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Abstract

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Keywords	Benefit of the Doubt; Composite indicators; Conditional efficiency; Spatial heterogeneity; Directional distance function; Undesirable outputs; Municipal Solid Waste
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Reviewer 1
I appreciate the efforts of author(s) to improve the paper according to suggestions and comments. I have only one remaining comment for the completeness of references regarding the BoD's methodology and author(s) developments in section 3. Please consider citing Aparicio and Kapelko (2019) – BoD model with undesirable factors.

Aparicio, J., Kapelko, M. (2019). Enhancing the measurement of composite indicators of Corporate Social Performance. Social Indicators Research, forthcoming https://doi.org/10.1007/s11205-018-02052-1

The reference has been updated. Thanks.

- Robust directional model in the case of undesirable outputs
- Integrating the spatial dependence into the composite indicator method
- Italian municipal solid waste collection and processing sector
- Local constraints evidences linked to facilities planned by higher level Authorities

Spatial directional robust Benefit of the Doubt approach in presence of undesirable output: an application to Italian waste sector

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Keywords: Benefit of the Doubt, Composite indicators, Conditional efficiency, Spatial heterogeneity, Directional distance function, Undesirable outputs, Municipal Solid Waste

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This paper introduces a new composite indicator method integrating the spatial dependence into the robust directional model in the case of undesirable outputs. The proposed approach is advantageous compared to the traditional and conditional robust Benefit-of-the-Doubt (BoD) models in that it allows to compare the performance of individual units with local cluster of peers. The methodology has been tested on a very detailed database of Italian municipalities for the year 2015 in the municipal solid waste collection and processing sector and confirms the existence of strong local constraints linked to the disposal facilities planned by higher level Authorities.

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1. Introduction

In recent decades, within the rules and constraints of the European Community, public accounting and auditing systems have rapidly evolved from purely accounting-administrative systems to governance systems that permit to evaluate public actions and services more effectively. Particularly in the context of limited public resources, the real challenge for public authorities at different levels is to build systems of expenditure equalisation and accounting control allowing public service

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levels to be kept as unchanged as possible, minimizing - at the same time - expenditure overruns due to inefficiency, incorrect allocations of production factors or chronic misalignment in the optimal size of local authorities. Therefore, the focus is increasingly on evaluating and monitoring the efficiency and effectiveness of actions and services provided by public authorities. In addition, in many European countries, there is the increasing shift towards more institutional decentralisation with greater financial autonomy for local public authorities (Boadway, 2004), the transfer of resources from richer regions and municipalities to more poor and disadvantaged ones. As a result, institutional decentralisation has enhanced horizontal equalisation systems in order to compensate territorial imbalances and favour a greater "*territorial equity*" (Buchanan, 1950). Given these premises, performance evaluations of local authorities entail a crucial task in order to enhance (cost or production) efficiency and equity especially given that local public authorities produce desirable and undesirable outputs in their pursuit of multiple policy objectives in heterogeneous contexts, subject to specific institutional and administrative constraints and bounded by predetermined local preferences (Hamilton et al., 2013).

An increasing number of studies evaluate the performances of public authorities at different levels (central, regional, local) by constructing composite indicators (CIs). Several of the recent studies employed non-parametric techniques inspired by the Data Envelopment Analysis (DEA) of Charnes et al., 1978. The key notion of this DEA-method is to evaluate the performance of public authorities by comparing and benchmark the provided public services and actions of these authorities to the performances of some attainable medium/long-term objectives. In the measurement and evaluation of the performances of public authorities, an important issue consists in correcting for the impact of the operating environment, factors like supply constraints, local preferences and external tangible and intangible (Vidoli et al., 2016) contextual variables. Neglecting this issues, as in the basic DEA-model which presumes that all public authorities are homogeneous in the sense that they perform similar activities under comparable operating circumstances, would mean to systematically benefit (or disadvantage) the performance evaluation of some public authorities as compared to the evaluations of other public authorities. A valid solution is the conditioning of the composite performance scores with respect to a set of exogenous variables, even if - *in our opinion* - the relationships between efficiency and environmental variables do not remain spatially constant especially when the estimation is carried out at a very detailed scale.

