).

In general terms, the demand for public services, such as municipal water supply, cannot be controlled by public managers (Cordero et al., 2017). In the present study, therefore, we adopt an input orientation, to act on the expenditure made or the distribution strategy employed. Thus, for S units $s = 1, \ldots, S$ there are N inputs $x^s = x_1^s, \ldots, x_n^s, \ldots, x_N^s \in \Re_+^N$ that produce M outputs $y^s = y_1^s, \ldots, y_m^s, \ldots, y_M^s \in \Re_+^M$. Then, to show how a unit operating at a certain level (x, y) can be compared with another using the joint production function, following an input orientation the production process can be represented as:

$$H_{XY}(x^s, y^s) = P(X \le x^s | Y \ge y^s) P(Y \ge y^s) = F_{X|Y}(x^s|y^s) S_Y(y^s)$$

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

To include the effect of environmental variables in the efficiency estimation, the vector of the exogenous variables $Z \in \Re_+^K$ is considered in the specification, to compare a unit operating at a certain level (x, y) with another that operates in similar environmental conditions $(Z = z)$. From this, and according to Daraio and Simar (2005) it is possible to obtain the estimator of the unconditional order-m efficiency function[1, 2 and 3].

For a given value of Z, the conditional distribution of (X, Y) can be specified as follows:

$$H_{XY|Z}(x^s, y^s|z^s) = P(X \le x^s, Y \ge y^s | Z = z^s) = F_{X,Y|Z}(x^s|y^s, z^s) S_{Y|Z}(y^s|z^s)$$

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

The order-m partial frontier model allows us to obtain the conditional estimator efficiency ($\theta_{(x,y|z)}$), which can be expressed as:

$$\tilde{\theta}_{m,n}(x, y|z) = \int_0^\infty \left[1 - \left(1 - S_{Y,n}(uy|x, z)\right)\right]^m du$$

In view of the above, in order to study the conditional efficiency achieved according to the way in which the service is managed, it is necessary to apply other techniques to compare the conditional efficiency indices achieved by the different forms of management. For this purpose, we use the metafrontier analysis developed by Battese and Rao (2002) and later by Battese et al. (2004) and which was used for the first time in the water sector by De Witte and Marques, 2009. This parameter can be defined as a function in which groups with different technological characteristics converge. From the estimation of the conditional efficiency for the metafrontier (*metafrontier, CE*), on the one hand, and for the local frontiers (*local frontiers, CE^f*) - for each of the subgroups of the sample (v_1, v_2, v_3, v_4) - on the other, the Technological Gap Ratio (*TGR^f*) can be obtained (Pérez-López et al., 2016; Giménez et al., 2019). This ratio measures the distance between the local frontier and the metafrontier, and is defined, for a given level of *output*, as the lowest possible level of *inputs* of the metafrontier divided by the lowest total level of *inputs* of the *Local frontier*. Thus, *TGR^f* results from the following formula:

$$TGR^f = \frac{CE}{CE^f}$$

where $CE = \theta_v^m$ and $CE^f = \theta_v^{m,v_1}, \theta_v^{m,v_2}, \theta_v^{m,v_3}, \theta_v^{m,v_4}$

In the present study, the metafrontier (*metafrontier, CE*) is formed by all the municipalities analysed regardless of the type of service management, while the local frontiers (*local frontiers, CE^f*) are determined by the forms of management analysed. Thus, there will be four local frontiers, formed by municipalities that provide the service through direct management, private management, public-private partnership, or intermunicipal cooperation. The Technological Gap Ratio, thus, enables us to determine the efficiency derived from the form of management employed.

According to Cazals et al. (2002), as this model is employed to deal with the presence of outliers, in contrast to traditional nonparametric techniques that compare each unit with the whole sample, order-m partial frontiers calculate the efficiency values of each unit by comparison with a sub-sample of *m* units, after resolving integer programming algorithms in which a non-convex technology is assumed. In this partial frontier method, the efficiency estimation is repeated *B* times, and by the end of the process *B* efficiency coefficients ($\tilde{\theta}^{m,b}$, where $b = 1; 2; \ldots B$) have been obtained. The mean of the *B* efficiency coefficients is calculated as:

$$\tilde{\theta}^m = \frac{1}{B} \sum_{b=1}^{B} \tilde{\theta}^{m,b}$$

[1] The mathematical specification of the method can be consulted in Pérez-López et al. (2021).

It is important to note that the application of order-m partial frontiers may give rise to super-efficient units, which can also affect the calculation of TGR (Pérez-López et al., 2016). Thus, when the *TGR* value is close to 1, it means that the efficiency achieved by a municipality within the group with the same form of management will be very close to that achieved within the total number of municipalities in the sample, and therefore this form of management will be more appropriate for the provision of the service than those with values below and far from 1. When *TGR* values are above 1, these units will be super-efficient (Campos-Alba et al., 2020).

5. Data and variables

This analysis was conducted using cross-sectional data for the fiscal year 2019, obtained from various databases, such as the statistics on the effective cost of public services, published by the Spanish Ministry of Finance and Public Administrations. Specifically, this information concerned the effective cost of public services in municipalities with between 1000 and 50,000 inhabitants, for the year 2019.

The same source was consulted to obtain data on forms of service management, corresponding to 1518 municipalities which provided domestic water supply services directly, privately, through Public-Private Partnership or through inter-municipal cooperation (see Table 1). In addition, the Local Infrastructure and Equipment Survey, published by the Ministry of Finance and Public Administrations, was consulted to obtain the data on outputs. Other databases, produced by the National Institute of Statistics (on population, among other parameters) and the Ministry of the Interior (on political ideologies and levels of political fragmentation) were consulted to obtain the environmental variables.

