European Journal of Operational Research 255 (2016) 583–592

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Innovative Applications of O.R.

Cost efficiency in municipal solid waste service delivery. Alternative management forms in relation to local population size

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ARTICLE INFO

Article history:
Received 8 April 2015
Accepted 18 May 2016
Available online 4 June 2016

Keywords:
Local government
Delivery forms
Cost efficiency
Metafrontier
Municipal solid waste

ABSTRACT

Considerable research has been devoted to the analysis of efficiency and of management forms for municipal waste collection, but widely varying results have been reported. In this paper, the metafrontier approach, by means of order-*m* frontiers, is used to analyse the efficiency of different ways of managing waste collection services, in order to determine which form is more appropriate. We compare the results obtained with this approach against those of previous theories. The advantage of applying this methodology is that unlike traditional nonparametric frontier analysis, we can compare the efficiency of different groups of municipalities according to their population size and to the management form adopted to supply the service. The results obtained suggest that, in general, cooperation formulas are the most suitable for the waste collection service. Thus, intermunicipal cooperation performs best in smaller municipalities (up to 20,000 inhabitants). However, we find that contracting out the service is associated with higher levels of efficiency in municipalities with more than 20,000 inhabitants.

1. Introduction

The search for greater efficiency is a key element in evaluating performance in the provision of public services (Nogueira & Jorge, 2015). However, these services may be provided in different ways, which influence the level of efficiency obtained. In this context, understanding the relationship between efficiency and service delivery forms for the provision of local public services is a question of vital importance for the public manager, because the control of these services is viewed as a fundamental issue in local government (Geys & Moesen, 2009).

Among the great variety of services offered by local authorities, that of municipal solid waste (MSW) collection and disposal is one of the most widely studied, due to the complexity of its provision, the significant cost involved and increasing environmental concerns in this respect (Bel, Fageda, Dijkgraaf, & Gradus, 2010; Benito-López, Moreno-Enguix, & Solana-Ibañez, 2011; De Jaeger & Rogge, 2013; Jacobsen, Buysse, & Gellynck, 2013; Simões & Marques, 2012a; Zafra-Gómez, Prior, Plata-Díaz, & López-Hernández, 2013).

Recent studies on the question of MSW services have focused on determining which form of service delivery – public or private – might achieve the highest levels of efficiency and cost savings (Bel & Fageda, 2010; Bel, Fageda, & Mur, 2014; Bel & Mur, 2009; Dijkgraaf & Gradus, 2013; Simões, Cruz, & Marques, 2012; Simões & Marques, 2012a; Zafra-Gómez et al., 2013; Mañez et al., 2016; Zafra-Gómez et al., 2016). Further empirical evidence would be useful to determine whether the public provision of this service achieves higher levels of cost efficiency than contracting out, or vice versa. In view of this background, it seems clear that research that only takes into account whether management of the service is public or private is insufficiently specific, and that the different service delivery alternatives for the MSW service must be defined. Within the wide range of possible forms of provision, those of municipal direct (MUD), municipal under contract (MUC), intermunicipal cooperation (IC) and private production with cooperation (PPC) are among the alternatives most commonly used in managing MSW services (Plata-Díaz, Zafra-Gómez, Pérez-López, & López-Hernández, 2014).

In short, the aim of the present study is to contribute to the literature on the analysis of cost efficiency in the provision of the MSW service, by analysing the differences that arise in cost efficiency from different ways of managing this service among Spanish local authorities, and thus to identify which service delivery form is best suited to its provision. To address this goal, we have examined a database composed of 771 Spanish municipalities, each with a population of 1000–50,000 inhabitants, for the period 2007–2010. For this study, the issue was addressed using a methodol-

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http://dx.doi.org/10.1016/j.ejor.2016.05.034
0377-2217/

ogy that distinguishes the different technological processes provided by each service delivery form and reflects their impact on efficiency, taking into account all the units concerned. In this respect, we use the term metafrontier – frontier separation – developed by Battese and Rao (2002) and Battese, Rao, and O'Donnell (2004). Additionally, to determine the cost efficiency of the MSW service for each of the municipalities in the sample, we propose the use of partial nonparametric frontiers, applying order-*m* frontiers (Cazals, Florens, & Simar, 2002; Daouia & Simar, 2007). As an alternative to DEA (data envelopment analysis), (Larrán-Jorge & García-Correas, 2015) partial nonparametric frontiers are robust to the presence of outliers and extreme values, and are unaffected by problems of dimensionality (Balaguer-Coll, Prior, & Tortosa-Ausina, 2013; Simões, Carvalho, & Marques, 2012).

The metafrontier concept facilitates the comparison of municipalities that present similar characteristics but deliver the service by different formulas. This methodology evaluates each municipality twice: in relation to the best practice for the form of service delivery adopted and also to the overall best practice among all the different forms of service delivery (De Witte & Marques, 2009). If efficiency values were computed without distinguishing the delivery form of the MSW service, taking municipalities as a whole, this would mean that two municipalities with similar characteristics that applied different forms of MSW service delivery could not be compared in terms of efficiency, since, for example, one town may present lower levels of efficiency than the other but be among the most efficient within its own form of service delivery. In such a context, the first-named municipality could improve its efficiency only by changing its form of service delivery to one that is more appropriate. For these reasons, the present study seeks to determine which service delivery form is most efficient for the MSW service, by making municipalities comparable in terms of efficiency through the metafrontier concept.

The results obtained suggest that cooperative forms achieve the highest levels of cost savings in the MSW service. However, the evidence suggests there are differences in cost efficiency between different service delivery forms according to the population size of the municipality. Specifically, in municipalities with a larger population the use of contracted-out management forms would be more appropriate.

The rest of this paper is organised as follows. In the second section, we present a theoretical review of the question of cost efficiency in MSW service delivery. The third section introduces the concept of metafrontier, the methodology applied in this study. In the fourth section, we present the data used in the analysis and the results obtained. Finally, the fifth section summarises the key findings and acknowledges the limitations of the study conducted.

2. Size, delivery forms and cost efficiency in the provision of MSW services

The debate over public or private management and its relationship to the cost of the MSW service has been widely discussed (Bel & Fageda, 2010; Bel et al., 2014; Bel & Mur, 2009; Bel & Warner, 2008, 2010; Benito, Solana, & Moreno, 2014; Jacobsen, Buysse, & Gellynck, 2013; Ohlsson, 2003; Simões, Cruz, et al., 2012; Stevens, 1978; Zafra-Gómez et al., 2013). This question is of great current interest due to the need to know which form of local service provision is most efficient (Bel et al., 2014), among the wide variety of service delivery forms possible (Jacobsen et al., 2013).

Diverse theoretical arguments have been proposed regarding the use of private firms to deliver public services, including public choice theory, property rights, organisational theory and the application of economies of scale (Bel & Fageda, 2006 , 2008; Simões, Cruz, et al., 2012; Zafra-Gómez et al., 2013). The advantages obtained from the contracting out of public services mainly result from the introduction of competition into municipal service provision (Warner, 2012); in particular, cost savings are facilitated by the fact that the private sector often presents lower production costs than is the case of the public sector (Bel & Fageda, 2006; Wassenaar, Dijkgraaf, & Gradus, 2010). In addition, if the service is contracted out, the private operator may have the possibility of providing the same service in different municipalities, which enables fixed costs to be shared among the different locations in which it operates, thus obtaining economies of scale and service cost reductions (Donahue, 1989). Accordingly, contracting out has been proposed as a means of reducing the costs of local service provision and of achieving higher levels of efficiency (Bel & Fageda, 2008).