To measure the performance of local public authorities more accurately, the present paper advocates to correct for spatial proximity as a proxy of the contextual variables and constraints: in other terms - in the proposed DEA-framework and, more specifically, in its related Benefit-of-the-Doubt (BoD) framework for constructing composite indicators for policy performance evaluation - it is no longer necessary to include in the model all the local factors that impact the public authorities' performance; the idea is that neighbouring units, in fact, are subjected to the same external conditions. More in particular, the main objective of the present paper is to introduce a new class of composite indicators - named Spatial directional Robust BoD-based CIs[1]. The reason for introducing the correction for spatial dependence in a directional version of the BoD-model is that, in practice, more often than not, local authorities produce desirable and undesirable outputs. As such, a comprehensive performance evaluation of local authorities requires considering a mixture of both desirable and undesirable performance criteria. However, one basic assumption of the standard BoD-model is that all performance criteria are desirable in the sense that higher values indicate better policy performances. The directional distance version of the BoD-model does enable to include both desirable and undesirable outputs in the performance evaluation of local authorities.

This new extension of the BoD-method is applied to evaluate and analyse the (cost)-efficiency of Municipal Solid Waste (MSW) collection and processing sector, in Italy for the year 2015, being one of the most important sectors for Italian municipalities from a financial point of view (average expenditure: 164€ per capita per year, year 2014), involving both desirable and undesirable performance criteria and being characterised by an heterogeneous policy behaviour in the collection, treatment and/or disposal of MSW along the Italian territory.

The remainder of the paper is structured as follows. Section 2 presents a brief review of the non-parametric frontier models for constructing multidimensional efficiency/performance measures, focusing on the specific characteristics of the waste sector (subsection 2.1) and on the operating environment and contextual characteristics that can have a significant effect on the municipalities performance (subsection 2.2). Section 3 presents the conditional and spatial conditional directional distance DEA-model aiming attention at the recent methodological extensions such as robust models, direction distance models, spatial models and conditional models. Section 4 discusses on the main features of the Italian MSW sector - *i.e.* the regulatory and administrative framework in which individual municipalities have to operate and manage the MSW activities - and the data (subsection 4.2) and the strategy of the analysis (subsection 4.3) are presented. In Section 5 results are re-

[1] Benefit of the Doubt (BoD) is a particular technique derived from the non-parametric DEA model.

ported. Finally, Section 6 summarises the main finding of the paper and proposes some concluding remarks and possible directions for future research.

2. Literature

2.1. Benchmarking in the waste sector

The crescendo of policy focus on organising and providing public services efficiently has led to heightened awareness in academic circles and a growing number of efficiency measurement and benchmarking studies. Broadly speaking, two streams of efficiency measurement techniques have been used: parametric techniques and non-parametric techniques. Key difference between both frameworks is that parametric efficiency measurement techniques such as Stochastic Frontier Analysis (SFA) (Meeusen and van Den Broeck, 1977; Aigner et al., 1977) presume a "functional form" that corresponds to the production or cost function. Non-parametric techniques such as the DEA-model do not impose a priori assumptions on the functional form of the production or cost function. Instead, these techniques determine the efficiency of each Decision Making Unit (DMU) endogenously, *i.e.* by putting the observed input and output data in relative perspective to the input and output data of the other DMUs, thereby looking for the input and output weights that maximize the relative efficiency score. This feature of DEA is particularly appealing in operational settings that are often characterised by no information (or at least no detailed or reliable information) on input and output prices and/or the "functional form" that corresponds to the production or cost function.[2] A second difference is that DEA enables to consider multiple inputs and multiple outputs in the measurement of the efficiency.[3]