The study variables were selected taking into account previous studies in this field of research, such as Romano and Guerrini (2011) and Zafra-Gómez et al. (2020). Table 2 details the variables taken as inputs and outputs in this analysis of the efficiency of municipal water services. In previous efficiency studies, the variables most often considered as inputs are the cost of labour, operational expenses, capital expenditure and total cost (Worthington, 2014; Cetrulo et al., 2019). In some cases, the length of the supply network has been employed as a proxy for capital (Berg and Marques, 2011), an approach also taken in the present study. We also consider the total cost as an input variable. As outputs, the amount of water provided, the coverage of the service and its quality are the variables most commonly employed (Worthington, 2014; Cetrulo et al., 2019). The outputs included in the present study are the number of houses connected to the water supply network (representing the number of households served), the consumption of water (as a proxy of the amount of potable water supplied) and the quality of the water supplied.

The exogenous factors were selected considering the features of the water sector, the available data and prior literature in this field (Carvalho and Marques, 2011; Marques et al., 2014; Pérez-López et al., 2021). In relation to the environmental variables, both socioeconomic and geographic factors are included (see Table 2), but not political ones, due to their categorical nature, which makes them unsuitable for inclusion in our study model.

As previously indicated, the objective of this study is to determine the efficiency of the local domestic drinking water supply service in Spanish municipalities, considering the environment in which the service is provided and the different forms of management employed for this purpose. Table 3 shows the descriptive statistics of the variables considered.

Table 1
Pattern of management methods for water supply service.

Form of management	Number of municipalities using the management form
Direct provision	790
Privatisation	448
Public-private partnership	72
Inter-municipal cooperation	208
Total	**1518**

Table 2
Study variables.[1,2]

Type of Variable	Variable	Description	Source
Inputs and Outputs			
Input	Cost (€/year)	Cost for the local entity of the domestic water supply service, expressed in euros per year.	Virtual Office of Local Government Financial Coordination, within the Ministry of Public Administration
	Net length (m)	Length of the municipal water network, expressed in metres.	Treasury Survey of Local Infrastructure and Equipment (EIEL), published by the Ministry of Public Administration.
Output	Daily average flow (m^3/day)	Average total daily consumption in the municipality, expressed in m^3.	
	Daily average flow*Quality[2] (m^3/day)	Quality of water consumption in the municipality.	
	Connected houses	Number of houses connected to the network.	
Environmental factors			
Socioeconomic and geographic factors	Unemployment (%)	Percentage of unemployment in the municipality	National Institute of Statistics
	Population density (m^3/inhabitants)	Number of inhabitants per m^3 in the municipality	
	Surface area (m^2)	Surface area of the municipality.	
	Tourism index	Tourism index for the municipality[3]	
	Altitude	Altitude of the municipality, in metres a.s.l.	National Geographic Institute
	Coast	Distance to the nearest coastline.	

6. Results

Table 4 shows the conditional efficiency values achieved by the different forms of service management. Specifically, it shows the descriptive statistics of the efficiency estimates obtained from the application of conditional order-m local frontiers, conditional metafrontier and conditional TGR.

Before analysing the efficiency of the management forms, the nonparametric Kruskal-Wallis test was performed to determine whether the data examined were derived from the same population. Intuitively, this test is identical to ANOVA, but with the data replaced by categories. In another words, it is an extension of the Mann-Whitney *U* test for three or more groups, applied to the local frontiers of each management form. The test results highlight the existence of significant differences among the TGR values obtained (Table 4), which justifies performing separate analyses according to the management form considered.

The Mann-Whitney *U* test was applied to determine whether there were significant differences between each pair of management forms, and thus to identify the most appropriate one for the water service. The results obtained confirmed the null hypothesis of equality between each of the management form pairs considered. In other words, there were significant differences between the efficiencies of the different management forms, and therefore robust conclusions can be drawn about

Table 3
Descriptive statistics.

Type of variable	Variable	Mean	Std. Dev.	Min	Max
	Management	1.80	1,04	1	4
Inputs[a]	Cost	473,214	975,788.2	10	1.96e+07
	Length	8,002,457	3.08e+08	5	1.20e+10
Outputs[a]	Consum	2131.74	2662.74	50	25,151
	Quality_cons	2261.35	2811.51	50	25,151
	Connected houses	4684.37	11,901.36	56	387,000
Environmental factors	Population	7599.95	9278.31	1001	49,783
	Unemployment	502.86	722.03	0	5422
	Coast	.76	.43	0	1
	Surface	7554.79	9205.59	0	49,727
	Population density	40	3.03	28	44
	Altitude	398.28	307.10	0	1324
	Tourism index	12.01	19.67	0	185

[a] The correlation matrix of inputs-outputs is shown in Appendix 1.

Table 4
Descriptive statistics: conditional metafrontier, conditional local frontier and conditional GRT, by form of management.

Management Form	Mean	Min	Max	Standard Deviation
Private (N = 448)[a]				
Meta-Frontier	.2230	.0376	.8117	.1684
Local Frontier	.6758	.0711	1.0314	.3227
TGR	.4017	.0220	.5468	.1615
Direct Provision (N = 790)[a]				
Meta-Frontier	.2043	.0011	1.2081	.2207
Local Frontier	.1312	.0009	.9916	.1489
TGR	1.1006	.5388	1.6637	.3142
Public-Private Partnership (N = 72)[a]				
Meta-Frontier	.2165	.0108	.6932	.1993
Local Frontier	.5537	.0132	1.0027	.3978
TGR	1.2214	.0105	1.3106	.8553
Intermunicipal Cooperation (N = 208)[a]				
Meta-Frontier	.1024	.0026	.7383	.1875
Local Frontier	.4951	.1409	1.2118	.3927
TGR	.2136	.0019	.7499	.2011

[a] Differences are assumed to be significant at 1% according to the Kruskal-Wallis test for the TGR.

how each one contributed to the level of efficiency.

