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Evaluating joint environmental and cost performance in municipal waste management systems through data envelopment analysis: Scale effects and policy implications☆

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ABSTRACT

The widespread need to reduce public expenditure and meet the targets for separate collection established by current national and European legislation requires regulatory authorities to reorganize their municipal waste management systems to improve both their economic and environmental performance. This process can be helped to a great extent by the availability of empirical measures of comparative efficiency. Adding to the literature that evaluates this through data envelopment analysis (DEA) – usually focused on economic (cost) efficiency alone – this article proposes a joint evaluation of the two aspects through a modified DEA model that includes unsorted waste as an undesired output to be minimized. The article also provides an application using data for 289 municipalities located in an Italian region, Abruzzo, for the period 2011–2013. The main focus of the empirical analysis is on dimensional aspects. In particular, comparing the results obtained through DEA models based on different hypotheses concerning returns to scale, in the first place it is verified whether a particular municipal dimension emerges as an efficient benchmark, and secondly if waste collection is organized above or below its optimal scale in the municipalities taken into consideration. Tobit and probit regression models are then applied to some of the results to isolate the influence of territorial specificities on different kinds of scale inefficiencies. The information obtained allows to shed light on the usefulness of designing multi-municipal optimal territorial areas (OTAs) to improve the joint benefits of environmental and cost efficiency in waste collection, and to understand which variables the regulator should preferably take into account in the process.

1. Introduction

During the last two decades, almost every municipality throughout the European Union has suffered from severe budgetary constraints, with the prospect of progressive shrinkage in the resources available in the near future (Zafra-Gómez et al., 2013). It is therefore not surprising that the organization and economic performance of municipal waste management systems (MWMSs),[1] which are commonly responsible for a significant share of local governments' total expenditure, have become a crucial issue for local policymakers. Research on organizational and technical strategies aimed at improving their economic efficiency has increased exponentially (Simões and Marques, 2012), so that an extensive literature is now available.

A relevant proportion of this literature is composed of benchmarking studies, the final purpose of which is to identify and describe best practices. Data envelopment analysis (DEA) is the most widely applied method in this field (Thanassoulis, 2001). It provides a measure of the relative efficiency of a set of homogeneous decision-making units (DMUs), which use multiple inputs

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[1] For convenience, a list of the acronyms and abbreviations used in the text is provided in Appendix B.

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to produce multiple outputs when no exact knowledge about the functional form of the production or cost function is available (*non-parametric method*). Less frequently, other non-parametric methods have been used, such as the free disposal hull (FDH) approach, as well as parametric methods (requiring a preliminary specification of the functional form of the production frontier), such as stochastic frontier analysis (SFA) and deterministic frontier analysis (DFA) (see Appendix A).

Early applications of these methods in waste management go back to Bosch et al. (2000), who investigate the relation between technical efficiency and the public or private management of collection services, and to Worthington and Dollery (2001), who measure pure technical efficiency and scale efficiency in separate collections at the municipal level. The former use both parametric models (DFA and SFA) and non-parametric models: two input-oriented DEA models with variable returns to scale (VRS), the first with exogenous variables and the second without them, as well as the FDH approach. The latter implement an output-oriented DEA model with constant returns to scale (CRS) and VRS.

Given the considerable role of non-discretionary inputs or exogenous variables in the assessment of technical and scale efficiency, an intense debate has developed in the literature concerning the most appropriate econometric tools to be used in association with DEA (Liu et al., 2016). The main options under discussion are the maximum likelihood estimation of a truncated regression (Simar and Wilson, 2007), the OLS regression model (McDonald, 2009), and the fractional regression model (Ramalho et al., 2010). Banker and Natarajan (2008) show also that the tobit model and OLS are suited to this context and that their application gives quite similar results.

In the specific field of waste services, the tobit model has mainly been applied. For example, Moore et al. (2001) and Segal et al. (2002) focus on urban municipalities in the United States, while Marques and Simões (2009) focus on waste service operators. In these papers, the results of CRS and VRS input-oriented DEA are compared, and then the scores obtained by each DMU are regressed through the model on different sets of exogenous (external) factors. A similar approach is used by Boetti et al. (2012), aiming to assess whether the inefficiency of local governments in a wide range of municipal services (including environmental management) is affected by the degree of vertical fiscal imbalance. To this end, the tobit model is applied to efficiency scores computed by applying an input-oriented DEA model with VRS and SFA. A slightly modified approach can be found in the methodological contribution of Rogge and De Jaeger (2013), which proposes the use of an adjusted version of the DEA model (shared inputs DEA) for evaluating the cost efficiency of waste collection at the municipal level, together with the usual tobit model to take account of exogenous variables.