The majority of the studies measuring the efficiency of national, regional and local public environmental authorities in the organisation and/or provision of public services are of the DEA-type. For Italy, for instance, DEA-based benchmarking and efficiency measurement techniques have been applied in a broad range of policy areas: (higher) education (*e.g.*, Agasisti and Salerno, 2007; Agasisti, 2013; Sibiano and Agasisti, 2013), water management (Guerrini et al., 2013; Romano and Guerrini, 2011), and transportation (Piacenza, 2006). Benchmarking efficiency studies, that evaluate the efficiency of Municipalities and Regions in Italy in the overall

[2]The economic meaning of Data Envelopment Analysis (and related techniques) has been discussed in several papers. We refer the interested reader to, amongst others, Cherchye et al. (2000) and Cherchye et al. (2014).

[3]For more on the comparison between DEA and SFA, see *e.g.* Hjalmarsson et al. (1996).

provision of public services, include Afonso and Scaglioni (2005), Agasisti et al., 2016 and Lo Storto (2013). DEA-based efficiency studies on the waste sector in other countries are Worthington and Dollery (2001) for New South Wales; Cubbin et al. (1987) for the UK; Simões and Marques (2012a), Marques and Simões (2009), Simões et al. (2012), Simões and Marques, 2012b and Simões et al. (2010) for Portugal; Rogge and De Jaeger (2013), Rogge and De Jaeger (2012), De Jaeger et al. (2011), De Jaeger and Rogge (2013) and De Jaeger and Rogge (2014) for Belgium (*i.e.*, Flanders); García-Sánchez (2008), Benito-López et al. (2011), Perez-Lopez et al. (2018), Plata-Diaz et al. (2014), Zafra et al. (2013), and Pérez-López et al. (2016) for Spain; and Chen and Chen (2012) and Chen et al. (2010) for Taiwan. The majority of the (benchmarking) exercises, assessing policy performance in municipal waste and materials' management, focus on municipalities. The selection of the inputs and the outputs in these studies depends on the exact efficiency concept under consideration. For instance, studies aiming at measuring technical efficiency typically include measures of physical inputs (*e.g.*, number of garbage trucks, number of FTE workers) whereas studies assessing cost efficiency consider as inputs the costs incurred for organising and/or providing the MSW services. Outputs are usually expressed in the amount of waste collected and/or processed. A recurrent finding in these studies is that there is room for efficiency improvement in the waste sector with some public authorities performing (cost-) efficiently, yet, with the majority of the authorities performing (cost-) inefficiently.

To measure the performance in MSW treatment and collection performances of public authorities, few recent papers employed an adjusted version of the DEA-model, the so-called Benefit-of-the-Doubt (BoD) method introduced by Melyn and Moesen (1991) and popularised by Cherchye et al. (2007), to construct composite performance measures.[4] Examples include De Jaeger and Rogge (2014) for the household packaging waste collection of Belgian municipal waste joint ventures and Rogge et al. (2017) for benchmarking the MSW management performance of the NUTS2-regions in the EU. In essence, the BoD-method is a version of the DEA-model in a "pure output setting" in the sense that it only looks at "achievements" (*i.e.*, outputs) without taking into account the input side. The viewpoint taken by the BoD-model is that each public authority is represented by a "helmsman" that pursues multiple policy objectives, corresponding to the different performance indicators (see, among others, Lovell et al., 1995 and Cherchye et al., 2007 for more on the helmsman interpretation). Both studies (De Jaeger and

[4]For other early studies on the use of the DEA-model without inputs and, thus, exclusive focus on outputs, see *e.g.* Thompson et al. (1986), Lovell and Pastor (1997) and Lovell and Pastor (1999).

Rogge, 2014 and Rogge et al., 2017) demonstrated considerable variation in the performance of the involved public authorities. In particular, De Jaeger and Rogge (2014) showed that despite the substantial cooperation among Belgian municipalities, considerable differences in municipality performance in household packaging waste collection exist. Rogge et al. (2017) reveal considerable differences in the MSW performance of the NUTS2-regions, even within Member States. Our paper fits within the second group of studies that use the BoD-model in that we advocate a new extension to the BoD-model to measure and evaluate the MSW performance of the Italian municipalities.