However, the empirical evidence in this respect is unclear (Bel & Warner, 2008). Some studies have reported no significant differences in service costs between public and private production (Bel & Fageda, 2010; Bel & Mur, 2009; Dijkgraaf & Gradus, 2003); others have reported the existence of such cost differences, but published results vary widely. Thus, some studies find that contracting out reduces costs (Benito et al., 2014; Reeves & Barrow, 2000; Simões, Cruz, et al., 2012) while others conclude that private management is associated with higher costs (Ohlsson, 2003; Stevens, 1978; Zafra-Gómez et al., 2013).

This disparity in results may be due to the fact that in the provision of public services there continues to be, in many cases, a lack of competition or an inadequate regulatory model (Simões, De Witte, & Marques, 2010). The market structure is different between countries, ranging from the absence of regulation in the United States (Warner & Bel, 2008), to the legal obligation to provide a MSW service, but with freedom to adopt the management form preferred, in the Netherlands and Spain (Bel et al., 2010) and the strict regulatory system in Portugal (Simões & Marques, 2012b). The inconsistent results might also be justified by reference to the theory of incomplete contracts and to the presence of transaction costs that affect the negotiation of contracts (Bel & Fageda, 2006; Girth, Hefetz, Johnston, & Warner, 2012; Hefetz & Warner, 2012; Warner, 2012). For these reasons, it has been concluded that private participation in the MSW service requires appropriate regulation and a suitable market structure (Bel & Warner, 2008; Cruz, Simões, & Marques, 2013). Another factor which may obscure the relationship between cost efficiency and contracting out is that the size of the municipality may not be sufficient for economies of scale to be achieved. Simões et al. (2010) and Carvalho and Marques (2014) reported economies of size for utilities in Portuguese MSW services and in the recycling sector, respectively. According to Bel and Fageda (2009) and González-Gómez, Picazo-Tadeo, and Guardiola (2011), the factors that decide municipal managers to contract out certain local public services vary with the size of the municipality, and so cost efficiency can also vary in this respect.

There is evidence that smaller municipalities can obtain better results from other formulas than contracting out the MSW service (Bel et al., 2014; Benito, Guillamón, & Bastida, 2015). Private operators may be unable to obtain economies of scale in these smaller municipalities (Bel & Fageda, 2006; Warner & Hebdon, 2001; Warner & Hefetz, 2003), for two main reasons. First, small and medium-sized municipalities may not be large enough to reduce the unit cost of the service (Bel & Fageda, 2006, 2008; Mohr, Deller, & Halstead, 2010; Zafra-Gómez et al., 2013). Second, they may also lack the negotiating power to conclude beneficial contracts with private operators (Warner & Hefetz, 2003). Accordingly, in such municipalities, joint management has been considered as an alternative to contracting out (Bel & Fageda, 2006,2008; Mohr et al., 2010; Warner & Hebdon, 2001; Warner & Hefetz, 2003; Zafra-Gómez et al., 2013).

Therefore, intermunicipal cooperation may be introduced, to jointly organise the service and thus exploit latent economies of

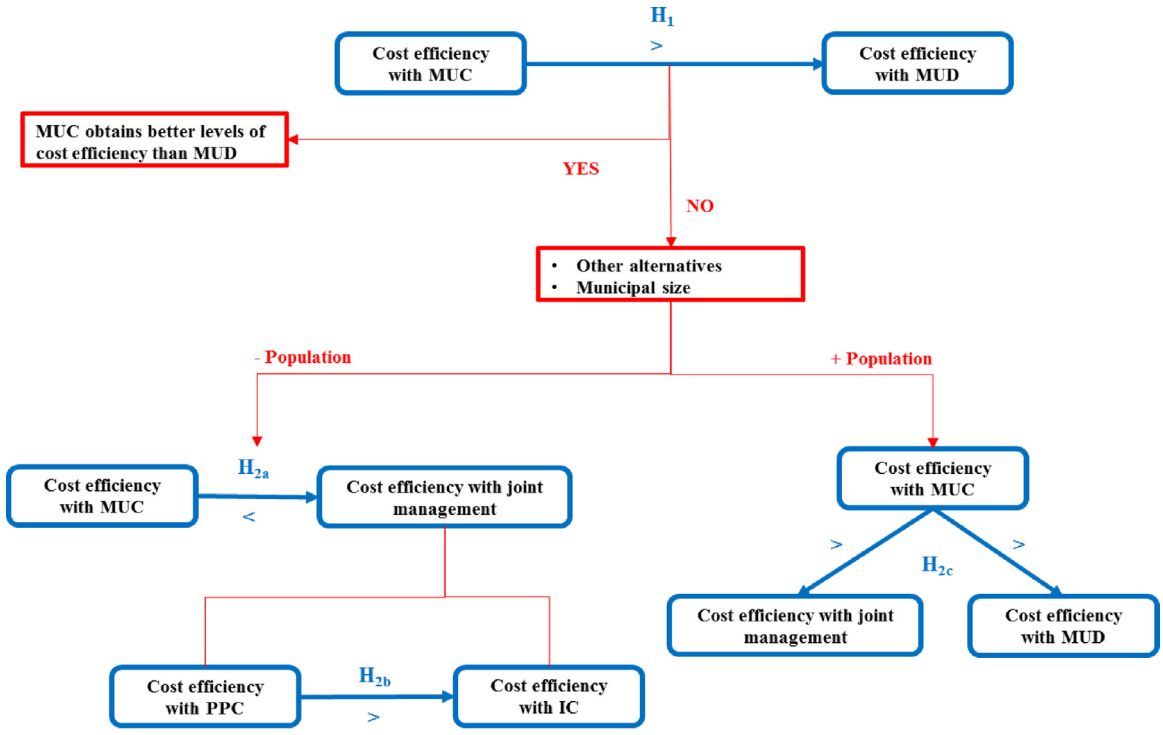


Fig. 1. Cost efficiency and service delivery forms: relations.

scale, sharing the costs of service provision among two or more local authorities (Warner, 2006; Warner & Hefetz, 2003; Zullo, 2009).

Moreover, for this type of municipality, there is an alternative to pure contracting out and intermunicipal cooperation, namely the establishment of a joint outsourcing management structure among municipalities that have opted for intermunicipal cooperation, a format known as *private production with cooperation* (Bel et al., 2014; Zafra-Gómez et al., 2013). This configuration of the service offers several advantages: first, it reduces the costs faced by each of the municipalities involved, and, second, it provides access to the advantages offered by private provision of the service, thus obtaining overall cost savings and greater efficiency (Plata-Díaz et al., 2014).

In all, therefore, four alternative forms of service delivery are distinguished in the present study, thus improving upon previous research in this field in which the only distinction normally made is that between public and private management. In this study, we differentiate the following forms of MSW service provision: direct provision by the municipality, or municipal direct (MUD); contracted out or municipal provision under contract (MUC); intermunicipal cooperation (IC); and private production with cooperation (PPC) (Plata-Díaz et al., 2014).