From the results shown in Table 4, and focusing on the values at the local frontier of each form of management, it can be observed that the average values of local efficiency for private management (67.58%), mixed management (55.37%) and intermunicipal cooperation reflect a certain homogeneity within each of these groups of municipalities, unlike the case of direct management, which shows an average local efficiency value of 13.12%, reflecting considerable disparity among the group of municipalities that provide the service through this form of management, and therefore, significant inefficiencies within it.

On comparing the results of these forms of management within the metafrontier, we see that the average efficiency value in the metafrontier of direct management (20.43%) is now above that in the metafrontier of intermunicipal cooperation (10.24%), reaching a value very close to that of private (22.3%) and mixed (21.65%) management. In other words, when the different production technologies of each group are ignored, direct management does not appear to be the least efficient. However, these differences must be taken into account in order to determine whether the way in which the service is managed improves its efficiency.

As the conditional local efficiency shows the position adopted by the municipalities in terms of efficiency compared with others with the same form of management, while metafrontier efficiency shows the position they occupy compared with the whole set of municipalities, regardless of the form in which the service is managed, by examining the distance between these values we can determine the efficiency achieved as a result of the form of management. Therefore, the TGR reflects which form of management presents the most appropriate technology in terms of service efficiency.

According to the results shown in Table 4, intermunicipal cooperation has the lowest average TGR value (0.2136), followed by private management (0.4017), while direct management and mixed management have an average TGR value above unity, which implies that most of the municipalities that manage the service through these forms of management are super-efficient compared to the rest of the sample analysed. Specifically, it is mixed management that presents the highest average value of the TGR (1.2214), and therefore is the most appropriate form of management to provide the service efficiently. On the other hand, direct management also shows a high average TGR value (1.1006), despite the fact that its local average efficiency shows considerable inefficiencies within the group. This phenomenon is explained by the fact that comparing the municipalities with direct management with the other groups of municipalities in the metafrontier, shows that those with direct management are more technologically efficient.

Previous studies of Spanish local services have not conclusively determined whether privatisation improves efficiency in contrast to direct provision (Torres et al., 2003). However, in their analysis of rural water efficiency, González-Gómez et al. (2013) found that private companies and public-private partnerships are more efficient than public companies, which is partially in line with the results obtained in the present study. González-Gómez et al. (2014) showed that privatisation does not necessarily improve the efficiency of the service, while Benito et al. (2019) demonstrated that direct provision improves service efficiency in contrast with private provision, a finding that corroborates Suárez-Varela et al. (2017) and is in line with results obtained for other European countries (Marques, 2008; Walter et al., 2009; Lo Storto, 2014).

However, the above results could be distorted by the size of municipalities analysed. Smaller municipalities have more limited access to private operators for service management, and some authors argue that cooperation is the solution to this problem. To examine whether the efficiency scores are affected by size, Table 5 shows the disaggregated results for two groups of municipalities, differentiated by size, one group with municipalities of between 1000 and 20,000 inhabitants, and the other with municipalities of between 20,000 and 50,000 inhabitants.

From the results shown in Table 5, we conclude that mixed

[2] Mean water consumption, in m3/day, corrected by the index of service quality, an internal measure based on the quality of water purification treatment, the volume of water flow and the pressure of domestic water supply.

[3] Ratio in which the numerator contains the sum of the accommodation units offered in the municipality (rural houses, holiday accommodation, rural hostelry and hotels), while the denominator includes the area of each municipality (km^2). This ratio is taken to represent the density of tourist activity in the municipality.

Table 5
Descriptive statistics: Conditional TGR, by forms of management and population size.

Form of service provision	Mean	Min.	Max.	Standard Deviation
Size 1: 1000 to 20,000 inhabitants (n = 1348)				
Private	.4009	.0220	.5091	.1601
Direct provision	1.1045	.5388	1.6637	.4534
Public-Private Partnership	1.2002	.0544	1.3106	.8402
Intermunicipal Cooperation	.2211	.0019	.7122	.2002
Size 2: >20,000 inhabitants (n=170)				
Private provision	.4097	.0266	.5468	.1620
Direct provision	1.0112	.5573	1.5642	.3452
Public-Private Partnership	1.1533	.0105	1.2982	.8101
Intermunicipal Cooperation	.2546	.0132	.7499	.2019

management through collaboration between the private and public sectors is the most efficient form of service management, for all population sizes. As can be seen, the average TGR value obtained for the two population groups is highest for mixed management (1.2002 for municipalities with between 1000 and 20,000 inhabitants; 1.1533 for municipalities with between 20,000 and 50,000 inhabitants). This shows that efficiency is greater when the private sector is involved in service provision, but the public sector remains involved, which makes it possible to control compliance with the quality standards demanded by stakeholders.

The better results of direct provision over intermunicipal cooperation are in line with the findings obtained by Zafra-Gómez et al. (2020) for medium-sized and small Spanish municipalities, according to which direct provision obtains higher levels of cost efficiency in small municipalities than intermunicipal cooperation. However, these findings contrast with those obtained by Mohr et al. (2010), Bel and Fageda (2006) and Silvestre et al. (2017) for other countries.

This discrepancy might be explained by the existence of economies of scale; as observed by Zafra-Gómez and Chica-Olmo (2019), even with joint service provision, the size of the population served may not be enough to reduce unit costs sufficiently.

7. Conclusions

Concern over growing global water consumption has led to a proliferation of studies that seek to assist public managers in their decisions regarding water services. The drinking water supply service is of particular interest because access to this basic necessity must be guaranteed to all citizens. Local entities are usually responsible for providing this service, and the economic and social difficulties to which they have been subjected in recent years, together with the growing demand for the service, have spurred the search for measures to improve its efficiency. One policy that has commonly been adopted to this end is that of privatisation. However, to date there is no consensus in the literature as to the effect of privatisation on service efficiency. A vital consideration in this regard is the effect on efficiency produced by different forms of service management. In addition, given the significant influence of the local environment on efficiency considerations, the factors that configure this environment must be addressed. In this paper, only geographic, demographic and socioeconomic factors are included, due to limited data availability.