2.2. The role of demographic and socio-economic characteristics

In the literature, many studies found that the operating environment and contextual characteristics can have a significant effect on the (cost) efficiency and/or performance of public authorities in collecting and processing MSW. Contextual characteristics that have frequently been studied in papers, examining the performance of public authorities in waste-related activities, include demographic and socio-economic characteristics such as the typology of a municipality/region, population density, per capita income and tourism.

In the evaluation of refuse collection costs, made by local authorities in the UK, Bello and Szymanski (1996) argued and demonstrated that local demographic and socio-economic characteristics (*e.g.*, rural vs. metropolitan area, etc.) can influence the costs (efficiency) of local MSW collection and processing services. As to the difference in costs of refusal collection, for instance, they showed that metropolitan authorities in some cases are more expensive compared to rural ones. As to the population density, empirical evidence is somewhat mixed. Simões et al. (2010) reported that for Portuguese urban solid waste entities, efficiency tends to decrease in rural and congested (high density) areas in Portugal. For Flanders (Belgium), De Jaeger et al. (2011) found that the cost advantages (relative shorter distance between waste pick-up points) and disadvantages (*e.g.*, congestion) of operating in densely populated areas more or less balance each other. An insignificant relation between population density and the regional performance, in MSW collection and processing for the NUTS2-regions in the EU, was found by Rogge et al. (2017). The impact of population size on efficiency scores is generally believed to be positive (see for instance García-Sánchez, 2008). Empirical evidence on the relationship between per capita income and respectively MSW generation and efficiency in MSW collection and processing is also mixed. In particular, whereas some studies reported a significant positive association (*e.g.* Linderhof et al., 2001; Mazzanti and Zoboli, 2013), other studies such as Mazzanti et al. (2012) found a more complex (*e.g.*, non-linear) relationship. For the NUTS2-region in the EU, Rogge et al. (2017) reported an insignificant relationship between the regional performance in MSW collection and processing and regional GDP per capita. Several studies found a positive relation between MSW generation and tourism (Mateu-Sbert et al., 2013; Arbulú et al., 2015). Rogge et al. (2017) reported a statistically significant and negative relation between the performance in MSW collection and processing of NUTS2-regions and the number of nights spent at tourist accommodation establishments. The demographic distribution has also been reported to have an impact. As shown by, De Jaeger et al. (2011), for example, the specific consumption patterns of different age groups can differ considerably leading to different levels of residual MSW generation. Examples of policy variables, that have been found to relate to the cost (efficiency) of local MSW collection and processing, are the collection method (Bello and Szymanski, 1996; De Jaeger et al., 2011), collection frequency (De Jaeger et al., 2011) or to the spatial allocation of the resources / policy; Dijkgraaf and Gradus, 2003). Atella et al. (2012) and Atella et al. (2014) highlighted how the institutional and administrative setting of the highest level authorities strongly constrain the allocation choices of the lower level ones. A similar remark was made by De Jaeger and Rogge (2013) for the Flemish MSW policy where the MSW-policy is formulated to a large extent at the municipal level, however, the Flemish regional government is still responsible for setting the general environmental targets and policies, including waste-related policy matters. Another political factor that has been demonstrated to be linked to waste performance is the regional and/or municipal political ideology (*e.g.*, the left wing vote share, percentage of socialist and the green votes). García-Sánchez (2008) argued that regional and/or municipal politics can have different goals with respect to the MSW management. Depending on the political ideology, municipalities might consider maximizing efficiency subservient to for instance maximizing the number of jobs in waste collection.