We propose a scenario in which a large sample of municipalities can be used to confirm or reject various hypotheses related to the theoretical assumptions reviewed above. Specifically, we propose two major hypotheses: first, a general one, related to the differences between contracting out and public service delivery; and a second, more specific one, referring to the differences among service delivery forms according to the size of the municipality. Thus, the following hypotheses are proposed:

H_1: *Municipal provision under contract (MUC) provides higher levels of efficiency than municipal direct (MUD).*

H_{2a}: *In smaller municipalities, joint management – intermunicipal cooperation and private production with cooperation (IC and PPC) – provide higher levels of efficiency than municipal under contract (MUC).*

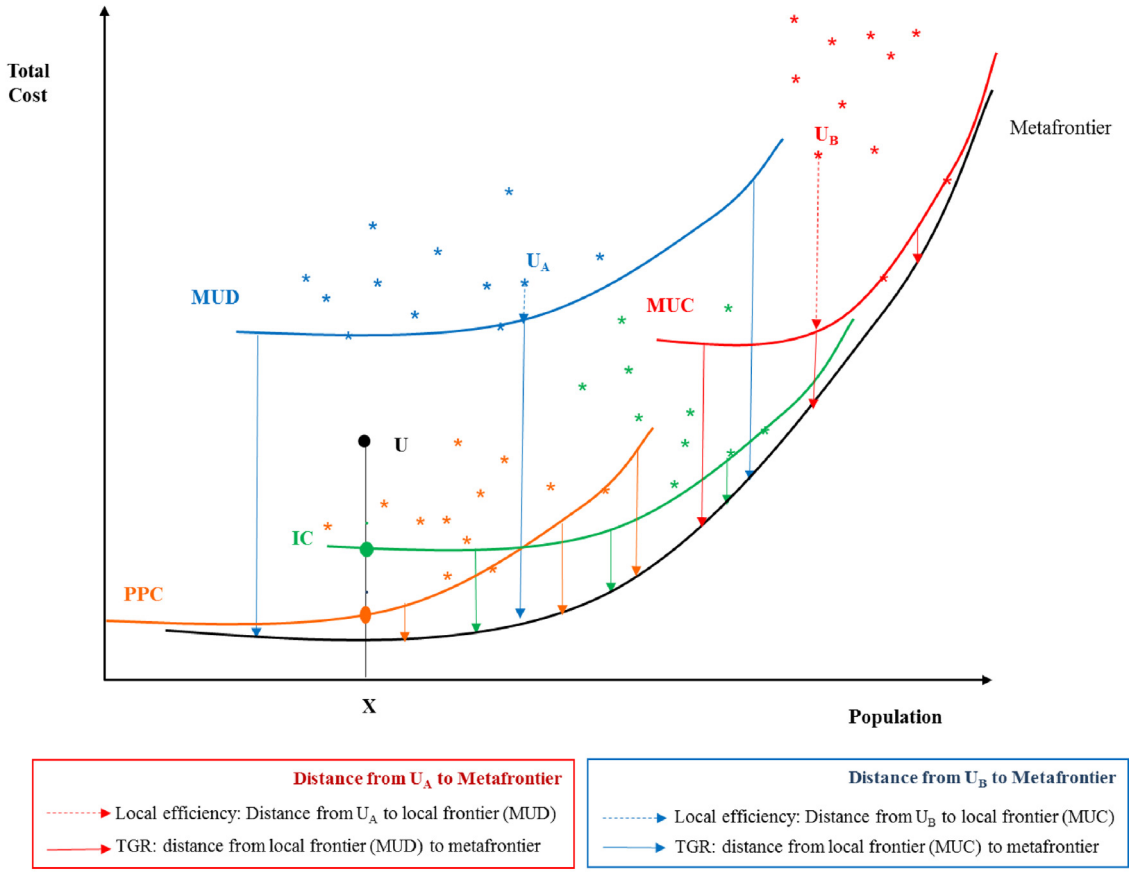
H_{2b}: *In smaller municipalities, private production with cooperation (PPC) provides higher levels of efficiency than intermunicipal cooperation (IC).*

H_{2c}: *In larger municipalities, municipal under contract (MUC) provides the highest levels of efficiency.*

Fig. 1 illustrates the relationships among the different hypotheses proposed in this study. The main objective of this paper is to contribute to the analysis of the cost efficiency of different alternatives for MSW service, and this is addressed by considering, first, the differences among the various alternatives, and then by observing which service delivery form obtains the best efficiency levels. Finally, we determine which form is most suitable taking into account the population size of the municipality.

3. Delivery forms and efficiency: the use of the metafrontier

To address the above hypotheses, we chose to apply the concept of metafrontier or frontier separation, developed by Battese and Rao (2002) and Battese et al. (2004), according to which the efficiency of decision making units (DMUs, in our study, municipalities) operating under a particular technology (or environmental factors) cannot be compared with that of other units operating under other technologies and/or other environmental factors (in our study, forms of service provision) (Beltrán-Esteve, Gómez-Limón, Picazo Tadeo, & Reig-Martínez, 2014; Cordero, Santín, & Simancas Rodríguez, 2015; De Witte & Marques, 2009). Previous studies have concluded that there are differences in efficiency levels between municipalities that use different operational designs (Balaguer-Coll et al., 2013; De Witte & Marques, 2009; Simões, Cruz, et al., 2012). Therefore, certain differences are intrinsic to each service delivery form and these differences make it difficult to compare the efficiency of individual service delivery of the MSW service from that obtained in cooperation with other municipalities. Similarly, it



Source: The authors

Fig. 2. Frontier separation and the metafrontier.

is very difficult to compare the results obtained from public versus private service delivery forms. To overcome this limitation, we apply the metafrontier concept. By means of this approach each municipality is evaluated in relation to those municipalities that apply the same service delivery form. As this delivery form is freely chosen by municipalities, each observation can be evaluated in relation to the overall best practice considering the different service delivery forms (De Witte & Marques, 2009), in order to compare the efficiency of each form of provision.

Fig. 2 shows an example of applying the concept of frontier separation for our study. It is apparent that when the metafrontier concept is applied, different efficiency frontiers are obtained for each of the delivery forms considered (local frontiers, CE^k). Thus, the cost efficiency values are estimated for each municipality corresponding to each local frontier, and hence the municipalities operating under the same delivery form will be comparable. In addition, a homogeneous frontier (metafrontier, CE) is obtained for all municipalities, without considering differences in delivery forms. The metafrontier can be considered an 'umbrella' term that includes the various frontiers of each technology (Rao, O'Donell, & Battese, 2003) and functions as a reference point to obtain the technology gap ratio (TGR^k) (Battese & Rao, 2002; Battese et al., 2004; O'Donnell, Rao, & Battese, 2008), i.e., the lowest possible cost for each DMU given a certain output.[1]

This figure shows that the municipalities corresponding to a particular delivery form may be more or less distant from their local frontier (CE^k); this factor determines the cost savings that units can achieve with respect to their own service delivery, that is, as a result of local efficiency. Additionally, local governments that deliver the service under a specific form may be more or less distant from the metafrontier (CE), which is captured by the technology gap ratio (TGR). By analysing this question, we can determine which service delivery form is closest to the metafrontier and is therefore most likely to reduce costs and raise levels of efficiency.

Thus, if unit U_A applies the municipal direct (MUD) service delivery form, the ratio that measures the distance from U_A to MUD reflects the cost efficiency within this group; similarly, the distance from MUD to the metafrontier determines the cost efficiency derived from membership of the MUD group (TGR^{MUD}). Together, these two distances represent the total distance to the metafrontier of unit U_A. On the other hand, unit U_B, despite its short distance from its local frontier (MUC) to the metafrontier, will find it more difficult to improve its position with respect to its local frontier (from U_B to MUC) than will unit U_A with respect to its own local frontier (MUD).[2] Accordingly, the inefficiency of unit U_B is mainly due to the internal government management of the service, and not to the service delivery form, as is the case of unit U_A, as other municipalities use this same service delivery form and achieve higher levels of efficiency through the same production process.

From the above information, it is possible to identify which service delivery form would be most suitable for each type of municipality, in order to achieve improvements in MSW service cost efficiency by changing the way in which the service is provided. Thus,

[1] For a given level of output, TGR is defined as the lowest possible cost of the metafrontier divided by the lowest total cost of the local frontier.