A more recent strand of literature has addressed the same problem through multi-stage or mixed DEA approaches. García-Sánchez (2008) uses a four-stage approach by applying two models with VRS (input-oriented and output-oriented), and two with CRS to assess both technical and scale efficiency in the provision of street cleaning and waste collection, while Simões et al. (2010) apply a non-parametric double bootstrap model to estimate the effect of various explanatory factors on the efficiency scores obtained by urban waste utilities. Simões et al. (2012a) use the traditional DEA method, bootstrap DEA, and Törnqvist and Malmquist productivity indexes to determine the efficiency of waste collection services and the productivity of waste treatment services provided by urban waste utilities, and to identify critical determinants of efficiency at the municipal level. Finally, Simões et al. (2012b) evaluate the performance of 196 municipal waste collection services in Portugal by applying a DEA model, and to provide robustness to their evaluation, they make use of bootstrapping and the order-m method.

All the above studies focus solely on the economic (cost) dimension of MWMS performance. However, the rapid worsening of the conditions of sustainability of urban systems in the last few years, and the need to find satisfactory solutions to ecological waste disposal, have made it clear that the organization of MWMSs should also be functional in terms of the achievement of environmental goals, even if this implies higher costs in the organization of their services.

With a view to attaining this, extensive and articulate regulation has been adopted throughout the European Union, determining different results at the national and regional levels (Rogge and De Jaeger, 2013). European Directive 2008/98/CE has provided detailed guidelines for MWMSs, setting specific targets for the process of the preparation of waste for reuse and recycling.[2] To this European framework, national disciplinary measures are to be added (some of which are even pre-existing). In Italy, for example, Legislative Decree no. 152/2006 (the so-called *Environmental Code*), sets targets at the local level in terms of separate collection,[3] integrating the European legislation and contributing to the rigid configuration now assumed by the sector. Moreover, further regulation is often adopted at the local level to establish certain organizational and territorially sensitive aspects of the services (geographical context, private or public nature of the operator entrusted with the service, operating procedures for the collection activity, if and when the responsibility for the collection of some materials lies with the municipality, etc.).

One of the inspiring principles of this articulate framework is that achieving the target levels set for separate collection should be a prerequisite for the evaluation of efficiency. Unfortunately, the performance of MWMSs varies widely, even under this specific perspective. In Italy, for example, given the tight budgetary constraints to which most municipalities are subject, many of them have been unable to invest the resources needed to obtain improved results; when this has not been the case, different strategies (public ownership, private ownership, public–private partnership) and operational solutions (door to door or proximity collections, etc.) have been adopted according to the financial resources available at the local level and local political priorities. Thus, substantial differences can be observed both in the amount of separate collections attained by each municipality and in the total expenditure.

In such a situation, a comparison between MWMSs based on cost efficiency alone can be misleading, and to support effective decision making and correctly identify best practices, joint assessment of cost and environmental performance is desirable, if not essential. Despite the crucial relevance of such an approach, the available literature tends to confront one issue at a time, with only a few exceptions that mainly use multi-criteria analysis (Bonoli et al., 2015).

To the best of our knowledge, DEA models have never been employed for this purpose. This is the reason why in this paper a proposal is presented to integrate both economic and environmental factors within a DEA framework for the evaluation of MWMSs.

[2] By 2020, preparation for the reuse and recycling of waste materials of at least paper, metal, plastic, and glass from households, and possibly from other origins to the extent that these waste streams are similar to waste from households, is to be increased to a minimum of 50% overall by weight. Again, by 2020, preparation for reuse, recycling, and other material recovery, including backfilling operations using waste to substitute other materials, of non-hazardous construction and demolition waste, excluding naturally occurring material defined in category 17 05 04 in the list of waste, is to be increased to a minimum of 70% by weight. Furthermore, art. 11, no. 1 of the cited Directive states that "Member States shall take measures to promote high quality recycling and, to this end, shall set up separate collections of waste where technically, environmentally and economically practicable and appropriate to meet the necessary quality standards for the relevant recycling sectors."

[3] According to Legislative Decree no. 152/2006, separate collection at the local level should have reached 65% by the end of 2012.

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