In sum, even though there is empirical evidence on the impact of the operation environment and contextual characteristics on the performance scores of public authorities in the collection, treatment and/or disposal of MSW, it does not rule out that one or more background conditions could have a significant influence. Moreover, there is also the practical experience from public authorities involved in the MSW-sector themselves which indicates that some operating environments are more constructive to a high performance (and, hence, high efficiency scores and/or composite performance scores), while, other operating environments make a high performance less evident. Therefore, studies should account and correct for differences in background conditions, in the benchmarking evaluation, trying to identify as much as possible the spatial non-stationarity of the relationships between efficiency and contextual variables. Not doing so, risks obtaining DEA- (BoD-) based efficiency estimates (performance scores) which are potentially flawed and, therefore, unreliable as a measure of actual efficiency (performance) in MSW.

3. Method

The present paper advocates an extended version of the BoD-model to measure and evaluate the MSW performance of the Italian municipalities. As noted previously, in essence, the BoD-method is a particular version of the non-parametric DEA-model which only looks at "achievements" (*i.e.*, outputs) without taking into account the input side. More technically, the BoD-model is formally tantamount to the original input oriented DEA-model of Charnes et al., 1978, with all sub-indicators considered as outputs and the input imposed as a dummy equal to one for all the observations (for more details, we refer the interested reader to Cherchye et al., 2007). Formally, for the BoD-setting, the production possibility set can be defined as:

$$\widetilde{\Psi} = \{(\mathbb{1}, y) \in \mathbb{R}_{+}^{1+q} | Y_j \geq y\}. \tag{1}$$

with q performance indicators $y = \{y_1, ..., y_q\}$ collected for $i = 1, ..., n$ observations to be aggregated and one input assumed to be equal to $\mathbb{1}$ for all units. Each of the q indicators measures a specific aspect of the policy domain under assessment. The non-parametric nature of BoD particularly reveals itself in the definition of the indicator weights.[5] In particular, the conceptual starting point of the BoD-model is that, as detailed knowledge on the correct importance weights for the performance indicators is usually absent (or at best partially known) in the estimation of the CI scores, information on the weights can be retrieved endogenously from the observed indicator data themselves. To this end, the BoD-model puts the indicator data of the DMUs in a relative perspective and compares them to each other, thereby looking for each DMU for the most favourable indicator weights that optimise its relative CI score. As discussed at length by Cherchye et al. (2007), one key advantage of BoD-based benchmarking is that, through, its data-driven manner of defining indicator importance weights and identifying benchmark practices, it provides policy makers with detailed information on weaknesses and/or strong points

[5]Note, however, that even though the BoD-model is non-parametric there are a number of economic axioms underlying the BoD-framework: No free lunch, free disposability, boundedness of the production possibility frontier, closeness of the production set, convexity of the frontier (see *e.g.*, Shephard, 1970 for details).

in their policy as well as target levels for indicators to improve policy performance. In addition, BoD-based benchmarking enables to incorporate some 'naming and shaming' in the evaluation of public authorities performance in providing public services. More specifically, the idea is that the knowledge of being compared and evaluated relative to others will trigger public authorities to search for continuous improvement in their policies. In the end this should lead to a general increase in the public service quality and quantity.

In its basic version, the BoD-model (but also, the more general DEA-model) suffers from the following limitations which may restrict the applicability of the method in practical settings: *(i)* the lack of robustness of the performance estimates; *(ii)* the issue of perfect compensability among indicators; *(iii)* the model not being able to treat undesirable indicators; *(iv)* the basic model not accounting and/or correcting for background conditions; and *(v)* the basic model not accounting and/or correcting for spatial proximities that might influence individual components of the CI (please see Greco et al., 2018 for a more detailed survey).

1. The *robustness issue*: due to the deterministic nature of the BoD-method, estimated composite performance scores are taken to be perfect reflections of the actual performance of public authorities without considering the potential for any noise or other irregularities in the indicator data. However, the presence of just one municipality with outlying and/or atypical performance data in the sample set suffices to downwardly bias the composite performance scores of all municipalities.