[2] Breaking down the overall efficiency value at the metafrontier as the product of the local efficiency ratio and the technology gap ratio reveals the efficiency derived from the municipal management (local efficiency) and that derived from the management form (TGR^k).

in Fig. 2 a municipality with X inhabitants which adopted intermunicipal cooperation (IC) would achieve better results if it switched to private production with cooperation (PPC). The local frontier for intermunicipal cooperation represents the minimum level of costs that municipalities could achieve by optimising their own service delivery, so that municipality U could achieve its minimum level of costs at U_{IC}, with the distance from U to U_{IC} representing the reduction in costs due to the improvement in internal management. However, if an alternative service delivery form were applied – in the case in question, PPC – the efficiency level corresponding to the frontier for this technology could be attained; in other words, costs could be reduced to U_{PPC} and efficiency substantially improved (from U_{IC} to U_{PPC}).

Several different techniques can be used to calculate these nonparametric frontiers. For metafrontier models, the method traditionally applied is that of DEA. However, this technique may not provide satisfactory results, due to its deterministic nature (De Witte & Marques, 2010) and to problems of dimensionality that can affect the results thus obtained (Balaguer-Coll et al., 2013; Simões, Cruz, et al., 2012). Specifically, by including all possible combinations of inputs and outputs, the estimates provided by DEA are extremely sensitive to the presence of outliers (Daouia & Simar, 2007). Moreover, this method assumes the absence of statistical errors (De Witte & Marques, 2010; Rogge & De Jaeger, 2013). As an alternative, which overcomes these limitations, the robust partial frontier approach allows us to consider observations beyond the efficiency frontier being estimated, which makes it a suitable technique to control for the possible presence of outliers (Simar & Wilson, 2008). Specifically, the order-m[3] frontier calculates the efficiency values of a unit by comparing it with a sub-sample of m pairs, unlike DEA, which compares a unit with the best one from the whole sample. So, to calculate the cost efficiency values, both at the metafrontier and at the local frontier, we propose to use the order-m frontier application[4] (Cazals et al., 2002; Daouia & Simar, 2007; Thiemea et al., 2016). This approach has been applied previously by (Simões, Carvalho, et al. 2012) to study the efficiency of the waste collection service in Portugal.

Finally, to complement the previous calculations and to further study the different levels of efficiency for each service delivery form, various statistical tests were applied: first, the Kruskal–Wallis test, to determine the existence of differences in the efficiency calculated for the different groups created (coincident with each of the local frontiers representing different service delivery forms). The Kruskal–Wallis test is a nonparametric method that does not assume a normal distribution of the variables analysed. It is used to determine whether two or more samples are independent (unrelated). However, this test does not quantify the differences between samples. For this reason, we also applied the Mann–Whitney U test, another nonparametric test, which examines the independence of two samples, with the null hypothesis that the difference between them is zero. Finally, we compared the distributions of the different groups using the Li test (Li, 1996), which measures the distance between two density functions through the integrated mean square error of the functions (Balaguer-Coll, Prior, & Tortosa-Ausina, 2010; Zafra-Gómez & Muñiz, 2010).

4. Measuring the practical efficiency of MSW service delivery forms in Spain

4.1. Data

In Spain, public services are provided by local governments, but specific requirements depend on the population of the municipality. In this respect, four different groups of services can be distinguished: those required in all municipalities, and those that are mandatory in municipalities with more than 5000 inhabitants, more than 20,000 inhabitants or more than 50,000 inhabitants (Balaguer-Coll et al., 2010, 2013; Benito et al., 2015). Among these categories, MSW collection and disposal is a local public service that all municipalities are required to provide.[5] However, the way in which this public service is provided is established by each municipality, which determines the management form it sees fit. The main service delivery forms in the provision of the MSW service are public management (directly provided by the municipality or by a public firm), private management (provision by a private firm) and intermunicipal cooperation (Bel et al., 2010, 2014; Zafra-Gómez et al., 2013). In this context, and in view of the various forms in which the MSW service can be provided in Spanish towns and cities, we analyse the following types of service delivery: direct provision by the municipality, municipal under contract, intermunicipal cooperation and cooperation with private production (Plata-Díaz et al., 2014; Warner & Bel, 2008).

To achieve the study goals, we examined a large database, and extracted the data for the period 2007–2010, with respect to 771[6] Spanish municipalities, each with a population of 1000–50,000.[7] These municipalities represent 37.32 percent of all Spanish municipalities in this population group, and the sample as a whole represents 22.23 percent of the municipalities within this population range.

Table 1 describes and states the source of the variables included in the calculation of cost efficiency for the MSW service. The corresponding descriptive statistics are given in Appendix B.

To analyse the efficiency of the MSW service according to the delivery form applied, the municipalities were classified into four categories, following Bel et al. (2014), Zafra-Gómez et al. (2013) and Plata-Díaz et al. (2014): municipal direct (MUD), municipal under contract (MUC), intermunicipal cooperation (IC) and private production with cooperation (PPC). To do so, the relevant information was obtained from the Virtual Office of Local Government Financial Coordination of the Ministry of Public Administration and the official provincial gazettes. Table 2 describes each of the categories.

[3] In addition to the order-m (Cazals et al., 2002), there is another robust partial frontier approach named order-α (Aragon et al., 2005). Considering the choice between them, Daouia and Simar (2007) observed that the main factor to be taken into account is the economic interpretation of the parameter (m – benchmarking the unit with the m best virtual competitors – and α – benchmarking with the level of output with a probability $(1-\alpha)\times 100\%$ of being dominated –), since both the order-m and the order-α frontiers obtain robust estimators of efficiency. However, it should be borne in mind that both estimators present certain disadvantages, while sharing some characteristics that differentiate them from the traditional nonparametric methods (DEA and FDH), namely that they are robust indicators both of dimensionality and of the presence of outliers and noise in the data (Matallín-Sáez et al., 2014). On the one hand, the order-α frontier can be "more robust to extremes when estimating the true full frontier" (Daouia & Gijbels, 2011) and its interpretation is easier than in the order-m estimator (Aragon et al., 2005). On the other hand, the order-m estimators are more statistically efficient when there is perturbation in the data, since in this context they remain more resistant to outliers than the order-α estimators (Daouia & Gijbels, 2011).

[4] See in Appendix A the description of the algorithm required to estimate the above-mentioned efficiency coefficients.

[5] This obligation is specified in Article 26 of Local Government Act 7/1985 of 2 April, as amended by Act 27/2013, of 27 December, on the rationalisation and sustainability of local government.

[6] The initial database for this study was composed of 771 Spanish municipalities, including those which during the analysis period changed the management form of the MSW service provided.

[7] Population data were obtained from the Statistical Yearbook published by La Caixa. This restriction with respect to the population size of the municipality arose from the non-availability of data for municipalities with fewer than 1000 inhabitants, and from a parallel absence of data on the MSW service (outputs) for municipalities with over 50,000 inhabitants.

Table 1
MSW service: inputs and outputs.

Variable	Definition	Source
Total cost[8]	Municipal budget expenditure, obtained from the functional budget classification, *Category 442 – MSW removal and street cleaning,* for each of the municipalities included in the sample. This classification has been used in several previous studies (Benito-López et al., 2011; Zafra-Gómez et al., 2013) for the years 2007, 2008 and 2009. Due to the implementation of a new classification system (O. EHA/3565/2008, of 3 December[9]), with respect to the year 2010 we used the equivalent, composed of *Category 162 – Waste collection, disposal and treatment* and *Category 163 – Street cleaning*.	Virtual Office of Local Government Financial Coordination of the Ministry of Public Administration and Treasury
MSW tonnes	Annual production of waste, in tonnes/year.	
MSW tonnes × quality	Annual production of waste, in tonnes/year, corrected by the index of service quality, which is an internal measure indicating the adequacy/inadequacy of the service provided, in terms of the availability and cleaning of the containers, and of the periodicity of the waste collection performed.	Survey of Local Infrastructure and Equipment (EIEL), from the Ministry of Public Administration's website
Containers	Number of containers available on public streets in the municipalities, for each type of MSW collection.	