In view of the above, the main aim of the present study is to analyse the conditional efficiency of the water supply service, through the application of conditional order-m partial frontiers (Cazals et al., 2002), thus enabling us to compare the effects of different forms of service management on efficiency, and at the same time to consider the environment in which the service is provided. For this purpose, a sample of 1518 Spanish municipalities each with 1000 to 50,000 inhabitants was used, with service information for the year 2019.

This analysis revealed that mixed management or public-private collaboration improves efficiency if the environment in which the service is provided is taken into account, thus confirming that this form of management exploits some advantages offered by the private sector, such as flexibility in response to changing environmental conditions, a higher level of innovation or greater experience (House, 2016). At the same time, it enables appropriate control by the public sector over service provision, thus fulfilling its public-service obligation and ensuring compliance with the quality standards required of the service (Prasad, 2006).

Nevertheless, and although previous studies have observed that small local entities often resort to direct service management because private operators decline to participate due to the inefficiencies derived from the limited size of the municipality, the present analysis of efficiency disaggregated by population size shows that public-private collaboration also allows small municipalities to achieve optimal levels of efficiency via collaboration with the private sector. These findings represent a breakthrough in academic literature, offering practical decision-making assistance to the public managers of small municipalities.

Direct management also achieves optimal efficiency levels, although below those achieved by mixed management; private management performs more poorly in this regard, and intermunicipal cooperation presents the lowest levels of efficiency.

These findings demonstrate that intermunicipal cooperation is not the most suitable solution for small municipalities, contrary to the views traditionally expressed in the literature. Smaller municipalities can access private providers via collaboration, establishing a mixed-ownership company co-funded by a local entity and a private provider, or even through the union of several municipalities with the private sector, creating mixed companies that provide the service to more than one municipality at a time.

In summary, public managers should take into consideration the environment in which the service is to be provided when taking decisions about the form of service provision, due to the significant impact of this factor on the performance achieved. Although the mixed management structure offers higher levels of efficiency, this mode is less commonly adopted by small and medium-sized municipalities in Spain, which frequently resort to privatisation. This unbalanced situation, considering the better results of mixed management, might have arisen because, as Carpintero and Helby Petersen (2016) point out, the implementation of public-private partnerships is a complex operation, due to the need to determine an equitable sharing of risks and to optimise performance. Moreover, in many cases the process is delayed by disagreements and bureaucratic requirements. Sometimes, even, a collaborative agreement is cancelled and the service is remunicipalised, despite the resulting prejudice to service efficiency. In our view, coordination and the assumption of equitable levels of responsibility and risk by both the public and the private sectors are necessary if an effective, efficient service is to be provided. In this regard, the development of a best practices guide for the creation of mixed-ownership companies or the establishment of public-private partnerships would be highly beneficial for public managers, providing them with greater confidence when deciding whether to pursue such agreements, and this could change the current landscape, in which relatively few small municipalities employ this form of management.

The present study has certain limitations that must be acknowledged: Firstly, the results show that the management method applied significantly influences the efficiency achieved by municipal water services, and so the available alternatives must be compared to determine which is most efficient. However, the study findings do not reveal the degree of improvement that could be achieved by adopting the optimum form of service provision. In addition, it is important to note that the management forms compared in this study operate under different conditions, as the private sector is subject to pressures that are reduced or absent in the public sector, such as depreciation rules, taxation, rent payments and considerations of acceptable risk (Marques and Simões, 2020).

Furthermore, the exogenous variables included in this study do not encompass operational factors, due to limited data availability.

In addition, the fact that our analysis is based exclusively on municipalities with a population of between 1000 and 50,000 inhabitants means that we have no data on the effects of these forms of management in large municipalities, although it is precisely these which face the greatest problems in this field, since in many cases these cities are experiencing significant population growth, and hence population density is increasing, which undoubtedly impacts on the service provided. Furthermore, as some authors note, the size of the municipality could influence the presence of scale economies, leading to cost reductions (Carvalho and Marques, 2014; Pérez-López et al., 2018), and the same could occur when scope economies are at play (Carvalho and Marques, 2014). For these reasons, the study of service efficiency could be enhanced by the study of scale and scope efficiency, for a better understanding of the impact of management forms on efficiency. Finally, in future research, it would be useful to consider a broader time period, thus reflecting the long-term effect of the management form on service efficiency and at the same time considering the changing circumstances of the environment in which the service is provided. This expanded scope would enhance the robustness of the results obtained.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors are unable or have chosen not to specify which data has been used.

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Appendix A

Appendix 1

	Cost	Long	Consump	Conquality	Connected houses
Cost	1				
Long	−0.0004	1			
Consump	0.486	0.0328	1		
Conquality	0.4503	0.0298	0.5621	1	
Connected houses	0.3572	0.0104	0.3724	0.3522	1

References

Abbott, M., Cohen, B., 2009. Productivity and efficiency in the water industry. Util. Pol. 17 (3–4), 233–244. https://doi.org/10.1016/j.jup.2009.05.001.

Albalate, D., Bel, G., Gradus, R., Reeves, E., 2021. Re-municipalization of local public services: incidence, causes and prospects. Int. Rev. Adm. Sci. 87 (3), 419–424. https://doi.org/10.1177/00208523211006455.

Aldag, A., Warner, M., Bel, G., 2019. It depends on what you share: the elusive cost savings from service sharing. J. Publ. Adm. Res. Theor. 30 (2), 275–289. https://doi.org/10.1093/jopart/muz023.

Antonioli, B., Filippini, M., 2001. The use of a variable cost function in the regulation of the Italian water industry. Util. Pol. 10 (3–4), 181–187.