2. The *issue of (perfect) compensability* among simple indicators: due to the use of a weighted arithmetic average aggregation procedure in the construction of the BoD-based composite performance indicators, low values of one indicator can be perfectly compensated by high values on other indicators.

3. The *issue of undesirable indicators*: a basic assumption of the standard BoD-model is that all q indicators $y = \{y_1, ..., y_q\}$ are "desirable", meaning that larger values indicate better achievements. Many real-world practical applications, however, also involve performance indicators that are "undesirable" in the sense that higher values correspond to a worse performance. Including the joint effect of good and bad outputs is fundamental to obtain correct results especially in environmental issues, as the MSW (see among others Färe et al. 1989, Färe et al. 1993, Chung et al. 1997, Khanna et al. 1998, Boyd and McClelland 1999, Hailu and Veeman 2001, Scheel 2001, Seiford and Zhu 2002, Färe et al. 2007, Liu et al. 2010, Zhou et al. 2010, Hoang

and Coelli 2011, Picazo-Tadeo et al. 2014, Zhou et al. 2017, Aparicio and Kapelko 2019).

4. The *issue of exogenous factors*: the standard BoD-model disregards the impact of contextual (exogenous) factors on the performance indicators and the performance possibility sets of public authorities. This essentially means that, in the benchmarking and estimation of the composite MSW policy performance scores, municipalities with different background characteristics can be compared to each other and this could lead to biased performance scores.

5. The *issue of spatial proximities/dependencies*: the BoD-model, in its basic version, does not account for spatial dependencies among municipalities like, *e.g.*, latent industrial networks, economic districts, local labour systems or administrative boundaries and so on, where homogeneity is maximum at local level, *i.e.* within groups, and is minimum among different local clusters, *i.e.* between groups. It is fairly common, in fact that, the aggregation of enterprises, firms or LAs is due to a common business culture or to higher level of government decisions and planning.

All of the BoD-studies (and DEA-studies) that have been applied in the measurement and evaluation of the performance ((cost-) efficiency) of the public authorities in providing waste-related services (collection, treatment and disposal of waste) suffer from one or a combination of these limitations. For instance, the most recent BoD-based study of MSW performances by Rogge et al. (2017), though addressing three of the aforementioned limitations (robustness issue, conditioning on contextual characteristics and the inclusion of undesirable performance indicators), still suffered from the compensability issue (be it only partially as they imposed weight restrictions in the BoD-model) and the lack of accounting for spatial dependencies. The version of the BoD-model that we propose in this paper combines recent extensions in the DEA-/BoD-literature that enable to address each of the five limitations discussed above. In the remainder of this section, we develop this version of the BoD-model thereby discussing each of these extensions more in depth.

Firstly, to account for the issue that the presence of one or more municipalities with atypical and/or outlying performance data may bias downward the BoD-estimated composite performance scores of all municipalities in the sample set, we use the robust order-m BoD-model after insights of Cazals et al. (2002). Without going into detail, this robust order-m version of the BoD-approach models the benchmarking assessments as a stochastic process and evaluates a municipality's composite waste policy performance score against the expected performance score achieved by municipalities with equal or better performance indicator values. In practice, the robust computations involve a Monte Carlo simulation in which each municipality's waste performance is evaluated in a large number of BoD-based computation rounds (in casu, 1000 rounds) in each of which the municipality's composite performance score is computed relative to a subsample of m[6] randomly selected municipalities with equal or better performance levels on the q indicators $y = \{y_1, ..., y_q\}$. Formally, for the robust order-m BoD-setting, the performance possibility set can be defined as:

$$\widetilde{\Psi}_m = \bigcup_{j=1}^{m} \{(\mathbb{1}, y) \in \mathbb{R}_+^{1+q} | Y_j \geq y\}. \tag{2}$$

Note that robust order-m BoD-model considerably mitigates the impact of a single municipality on the performance evaluations of other municipalities. The robust order-m version of the BoD-model was already applied in earlier studies, *e.g.* Vidoli and Mazziotta (2013).