Source: The authors, based on data supplied by the Virtual Office of Local Government FinancialCoordination and on the Survey of Local Infrastructure and Equipment.

4.2. Results

To test the hypotheses proposed, we estimated the cost efficiency scores for each municipality, both for the local frontier and for the metafrontier, and ascertained the technology gap ratio.[10] Although the order-*m* partial frontier technique detects outliers (Simões, Carvalho, et al., 2012), it was observed that certain mean efficiency values were very low, and so a sensitivity analysis of the results was also performed. To do so, the trimmean function was applied to 5 percent of the sample in order to conduct a more detailed analysis and to delete the outliers.

As explained in the methodology section, we must first ascertain that there are significant differences between different ways of managing the waste collection service, in order to compare the efficiency of these management forms. Accordingly, the Kruskal–Wallis test was applied, to determine whether the efficiency levels of the different categories of service delivery differed from each other, with the null hypothesis being that the median efficiency of the *k* groups was equal in every case. This test was applied to the

Table 2
Service delivery forms for the MSW.

Category	Concept
Municipal direct (MUD)	The service is managed by the municipality itself or through a public agency or public enterprise controlled by the municipality.
Municipal under contract (MUC)	Management is contracted out to a single private company.
Intermunicipal cooperation (IC)	Joint management by various municipalities, through a public entity created for this specific purpose (consortium or association) or through the transfer of management to a supra-local public entity (regional council).
Private production with cooperation (PPC)	Joint management among two or more municipalities, contracted out to a private company.

Source: The authors, based on Bel et al. (2014), Zafra-Gómez et al. (2013) and Plata-Díaz et al. (2014).

Table 3
Kruskal–Wallis test for the local frontier, by service delivery form and year.

	Service delivery forms: MUD–MUC–IC–PPC			
	2007	2008	2009	2010
Chi-squared	65.669	171.961	180.377	6.437
Degrees of freedom	3	3	3	3
p-value	0.0001	0.0001	0.0001	0.0922

Results obtained using Stata 12.
MUD: municipal direct; MUC: municipal under contract; IC: intermunicipal cooperation; PPC: private production with cooperation.

cost efficiency coefficients of the municipalities, for the local frontier (CE^k) (Table 3). Analysis of these results led us to reject the null hypothesis, at a significance level of 99 percent for every year considered, except for the year 2010, for which it was rejected at 90 percent significance. Thus, the cost efficiency of each of the categories considered varied from that of the others.

In the next phase of the analysis, the Mann–Whitney *U* test (also called the Wilcoxon–Mann–Whitney test) and the Li test were performed, because the Kruskal–Wallis test does not identify differences between the different categories. The results of these two tests (Appendix C) were very consistent, thus indicating the existence of differences between the efficiency levels of the different service delivery forms, with only two exceptions. Accordingly, we conclude that there are significant differences between different service delivery forms, and so the potential cost savings in providing the MSW service will depend on the form of service delivery adopted.

Having established the existence of differences in the efficiency levels of each service delivery form, we then analysed the results obtained for each one. To address the first hypothesis proposed, we analysed the mean values obtained for the technology gap ratio (TGR^k), which is calculated, for each municipality, as the ratio of the efficiency value at the metafrontier to the corresponding value at the local frontier. For values close to 1, the distance from the frontier of the specific service delivery form (local frontier) to the metafrontier is minimal, while values below 1 represent a greater distance between these frontiers.[11] Therefore, the service delivery form that is closest to the metafrontier will usually present the highest TGR.

Table 4 shows, for each year, the main results of the estimates of the order-*m* frontiers for each of the local frontiers (CE^k),

[8] The total cost of the waste collection service is composed of the capital and the operational costs of the service. In addition, the fees charged for the provision of the service must cover the total costs, i.e. no subsidy in this respect is received from other local government budget items.

[9] Ministerio de Economía y Hacienda, España. ORDEN EHA/3565/2008, de 3 de diciembre, por la que se aprueba la estructura de los presupuestos de las entidades locales. *Boletín Oficial del Estado*, 10 de diciembre de 2008, 297, 49,318–49,362.

[10] The estimation of cost efficiency was performed using R (R Development Core Team, 2011) and the FEAR package (Wilson, 2006).

[11] TGR greater than 1 is also obtained due to the presence of super-efficient units. This enables us to use an order-*m* approach and to select a single value of *m* to estimate both local boundaries and the metafrontier (Balaguer-Coll et al., 2013; Cordero et al., 2015), which each contain a different number of units, as explained in the Method section.

Table 4
Cost efficiency of delivery forms for the MSW service, each year.

Service delivery form		*N*	Mean	Minimum	Maximum	Eff. Obs[14]. (percent)
Year: 2007***						
MUD	CE	139	0.143	0.006	1.174	4
	CE^k	139	0.326	0.017	1.802	5
	TGR	139	0.399	0.011	1.401	
MUC	CE	249	0.136	0.005	1.386	3
	CE^k	249	0.222	0.016	1.946	5
	TGR	249	0.730	0.074	1.507	
IC	CE	223	0.256	0.005	8.373	1
	CE^k	223	0.302	0.015	3.396	4
	TGR	223	1.268	0.008	2.540	
PPC	CE	83	0.321	0.010	7.690	6
	CE^k	83	0.489	0.018	1.650	16
	TGR	83	0.602	0.015	4.659	
Year: 2008***						
MUD	CE	131	0.120	0.005	1.000	3
	CE^k	131	0.673	0.038	1.828	6
	TGR	131	0.167	0.015	1.002	
MUC	CE	260	0.131	0.005	1.523	2
	CE^k	260	0.236	0.014	1.924	6
	TGR	260	0.650	0.063	1.372	
IC	CE	219	0.247	0.007	3.876	0
	CE^k	219	0.276	0.007	1.682	4
	TGR	219	1.467	0.013	2.637	
PPC	CE	84	0.304	0.013	9.266	8
	CE^k	84	0.500	0.033	1.806	18
	TGR	84	0.464	0.013	5.129	
Year: 2009***						
MUD	CE	126	0.111	0.008	1.000	2
	CE^k	126	0.540	0.041	2.203	5
	TGR	126	0.152	0.013	1.054	
MUC	CE	273	0.104	0.003	1.340	1
	CE^k	273	0.171	0.011	1.132	4
	TGR	273	0.602	0.015	1.484	
IC	CE	205	0.206	0.009	4.047	0
	CE^k	205	0.228	0.001	1.716	3
	TGR	205	1.780	0.016	3.375	
PPC	CE	90	0.148	0.003	5.434	7
	CE^k	90	0.452	0.050	1.945	17
	TGR	90	0.172	0.003	2.795	
Year: 2010*						
MUD	CE	113	0.154	0.002	1.982	2
	CE^k	113	0.325	0.001	2.066	4
	TGR	113	0.868	0.027	2.982	
MUC	CE	290	0.181	0.000	4.583	1
	CE^k	290	0.283	0.001	5.510	3
	TGR	290	1.046	0.011	3.145	
IC	CE	202	0.140	0.001	2.041	0
	CE^k	202	0.297	0.001	1.592	2
	TGR	202	0.884	0.019	3.284	
PPC	CE	89	0.093	0.012	1.408	10
	CE^k	89	0.272	0.001	1.204	17
	TGR	89	0.595	0.017	3.256	

CE: metafrontier; CE^k: local frontier; TGR: technology gap ratio; MUD: municipal direct; MUC: municipal under contract; IC: intermunicipal cooperation; PPC: private production with cooperation.

* Results with mean independence of service delivery forms at 90 percent significance, according to the Kruskal–Wallis test.