Anwandter, L., Ozuna, T., 2002. Can public sector reforms improve the efficiency of public water utilities? Environ. Dev. Econ. 7 (4), 687–700.

Balaguer-Coll, M., Prior, D., Tortosa-Ausina, E., 2013. Output complexity, environmental conditions, and the efficiency of municipalities. J. Prod. Anal. 39 (3), 303–324. https://doi.org/10.1007/s11123-012-0307-x.

Balaguer-Coll, M.T., Brun-Martos, M.I., Márquez-Ramos, L., Prior, D., 2019. Local government efficiency: determinants and spatial interdependence. Appl. Econ. 51 (14), 1478–1494.

Battese, G.E., Rao, D.S., O'donnell, C.J., 2004. A metafrontier production function for estimation of technical efficiencies and technology gaps for firms operating under different technologies. J. Prod. Anal. 21 (1), 91–103.

Battese, G.E., Rao, D.P., 2002. Technology gap, efficiency, and a stochastic metafrontier function. Int. J. Bus. Econ. 1 (2), 87.

Bel, G., Esteve, M., Garrido, J., Zafra-Gómez, J., 2021. The costs of corporatization: analysing the effects of forms of governance. Publ. Adm. 100 (2), 232–249. https://doi.org/10.1111/padm.12713.

Bel, G., Fageda, X., 2006. Between privatization and intermunicipal cooperation: small municipalities, scale economies and transaction costs. Urbanublic Econ. Rev. (6), 13–31.

Bel, G., Fageda, X., Warner, M., 2010. Is private production of public services cheaper than public production? A meta-regression analysis of solid waste and water services. J. Pol. Anal. Manag. 29 (3), 553–577. https://doi.org/10.1002/pam.20509.

Berg, S., Marques, R., 2011. Quantitative studies of water and sanitation utilities: a benchmarking literature survey. Water Pol. 13 (5), 591–606. https://doi.org/10.2166/wp.2011.041.

Bauer, H., Markmann, F., 2016. Models of local public service delivery: privatisation, publicisation and the renaissance of the cooperative?. In: Public and Social Services in Europe: from Public and Municipal to Private Sector Provision, pp. 281–296.

Bel, G., Gradus, R., 2018. Privatisation, contracting-out and inter-municipal cooperation: new developments in local public service delivery. Local Govern. Stud. 44 (1), 11–21.

Beltrán-Esteve, M., Giménez, V., Picazo-Tadeo, A., 2019. Environmental productivity in the European Union: a global Luenberger-metafrontier approach. Sci. Total Environ. 692, 136–146. https://doi.org/10.1016/j.scitotenv.2019.07.182.

Benito, B., Faura, Ú., Guillamón, M., Ríos, A., 2019. Empirical evidence for efficiency in provision of drinking water. J. Water Resour. Plann. Manag. 145 (4) https://doi.org/10.1061/(asce)wr.1943-5452.0001049.

Benito, B., Guillamón, M.D., Martínez-Córdoba, P.J., Ríos, A.M., 2021. Influence of selected aspects of local governance on the efficiency of waste collection and street cleaning services. Waste Manag. 126, 800–809.

Blaeschke, F., Haug, P., 2018. Does intermunicipal cooperation increase efficiency? A conditional metafrontier approach for the Hessian wastewater sector. Local Govern. Stud. 44 (1), 151–171. https://doi.org/10.1080/03003930.2017.1395741.

Blank, J., Niaounakis, T., 2021. Economies of scale and sustainability in local government: a complex issue. Sustainability 13 (23), 13262. https://doi.org/10.3390/su132313262.

Borge, L.E., Falch, T., Tovmo, P., 2008. Public sector efficiency: the roles of political and budgetary institutions, fiscal capacity, and democratic participation. Publ. Choice 136 (3), 475–495.

Campos-Alba, C., De La Higuera Molina, E., Pérez-López, G., Zafra-Gómez, J., 2020. Drivers of contracting back in local governments: analysing efficiency, opportunistic political cycles, political corruption and financial factors. Journal of Economic Policy Reform 24 (3), 347–360. https://doi.org/10.1080/17487870.2019.1689359.

Campos-Alba, C., De la Higuera-Molina, E., Pérez-López, G., Zafra-Gómez, J., 2019. Measuring the efficiency of public and private delivery forms: an application to the waste collection service using order-m data panel frontier analysis. Sustainability 11 (7), 2056. https://doi.org/10.3390/su11072056.

Campos-Alba, C.M., Prior, D., Pérez-López, G., Zafra-Gómez, J.L., 2020. Long-term cost efficiency of alternative management forms for urban public transport from the public sector perspective. Transport Pol. 88, 16–23.

Campos-Alba, C., Garrido-Rodríguez, J., Plata-Díaz, A., Pérez-López, G., 2021. The selective collection of municipal solid waste and other factors determining cost efficiency. An analysis of service provision by Spanish municipalities. Waste Manag. 134, 11–20. https://doi.org/10.1016/j.wasman.2021.07.039.

Carvalho, P., Marques, R.C., 2014. Computing economies of vertical integration, economies of scope and economies of scale using partial frontier nonparametric methods. Eur. J. Oper. Res. 234 (1), 292–307. https://doi.org/10.1016/j.ejor.2013.09.022.