** Results with mean independence of service delivery forms at 99 percent significance, according to the Kruskal–Wallis test.

representing different forms of MSW delivery, and the metafrontier (CE) and the technology gap ratio (TGR^k) for each delivery form. Initial analysis of the results for the metafrontier (CE) and the local frontiers (CE^k) shows that the average cost efficiency values are relatively low for all service delivery forms.[12] The percentage of efficient units (municipalities whose efficiency is equal to 1) is also low. However, application of the order-*m* frontiers allows us to obtain super-efficient units, as shown by the maximum values[13] (see Table 4), which are far removed from the minimum values, implying the existence of differences between municipalities that employ the same delivery form.

The highest TGR values were found for intermunicipal cooperation (IC) for the whole period considered, except for the year 2010,

[12] The values obtained might be explained in terms of the intrinsic characteristics of the provision of this service, which requires the presence of indivisible inputs (inputs which cannot be scaled down to produce a small quantity of output), such as vehicles and personnel, without which it would be impossible to provide the service.

[13] Unlike stochastic frontier analysis, according to which the metafrontier includes the most efficient points at each of the local frontiers (Battese & Rao, 2002), the metafrontier values obtained by applying order-*m* frontiers need not coincide with the most efficient values at each local frontier, and so there may be super-efficient points beyond the metafrontier and the local frontiers.

[14] The percentage of efficiency observations reflects the number of municipalities that make up the frontier for each service delivery form.

Table 5
TGR for each service delivery form, according to population size.

Size/year	1000 ≤ Population ≤ 5000				5001 ≤ Population ≤ 20,000				20,001 ≤ Population ≤ 50,000			
Service delivery form	2007***	2008***	2009***	2010*	2007***	2008***	2009***	2010*	2007***	2008***	2009***	2010*
MUD	D	D	D	B	C	D	C	C	C	C	C	B
MUC	C	C	C	C	B	B	B	A	A	A	A	C
IC	A	A	A	A	A	A	A	B	B	B	B	A
PPC	B	B	B	D	D	C	D	D	D	D	D	D

A: the highest technology gap ratio (TGR); D: the lowest technology gap ratio (TGR).
* Results with mean independence of service delivery forms at 90 percent significance according to the Kruskal–Wallis test (results for the test reported in Appendix E, Table E.1).
*** Results with mean independence of service delivery forms at 99 percent significance according to the Kruskal–Wallis test (results for the test reported in Appendix E, Table E.1).

when the highest TGR was obtained by municipal under contract (MUC), which in general terms is the service delivery form with the highest TGR after intermunicipal cooperation (IC). By contrast, when we determined which service delivery form was furthest from the metafrontier, we found that municipal direct (MUD) obtained the lowest mean TGR values in 2007, 2008, and 2009 while in 2010, the lowest mean TGR value corresponded to private production with cooperation (PPC). These results are also illustrated in the graphs included in Appendix D, to reflect the mean distance of each service delivery form from its local frontier to the metafrontier (TGR) for each year. In this case, in the blue-shaded area, it can be seen that, on average for all years observed, private production with cooperation (PPC) and municipal direct (MUD) are the least efficient service delivery forms (hence the area is lower), while intermunicipal cooperation (IC) is closest to the metafrontier, presenting the largest area.[15]

The TGR analysis, therefore, leads us to reject the hypothesis that contracting out produces higher levels of efficiency than public service delivery formulas (H_1), since the results show that intermunicipal cooperation (IC) was the most efficient formulation. In consequence, in analysing the efficiency of the MSW service, formulas other than public or private management should also be considered.

As the first hypothesis cannot be accepted, and in accordance with the study structure shown in Fig. 1, we now analyse which MSW service delivery form is most appropriate according to the population size of the municipality. The fact that previous studies have suggested that intermunicipal cooperation is more commonly adopted by smaller municipalities constitutes empirical evidence that this type of study is influenced by the population size. For this reason, we now test hypotheses H_{2a}, H_{2b} and H_{2c}; thus, Table 5 presents the TGR for each service delivery form, distinguishing three population tranches[16]: 1000–5000, 5001–20,000 and 20,001–50,000 inhabitants, ordered according to the mean value obtained. Thus, for each year, each service delivery form receives a grade from A to D, according to the average TGR value obtained (the numerical values are given in Appendix E, Table E.2).

In the case of the municipalities belonging to the first population tranche, the shortest distance between the local frontiers and the metafrontier is obtained by the formula of intermunicipal cooperation (IC). In addition, for this population tranche, the results suggest that the municipal direct (MUD) and municipality under contract (MUC) formulas are less suitable for MSW service delivery.

The same situation can be observed for municipalities with a population size of 5001–20,000, in which intermunicipal cooperation (IC) obtains better levels of cost efficiency. However, in this population tranche, the second most suitable delivery form is municipal under contract (MUC), which is the service delivery form that came closest to the metafrontier for the larger municipalities – with 20,001–50,000 inhabitants –, except in the year 2010. Finally, for municipalities of this population size, the formula that obtains the lowest level of efficiency is that of private production with cooperation (PPC).

In summary, these results show that the efficiency of each form of MSW service delivery depends on the size of the municipality in which it is applied. Although the intermunicipal cooperation (IC) formula is relatively good for all population sizes, for municipalities in the largest population tranche, municipal under contract (MUC) outperforms IC.

In this respect, and as suggested by Bel and Mur (2009), Zafra-Gómez et al. (2013) and Bel et al. (2014), smaller municipalities can obtain cost savings, and thus improve the efficiency of their MSW service delivery, when they adopt joint service delivery formulas, in accordance with hypothesis H_{2a}. Specifically, in the smaller municipalities (with up to 20,000 inhabitants), joint management is a highly recommended alternative to contracting out, as it provides higher levels of efficiency. In this regard, we hypothesised that smaller populations may achieve greater cost savings through a combination of joint management with contracting out, but the results obtained lead us to reject hypothesis H_{2b}. However, in contrast to previous studies, we found that in municipalities with the highest populations in our sample (20,001–50,000 inhabitants), contracting out the MSW service provides better levels of efficiency, and therefore the last hypothesis (H_{2c}) is accepted.

Hence, municipal size determines which service delivery form is the most appropriate, and therefore municipalities of a certain size can take advantage of the benefits offered by contracting out their MSW service.

5. Conclusions

This paper presents an analysis of the cost efficiency achieved by different forms of MSW service delivery. Research in this field has traditionally focused on the debate between public and private provision. However, recent studies have examined other options, one of which is intermunicipal cooperation. In the present study, therefore, the service delivery forms analysed are municipal direct, municipal under contract, intermunicipal cooperation and private production under contract.

To determine which service delivery form achieves the highest levels of MSW service cost efficiency, the concept of metafrontier (Battese & Rao, 2002; Battese et al., 2004) was applied to a

[15] Note that analyses of local efficiency and of metafrontier values reflect comparable results. With respect to the mean value of local frontiers, the municipalities with municipal direct provision (MUD) and private production with cooperation (PPC) are more efficient. However, in terms of mean metafrontier values, the intermunicipal cooperation (IC) is generally the most efficient delivery form.

[16] The study focused on municipalities with a population between 1000 and 50,000 inhabitants. The population tranches examined were adopted taking into account the requirements of Royal Decree Law 2/2004, of 5 March, approving the consolidated text of the Local Finance Regulating Act.

sample of 771 Spanish municipalities each with a population of 1000–50,000 inhabitants, for the period 2007–2010. The efficiency of each municipality was calculated according to the service delivery form adopted for its MSW service. In addition, we determined the cost efficiency that would be obtained if there were no service delivery form differences. Order-*m* frontiers were used to calculate cost efficiency coefficients, thus obtaining more robust results than is the case with other non-parametric techniques. Under this methodology, the efficiency of municipalities in different groups can be compared; hence, this study was performed taking into account the application of a particular management form, as well as the local population size.

The results obtained reveal significant differences between cost efficiency levels for the different forms of MSW service delivery. Corroborating previous studies (Bel et al., 2014; Bel & Mur, 2009; Zafra-Gómez et al., 2013), we found that, in general, intermunicipal cooperation is the most efficient service delivery form for the MSW service.

However, unlike these earlier studies, we found that the optimum service delivery form for this service depends on the size of the municipal population. Our results suggest that joint service delivery formulas are more appropriate in municipalities with a population of up to 20,000 but that the largest municipalities (over 20,000 inhabitants) should opt for contracting out. Thus, our findings suggest that private operators obtain higher levels of efficiency in MSW service delivery when the town reaches a certain population size.

The present study highlights the existence of cost differences arising from different approaches to managing MSW services and from population size. The latter factor is shown to be of particular importance in this analysis of cost efficiency, and so studies examining the relationship between cost efficiency and service delivery forms for the MSW service should take into account the size of the municipality.

As concerns the policy implications of the results obtained, we suggest that a key factor in determining how local public services, and particularly MSW collection and disposal, should be managed is the size of the municipality. In this regard, there has been a proliferation of formulas for joint provision in recent years, especially among smaller municipalities, with the idea of achieving cost savings by exploiting latent economies of scale (Warner, 2006; Warner & Hefetz, 2003; Zullo, 2009). In this respect, the results obtained by Marques, Kortt, and Dollery (2015) for municipalities in Tasmania (Australia) suggest that collaborative formulas improve the efficiency of public services by enabling resources to be shared among different services. The results obtained in the present study provide empirical evidence that smaller municipalities can indeed achieve better levels of cost efficiency when the service delivery form is shared, together with the resources and costs of the service.

On the other hand, it is important to note that our results also show that joint management formulas do not constitute an alternative to private management in larger municipalities, where outsourcing the MSW service clearly achieves greater cost savings. Thus, larger municipalities prove more attractive for private operators, which can achieve better results by taking advantage of economies of scale that are not available to small municipalities (Bel & Fageda, 2006, 2008; Mohr et al., 2010; Zafra-Gómez et al., 2013). However, as a future line of investigation, it would be useful to determine the optimal municipal size below which the joint provision of the MSW service should be considered.

Acknowledgements

This work was supported by the Spanish Ministry of Science and Education (ECO2013-48413-R), P11-SEJ-7700, from Proyectos de Excelencia de la Consejería de Innovación, Ciencia y Empresa, Junta de Andalucía (Spain) and the Fundación Centro de Estudios Andaluces, Junta de Andalucía (Spain) (PRY139/14).

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ejor.2016.05.034.

References

Aragon, Y., Daouia, A., & Thomas-Agnan, C. (2005). Nonparametric frontier estimation: a conditional quantile-based approach. *Econometric Theory, 21*, 358–389.
Balaguer-Coll, M. T., Prior, D., & Tortosa-Ausina, E. (2010). Decentralization and efficiency of local government. *The Annals of Regional Studies, 45*, 571–601.
Balaguer-Coll, M. T., Prior, D., & Tortosa-Ausina, E. (2013). Output complexity, environmental conditions, and the efficiency of municipalities. *Journal of Productivity Analysis, 39*(3), 303–324.
Battese, G. E., & Rao, D. (2002). Technology gap, efficiency, and a stochastic metafrontier function. *International Journal of Business and Economics, 1*(2), 87–93.
Battese, G. E., Rao, D., & O'Donnell, C. J. (2004). A metafrontier production function for estimation of technical efficiencies and technology gaps for firms operating under different technologies. *Journal of Productivity Analysis, 21*(1), 91–103.
Bel, G., & Fageda, X. (2006). Between privatization and intermunicipal cooperation: Small municipalities, scale economies and transaction costs. *Urban Public Economics Review, 006*, 13–31.
Bel, G., & Fageda, X. (2008). Reforming the local public sector: Economics and politics in privatization of water and solid waste. *Journal of Economic Policy Reform, 11*(1), 45–65.
Bel, G., & Fageda, X. (2009). Factors explaining local privatization: A meta-regression analysis. *Public Choice, 139*(1), 105–119.
Bel, G., & Fageda, X. (2010). Empirical analysis of solid management waste costs: Some evidence from Galicia, Spain. *Resources, Conservation and Recycling, 54*(3), 187–193.
Bel, G., Fageda, X., Dijkgraaf, E., & Gradus, R. (2010). Similar problems, different solutions: Comparing refuse collection in the Netherlands and Spain. *Public Administration, 88*(2), 479–495.
Bel, G., Fageda, X., & Mur, M. (2014). Does cooperation reduce service delivery costs? Evidence from residential solid waste services. *Journal of Public Administration Research and Theory, 24*(1), 85–107.
Bel, G., & Mur, M. (2009). Intermunicipal cooperation, privatization and waste management costs: Evidence from rural municipalities. *Waste Management (New York, N.Y.), 29*(10), 2772–2778.
Bel, G., & Warner, M. E. (2008). Does privatization of solid waste and water services reduce costs? A review of empirical studies. *Resources, Conservation and Recycling, 52*(12), 1337–1348.
Bel, G., & Warner, M. E. (2010). Is private production of public services cheaper than public production? A meta-regression analysis of solid waste and water service. *Journal of Policy Analysis and Management, 29*(3), 553–577.
Beltrán-Esteve, M., Gómez-Limón, J. A., Picazo Tadeo, A. J., & Reig–Martínez, E. (2014). A metafrontier directional distance function approach to assessing eco-efficiency. *Journal of Productivity Analysis, 41*, 69–83.
Benito, B., Guillamón, M. D., & Bastida, F. (2015). Public versus private in municipal services management. *Lex Localis - Journal of Local Self-Government, 13*(4), 995–1018.
Benito-López, B., Moreno-Enguix, M. R., & Solana-Ibañez, J. (2011). Determinants of efficiency in the provision of municipal street-cleaning and refuse collection services. *Waste Management (New York, N.Y.), 31*(6), 1099–1108.
Benito, B., Solana, J., & Moreno, M. R. (2014). Explaining efficiency in municipal services providers. *Journal of Productivity Analysis, 42*, 225–239.
Carvalho, P., & Marques, R. C. (2014). Economies of size and density in municipal solid waste recycling in Portugal. *Waste Management, 34*(1), 12–20.
Cazals, C., Florens, J. P., & Simar, L. (2002). Nonparametric frontier estimation: A robust approach. *Journal of Econometrics, 106*, 1–25.
Cordero, J. M., Santín, D., & Simancas Rodríguez, R. (2015). Assessing European primary school performance through a conditional nonparametric model. *Journal of the Operational Research Society*. doi:10.1057/jors.2015.42.
Cruz, N. F., Simões, P., & Marques, R. C. (2013). The hurdles of local governments with PPP contracts in the waste sector. *Environment and Planning C: Government and Policy, 31*(2), 292–307.
Daouia, A., & Simar, L. (2007). Nonparametric efficiency analysis: A multivariate conditional quantile approach. *Journal of Econometrics, 140*(2), 375–400.
Daouia, A., & Gijbels, I. (2011). Robustness and inference in nonparametric partial frontier modeling. *Journal of Econometrics, 161*(2), 147–165.
De Jaeger, S., & Rogge, N. (2013). Waste pricing policies and cost-efficiency in municipal waste services: The case of Flanders. *Waste Management & Research: The Journal of the International Solid Waste and Public Cleansing Association, ISWA, 31*(7), 751–758.
De Witte, K., & Marques, R. C. (2009). Capturing the environment, a metafrontier approach to the drinking water sector. *International Transactions in Operational Research, 16*, 257–271.