Carvalho, P., Marques, R.C., 2011. The influence of the operational environment on the efficiency of water utilities. J. Environ. Manag. 92 (10), 2698–2707. https://doi.org/10.1016/j.jenvman.2011.06.008.
Carpintero, S., Helby Petersen, O., 2016. Public–private partnerships (PPPs) in local services: risk-sharing and private delivery of water services in Spain. Local Govern. Stud. 42 (6), 958–979.
Cazals, C., Florens, J.P., Simar, L., 2002. Nonparametric frontier estimation: a robust approach. J. Econom. 106 (1), 1–25.
Cetrulo, T.B., Marques, R.C., Malheiros, T.F., 2019. An analytical review of the efficiency of water and sanitation utilities in developing countries. Water Res. 161, 372–380.
Church, R.L., Li, W., 2016. Estimating spatial efficiency using cyber search, GIS, and spatial optimization: a case study of fire service deployment in Los Angeles County. Int. J. Geogr. Inf. Sci. 30 (3), 535–553.
Coelho, B., Andrade-Campos, A., 2014. Efficiency achievement in water supply systems - a review. Renew. Sustain. Energy Rev. 30, 59–84.
Conti, M., 2005. Ownership relative efficiency in the water industry: a survey of the international empirical evidence. Economia Internazionale/International Economics 58 (3), 273–306.
Cordero, J.M., Pedraja-Chaparro, F., Pisaflores, E.C., Polo, C., 2017. Efficiency assessment of Portuguese municipalities using a conditional nonparametric approach. J. Prod. Anal. 48 (1), 1–24.
Correia, T., Marques, R.C., 2011. Performance of Portuguese water utilities: how do ownership, size, diversification and vertical integration relate to efficiency? Water Pol. 13 (3), 343–361.
Cuadrado-Ballesteros, B., García-Sánchez, I., Prado-Lorenzo, J., 2012. Effects of different modes of local public services delivery on quality of life in Spain. J. Clean. Prod. 37, 68–81. https://doi.org/10.1016/j.jclepro.2012.06.008.
da Cruz, N., Marques, R., 2014. Revisiting the determinants of local government performance. Omega 44, 91–103. https://doi.org/10.1016/j.omega.2013.09.002.
Daraio, C., Diana, M., Di Costa, F., Leporelli, C., Matteucci, G., Nastasi, A., 2016. Efficiency and effectiveness in the urban public transport sector: a critical review with directions for future research. Eur. J. Oper. Res. 248 (1), 1–20. https://doi.org/10.1016/j.ejor.2015.05.059.
Daraio, C., Simar, L., 2007. Advanced Robust and Nonparametric Methods in Efficiency Analysis: *Methodology and Applications*. Springer, New York.
Daraio, C., Simar, L., 2005. Introducing environmental variables in nonparametric frontier models: a probabilistic approach. J. Prod. Anal. 24 (1), 93–121. https://doi.org/10.1007/s11123-005-3042-8.
De Witte, K., Marques, R.C., 2009. Capturing the environment, a metafrontier approach to the drinking water sector. Int. Trans. Oper. Res. 16 (2), 257–271. https://doi.org/10.1111/j.1475-3995.2009.00675.x.
De Witte, K., Marques, R.C., 2010. Influential observations in frontier models, a robust non-oriented approach to the water sector. Ann. Oper. Res. 181 (1), 377–392.
Donahue, A.K., 2004. The influence of management on the cost of fire protection. J. Pol. Anal. Manag. 23 (1), 71–92.
Ferreira, D.C., Graziele, I., Marques, R.C., Gonçalves, J., 2021. Investment in drinking water and sanitation infrastructure and its impact on waterborne diseases dissemination: the Brazilian case. Sci. Total Environ. 779, 146279 https://doi.org/10.1016/j.scitotenv.2021.146279.
Ferro, G., Lentini, E., Mercadier, A., Romero, C., 2014. Efficiency in Brazil's water and sanitation sector and its relationship with regional provision, property and the independence of operators. Util. Pol. 28, 42–51. https://doi.org/10.1016/j.jup.2013.12.001.
García-Sánchez, I.M., 2006. Efficiency measurement in Spanish local government: the case of municipal water services. Rev. Pol. Res. 23 (2), 355–372. https://doi.org/10.1111/j.1541-1338.2006.00205.x.
Geys, B., Heinemann, F., Kalb, A., 2010. Voter involvement, fiscal autonomy and public sector efficiency: evidence from German municipalities. Eur. J. Polit. Econ. 26 (2), 265–278.
Girth, A.M., Hefetz, A., Johnston, J.M., Warner, M.E., 2012. Outsourcing public service delivery: management responses in noncompetitive markets. Publ. Adm. Rev. 72 (6), 887–900.
Giménez, V., Prieto, W., Prior, D., Tortosa-Ausina, E., 2019. Evaluation of efficiency in Colombian hospitals: an analysis for the post-reform period. Soc. Econ. Plann. Sci. 65, 20–35.
González-Gómez, F., García-Rubio, M., González-Martínez, J., 2014. Beyond the public-private controversy in urban water management in Spain. Util. Pol. 31, 1–9. https://doi.org/10.1016/j.jup.2014.07.004, 10.1016/j.jup.2014.07.004.
González-Gómez, F., García-Rubio, M.A., Alcalá-Olid, F., Ortega-Díaz, M.I., 2013. Outsourcing and efficiency in the management of rural water services. Water Resour. Manag. 27, 731–747.
Gradus, R., van Koppen, R., Dijkgraaf, E., Nillesen, P., 2016. A cost-effectiveness analysis for incineration or recycling of Dutch household plastics. SSRN Electron. J. https://doi.org/10.2139/ssrn.2781933.
Guerrini, A., Carvalho, P., Romano, G., Cunha-Marques, R., Leardini, C., 2017. Assessing efficiency drivers in municipal solid waste collection services through a non-parametric method. J. Clean. Prod. 147, 431–441. https://doi.org/10.1016/j.jclepro.2017.01.079.
Henriques, A.A., Fontes, M., Camanho, A.S., D'Inverno, G., Amorim, P., Silva, J.G., 2022. Performance evaluation of problematic samples: a robust nonparametric approach for wastewater treatment plants. Ann. Oper. Res. https://doi.org/10.1007/s10479-022-04629-z.
Higuera-Molina, E.J.D.L., Esteve, M., Plata-Díaz, A.M., Zafra-Gómez, J.L., 2022. The political hourglass: opportunistic behavior in local government policy decisions. Int. Publ. Manag. J. 25 (5), 767–784.
House, S., 2016. Responsive regulation for water PPP: balancing commitment and adaptability in the face of uncertainty. Policy and Society 35 (2), 179–191. https://doi.org/10.1016/j.polsoc.2016.06.001.
Kalb, A., Geys, B., Heinemann, F., 2012. Value for money? German local government efficiency in a comparative perspective. Appl. Econ. 44 (2), 201–218. https://doi.org/10.1080/00036846.2010.502110.
Karlaftis, M., Tsamboulas, D., 2012. Efficiency measurement in public transport: are findings specification sensitive? Transport. Res. Pol. Pract. 46 (2), 392–402. https://doi.org/10.1016/j.tra.2011.10.005.
Kim, Y., Warner, M.E., 2016. Pragmatic municipalism: local government service delivery after the Great Recession. Publ. Adm. 94 (3), 789–805. https://doi.org/10.1111/padm.12267.
Liu, J., Fukushige, M., 2020. Efficiency and pricing of water supply and sewerage services in Japan. Util. Pol. 62, 100984.
Lo Storto, C., 2014. Benchmarking operational efficiency in the integrated water service provision. Benchmark Int. J. 21 (6), 917–943. https://doi.org/10.1108/bij-11-2012-0076.
López-Hernández, A., Zafra-Gómez, J., Plata-Díaz, A., de la Higuera-Molina, E., 2018. Modeling fiscal stress and contracting out in local government: the influence of time, financial condition, and the Great Recession. Am. Rev. Publ. Adm. 48 (6), 565–583. https://doi.org/10.1177/0275074017699276.
Lorenzo, J.M.P., Sánchez, I.M.G., 2007. Efficiency evaluation in municipal services: an application to the street lighting service in Spain. J. Prod. Anal. 27 (3), 149–162.
Luca, D., Modrego, F., 2020. Stronger together? Assessing the causal effect of inter-municipal cooperation on the efficiency of small Italian municipalities. J. Reg. Sci. 61 (1), 261–293. https://doi.org/10.1111/jors.12509.
Marques, R.C., 2008. Comparing private and public performance of Portuguese water services. Water Pol. 10 (1), 25–42.
Marques, R.C., Berg, S., Yane, S., 2014. Nonparametric benchmarking of Japanese water utilities: institutional and environmental factors affecting efficiency. J. Water Resour. Plann. Manag. 140 (5), 562–571. https://doi.org/10.1061/(asce)wr.1943-5452.0000366.
Marques, R.C., Simões, P., 2020. Revisiting the comparison of public and private water service provision: an empirical study in Portugal. Water 12 (5), 1477. https://doi.org/10.3390/w12051477.
Mohr, R., Deller, S., Halstead, J., 2010. Alternative methods of service delivery in small and rural municipalities. Publ. Adm. Rev. 70 (6), 894–905. https://doi.org/10.1111/j.1540-6210.2010.02221.x.
Molinos-Senante, M., Maziotis, A., Villegas, A., 2020. Estimating technical efficiency and allocative distortions of water companies: evidence from the English and Welsh water and sewerage industry. Environ. Sci. Pollut. Control Ser. 27, 35174–35183.
Molinos-Senante, M., Maziotis, A., 2018. Assessing the influence of exogenous and quality of service variables on water companies' performance using a true-fixed stochastic frontier approach. Urban Water J. 15 (7), 682–691.
Narbón-Perpiñá, I., De Witte, K., 2017. Local governments' efficiency: a systematic literature review-part II. Int. Trans. Oper. Res. 25 (4), 1107–1136. https://doi.org/10.1111/itor.12389.
Niaounakis, T., Blank, J., 2017. Inter-municipal cooperation, economies of scale and cost efficiency: an application of stochastic frontier analysis to Dutch municipal tax departments. Local Govern. Stud. 43 (4), 533–554. https://doi.org/10.1080/03003930.2017.1322958.
Odeck, J., 2008. The effect of mergers on efficiency and productivity of public transport services. Transport. Res. Pol. Pract. 42 (4), 696–708. https://doi.org/10.1016/j.tra.2007.12.004.
OECD, 2012. Environmental Outlook to 2050: the Consequences of Inaction. Retrieved from. https://www.oecd-ilibrary.org/docserver/9789264122246-en.pdf?expires=1634273874&id=id&accname=guest&checksum=0CBB5D5F55E4C7DC4C1C7D0A64B4C6D8.
Pereira, M.A., Marques, R.C., 2021. Sustainable water and sanitation for all: are we there yet? Water Res. 207, 117765 https://doi.org/10.1016/j.watres.2021.117765.
Pereira, M.A., Marques, R.C., 2022a. From a millennium to a sustainable water and sanitation development: were we there already? J. Water Supply Res. Technol. - Aqua 71 (2), 293–300. https://doi.org/10.2166/aqua.2022.124.
Pereira, M.A., Marques, R.C., 2022b. Technical and scale efficiency of the Brazilian municipalities' water and sanitation services: a two-stage data envelopment analysis. Sustainability 14 (1), 199. https://doi.org/10.3390/su14010199.
Pérez-López, G., Prior, D., Zafra-Gómez, J., 2018. Temporal scale efficiency in DEA panel data estimations. An application to the solid waste disposal service in Spain. Omega 76, 18–27. https://doi.org/10.1016/j.omega.2017.03.005.
Pérez-López, G., Prior, D., Zafra-Gómez, J., 2021. Modelling environmental constraints on the efficiency of management forms for public service delivery. Waste Manag. 126, 443–453. https://doi.org/10.1016/j.wasman.2021.03.007.
Pérez-López, G., Prior, D., Zafra-Gómez, J., Plata-Díaz, A., 2016. Cost efficiency in municipal solid waste service delivery. Alternative management forms in relation to local population size. Eur. J. Oper. Res. 255 (2), 583–592. https://doi.org/10.1016/j.ejor.2016.05.034.
Petkovšek, V., Hrovatin, N., Pevcin, P., 2021. Local public services delivery mechanisms: a literature review. Lex Localis - Journal of Local Self-Government 19 (1), 39–64. https://doi.org/10.4335/19.1.39-64(2021).
Picazo-Tadeo, A.J., Sáez-Fernández, F.J., González-Gómez, F., 2009. The role of environmental factors in water utilities' technical efficiency. Empirical evidence from Spanish companies. Appl. Econ. 41 (5), 615–628.
Pinto, F.S., Costa, A.S., Figueira, J.R., Marques, R.C., 2017. The quality of service: an overall performance assessment for water utilities. Omega 69, 115–125. https://doi.org/10.1016/j.omega.2016.08.006.