De Witte, K., & Marques, R. C. (2010). Influential observations in frontier models, a robust non-oriented approach to the water sector. *Annals of Operations Research, 181*(1), 377–392.
Dijkgraaf, E., & Gradus, R. H. J. M. (2003). Cost savings of contracting out refuse collection. *Empirica, 30*, 149–161.
Dijkgraaf, E., & Gradus, R. H. J. M. (2013). Cost advantage cooperations larger than private waste collectors. *Applied Economics Letters, 20*(7), 702–705.
Donahue, J. D. (1989). *The privatization decision: Public ends, private means*. New York: Basic Books.
Geys, B., & Moesen, W. (2009). Exploring sources of local government technical inefficiency: Evidence from Flemish municipalities. *Public Finance & Management, 9*(1), 1–29.
Girth, A. M., Hefetz, A., Johnston, J. M., & Warner, M. E. (2012). Outsourcing public service delivery: Management responses in noncompetitive markets. *Public Administration Review, 72*(6), 887–900.
González-Gómez, F., Picazo-Tadeo, A. J., & Guardiola, J. (2011). Why do local governments privatize the provision of water services? Empirical evidence from Spain. *Public Administration, 89*(2), 471–492.
Hefetz, A., & Warner, M. E. (2012). Contracting or public delivery? The importance of service, market, and management characteristics. *Journal of Public Administration Research and Theory, 22*(2), 289–317.
Jacobsen, R., Buysse, J., & Gellynck, X. (2013). Cost comparison between private and public collection of residual household waste: Multiple case studies in the Flemish region of Belgium. *Waste Management (New York, N.Y.), 33*(1), 3–11.
Larrán-Jorge, M., & García-Correas, A. (2015). ¿Influyen los modelos de financiación autonómicos en la eficiencia de las universidades públicas españolas. *Revista de Contabilidad Spanish Accounting Review, 18*(2), 162–173.
Li, Q. (1996). Nonparametric testing of closeness between two unknown distribution functions. *Econometric Reviews, 15*(3), 261–274.
Mañez, J., Pérez-López, G., Prior, D., & Zafra-Gómez, J. L. (2016). Understanding the Dynamic Effect of Contracting Out on the Delivery of Local Public Services. *Regional Studies*. doi:10.1080/00343404.2015.1090561.
Marques, R. C., Kortt, M. A., & Dollery, B. (2015). Determining the optimal size of local government: The case of Tasmanian councils. *Australian Journal of Public Administration, 74*(2), 212–226.
Matallín-Sáez, J. C., Soler-Domínguez, A., & Tortosa-Ausina, E. (2014). On the informativeness of persistence for evaluating mutual fund performance using partial frontiers. *Omega, 42*(1), 47–64.
Mohr, R., Deller, S. C., & Halstead, J. M. (2010). Alternative methods of service delivery in small and rural municipalities. *Public Administration Review, 70*(6), 894–905.
Nogueira, S. P. S., & Jorge, S. M. F. (2015). Explanatory factors for the use of the financial report in decision-making: Evidence from Local Government in Portugal. *Revista de Contabilidad - Spanish Accounting Review*. doi:10.1016/j.rcsar.2015.09.002.
O'Donnell, C. J., Rao, D. S., & Battese, G. E. (2008). Metafrontier frameworks for the study of firm-level efficiencies and technology ratios. *Empirical Economics, 34*, 231–255.
Ohlsson, H. (2003). Ownership and production costs. Choosing between public production and contracting-out in the case of Swedish refuse collection. *Fiscal Studies, 24*(4), 451–476.
Plata-Díaz, A. M., Zafra-Gómez, J. L., Pérez-López, G., & López-Hernández, A. M. (2014). Alternative management structures for municipal waste collection services: The influence of economic and political factors. *Waste Management, 34*(11), 1967–1976.
R Development Core Team. (2011). *R:* A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria: School of Economics, University of Queensland http://www.R-project.org/.
Rao, D.S.P., O'Donell, C.J., & Battese, G.E., (2003). *Metafrontier functions for the study of inter-regional productivity differences* (CEPA Working Paper No. 01/2003). Australia.
Reeves, E., & Barrow, M. (2000). The impact of contracting-out on the costs of refuse collection services. The case of Ireland. *Economic and Social Review, 31*(2), 129–150.
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.
Simar, L., & Wilson, P. W. (2008). Statistical inference in nonparametric frontier models: Recent developments and perspectives. In H. O. Fried, C. A. K. Lovell, & S. S. Schmidt (Eds.), *The measurement of productive efficiency and productivity growth* (pp. 421–521). Oxford: Oxford University Press.
Simões, P., Carvalho, P., & Marques, R. C. (2012). Performance assessment of refuse collection services using robust efficiency measures. *Resources, Conservation & Recycling, 67*(10), 56–66.
Simões, P., Cruz, N. F., & Marques, R. C. (2012). The performance of private partners in the waste sector. *Journal of Cleaner Production, 29–30*, 214–221.
Simões, P., De Witte, K., & Marques, R. C. (2010). Regulatory structures and the operational environment in the Portuguese solid waste sector. *Waste Management, 30*(6), 1130–1137.
Simões, P., & Marques, R. C. (2012). On the economic performance of the waste sector. A literature review.. *Journal of Environmental Management, 106*, 40–47.
Simões, P., & Marques, R. C. (2012). Influence of regulation on the productivity of waste utilities. What can we learn with the Portuguese experience? *Waste Management, 32*(6), 1266–1275.
Stevens, B. J. (1978). Scale, market structure, and the cost of refuse collection. *Review of Economics and Statistics, 60*(3), 438–448.
Thiemea, C., Prior, D., Tortosa-Ausina, E., & Gemppa, R. (2016). Value added, educational accountability approaches and their effects on schools' rankings: Evidence from Chile. *European Journal of Operational Research, 253*, 456–471.
Warner, M. E. (2006). Market-based governance and the challenge for rural governments: US trends. *Social Policy and Administration: An International Journal of Policy Research, 40*(6), 612–631.
Warner, M. E. (2012). Privatization and urban governance: The continuing challenges of efficiency, voice and integration. *Cities, 29*, S38–S43.
Warner, M. E., & Bel, G. (2008). Competition or monopoly? Comparing privatization of local public services in the U.S. and Spain. *Public Administration, 86*(3), 723–735.
Warner, M. E., & Hebdon, R. (2001). Local government restructuring: Privatization and its alternatives. *Journal of Policy Analysis and Management, 20*, 315–336.
Warner, M. E., & Hefetz, A. (2003). Rural-urban differences in privatization: Limits to the competitive state. *Environment and Planning C: Government and Policy, 21*, 703–718.
Wassenaar, M. C., Dijkgraaf, E., & Gradus, R. H. J. M. (2010). Contracting out: Dutch municipalities reject the solution for the VAT distortion. *Local Government Studies, 36*(5), 617–636.
Wilson, P. (2006). *FEAR: Frontier efficiency analysis with R*. US: University of Clemson.
Zafra-Gómez, J. L., López-Hernández, A. M., Plata-Díaz, A. M., & Garrido-Rodríguez, J. C. (2016). Financial and Political Factors Motivating the Privatisation of Municipal Water Services, *42*(2), 287–308.
Zafra-Gómez, J. L., & Muñiz, M. A. (2010). Overcoming cost-inefficiencies within small municipalities: Improve financial condition or reduce the quality of public services? *Environment and Planning C: Government and Policy, 28*, 609–629.
Zafra-Gómez, J. L., Prior, D., Plata-Díaz, A. M., & López-Hernández, A. M. (2013). Reducing costs in times of crisis: Delivery forms in small and medium sized local governments' waste management services. *Public Administration, 91*(1), 51–68.
Zullo, R. (2009). Does fiscal stress induce privatization? Correlates of private and intermunicipal contracting, 1992–2002. *Governance, 22*(3), 459–481.