Plata-Díaz, A., de la Higuera-Molina, E., Garrido-Rodríguez, J., Zafra-Gómez, J., 2019. Contracting out and social services: responses to the austerity machine, financial condition and political parties. Administration & Society 51 (6), 951–990. https://doi.org/10.1177/0095399717713797.

Plata-Díaz, A., Zafra-Gómez, J., Pérez-López, G., López-Hernández, A., 2014. Alternative management structures for municipal waste collection services: the influence of economic and political factors. Waste Manag. 34 (11), 1967–1976. https://doi.org/10.1016/j.wasman.2014.07.003.

Prasad, N., 2006. Privatisation results: private sector participation in water services after 15 years. Dev. Pol. Rev. 24 (6), 669–692.

Prior, D., Martín-Pinillos-Castellanos, I., Pérez-López, G., Zafra-Gómez, J., 2019. Cost efficiency and financial situation of local governments in the Canary Isles during the recession. Revista De Contabilidad 22 (2), 129–144. https://doi.org/10.6018/rcsar.376091.

Revelli, F., Tovmo, P., 2007. Revealed yardstick competition: local government efficiency patterns in Norway. J. Urban Econ. 62 (1), 121–134.

Rogge, N., De Jaeger, S., 2013. Measuring and explaining the cost efficiency of municipal solid waste collection and processing services. Omega 41 (4), 653–664. https://doi.org/10.1016/j.omega.2012.09.006.

Saal, D.S., Parker, D., 2001. The impact of privatization and regulation on the water and sewerage industry in England and Wales: a translog cost function model. Manag. Decis. Econ. 21 (6), 253–268. https://doi.org/10.1002/mde.988.

Schoute, M., Gradus, R., Budding, T., 2021. Drivers of service delivery modes in Dutch local government: an analysis over time and across domains. Int. Rev. Adm. Sci. 87 (3), 425–439.

Silvestre, H., Marques, R., Gomes, R., 2017. Joined-up government of utilities: a meta-review on a public-public partnership and inter-municipal cooperation in the water and wastewater industries. Publ. Manag. Rev. 20 (4), 607–631. https://doi.org/10.1080/14719037.2017.1363906.

Soukopová, J., Klimovský, D., 2016. Local governments and local waste management in the Czech Republic: producers or providers? NISPAcee J. Public Adm. Policy 9 (2), 217–237. https://doi.org/10.1515/nispa-2016-0021.

Suárez-Varela, M., de los Ángeles García-Valiñas, M., González-Gómez, F., Picazo-Tadeo, A.J., 2017. Ownership and performance in water services revisited: does private management really outperform public? Water Resour. Manag. 31 (8), 2355–2373.

Thomas, S., Hall, D., Lethbridge, J., Lobina, E., Popov, V., Corral, V., van Niekerk, S., 2012. Why Water Is a Public Service: Exposing the Myths of Privatization. Public Services International Research Unit. University of Greenwich, London.

Torres, L., Pina, V., Acerete, B., 2003. Public-private partnership in Spanish local governments. Eur. Bus. Organ Law Rev. 4, 429–452.

Wada, Y., Flörke, M., Hanasaki, N., Eisner, S., Fischer, G., Tramberend, S., Satoh, Y., van Vliet, M.T., Yillia, P., Ringler, C., Burek, P., Wiberg, D., 2016. Modeling global water use for the 21st century: the water futures and solutions (WFAS) initiative and its approaches. Geosci. Model Dev. (GMD) 9 (1), 175–222. https://doi.org/10.5194/gmd-9-175-2016.

Walter, M., Cullmann, A., Hirschhausen, C.V., Wand, R., Zschille, M., 2009. Quo vadis efficiency analysis of water distribution? A comparative literature review. Util. Pol. 17, 225–232.

Woodbury, K., Dollery, B., 2004. Efficiency measurement in Australian local government: the case of New South Wales municipal water services. Rev. Pol. Res. 21 (5), 615–636.

Worthington, A.C., 2014. A review of frontier approaches to efficiency and productivity measurement in urban water utilities. Urban Water J. 11 (1), 55–73.

Zafra-Gómez, J., Chica-Olmo, J., 2019. Spatial spillover effect of delivery forms on cost of public services in small and medium-sized Spanish municipalities. Cities 85, 203–216. https://doi.org/10.1016/j.cities.2018.09.008.

Zafra-Gómez, J., Giménez-García, V., Campos-Alba, C., de la Higuera-Molina, E., 2020. Direct management or inter-municipal cooperation in smaller municipalities? Exploring cost efficiency and installed capacity in drinking water supply. Water Resour. Manag. 34 (13), 4289–4302. https://doi.org/10.1007/s11269-020-02676-4, 10.1007/s11269-020-02676-4.

Zafra-Gómez, J., Plata-Díaz, A., Pérez-López, G., López-Hernández, A., 2015. Privatisation of waste collection services in response to fiscal stress in times of crisis. Urban Stud. 53 (10), 2134–2153. https://doi.org/10.1177/0042098015586697.