Secondly, to allow for the accommodation of undesirable indicators in their original form in the computations of the composite performance scores (so without requiring any prior transformation/normalisation), the BoD-model is adapted using a recent extension discussed by Zanella et al. (2015) and Rogge et al. (2017) in the BoD-model so as to be able to consider a mixture of desirable and undesirable performance indicators in the construction of CIs. This extension transforms the Robust BoD-model into a robust directional distance version of the BoD-model. Directional distances (for an exhaustive updated discussion, please see Daraio and Simar, 2014, 2016), in fact, "*provide useful, flexible measures of technical efficiency of production units relative to the efficient frontier of the attainable set in input-output space*" (Daraio et al., 2018) allowing to assess settings in case of negative input or output.

As a result, the formulation of the performance possibility set of the robust order-m BoD-model as in equation (2) is adjusted as follows:

$$\vec{\Psi}_m = \bigcup_{j=1}^{m} \{(\mathbb{1}, y^g, y^u) \in \mathbb{R}_+^{1+g+u} | Y_j^g \geq y^g, Y_j^u \leq y^u\}. \tag{3}$$

[6]Please note that, in this framework, the m parameter has a dual nature: *(i)* it is a trimming parameter used to test the robustness of estimated efficiencies or *(ii)* it identifies the number of the potential competitors for each firm/unit. In our application (Section 4) this parameter has been used to ensure the robustness of the estimates in the presence of out-sized cities rather than to select potential competitors since this selection was made by exploiting the spatial proximity among units.

with g being the number of desirable indicators and u the number of undesirable indicators measuring different aspects of the municipal waste performance and $q = g+u$. The $Y_j^u \leq y^u$ constraint assumes that the standard assumption of *strong disposability* also applies to undesirable performance indicators. This ensures that municipalities will reach the best practice frontier when no further improvements to both desirable and undesirable indicators are possible. In the computations of the robust directional distance BoD-model, for each iteration $b \in B$ ($b = 1,\ldots,B$; with B = 1,000), the composite performance score for each municipality can be computed from the following linear programming problem:

$$\vec{D}_m^b(\mathbb{1}, y^g, y^u; d^g, d^u) = \sup\{\beta | (\mathbb{1}, y^g + \beta d^g, y^u - \beta d^u) \in \vec{\Psi}_m\}, \forall \quad b = 1,\ldots,B. \quad (4)$$

where $d = (d^g, -d^u)$ is directional vector for desirable and undesirable indicators, respectively and β represents the maximal feasible expansion of desirable indicators and contraction of undesirable indicators that can be achieved simultaneously. The robust directional distance BoD-based performance score is given by the expected value of the B samples scores:

$$\vec{D}_m(\mathbb{1}, y^g, y^u; d^g, d^u) = \mathbb{E}\left[\vec{D}_m^b\right] \quad (5)$$

The subsequent improvement of the model (4) is the conditioning of the construction of the composite performance scores with respect to a set of exogenous factors *i.e.* z, which characterise the operating environment in which municipalities have to organise their waste-related public services. To develop a conditional version of the BoD-model, insights of, among others, Daraio and Simar (2007), De Witte and Kortelainen (2013), and Bădin et al. (2012) can be followed. The basic idea of the conditional version of the robust order-m BoD framework is straightforward. The composite performance scores are computed in a robust manner, thereby accounting for the exogenous conditions by comparing only like with likes. That is, whereas the unconditional version of the BoD-model compares each municipality with all other municipalities in the estimation of the robust composite performance score, irrespective of the (dis)similarity of their background conditions, the conditional version of the BoD-model only compares each municipality with municipalities that operate under similar background conditions, $Z = z$. To condition on the operating environment, the performance possibility set of the robust order-m BoD-model as in equation (4) is modified as follows:

$$\vec{\Psi}_{m_z} = \bigcup_{j=1}^{m} \{(\mathbb{1}, y^g, y^u) \in \mathbb{R}_+^{1+g+u} | Y_{j,Z=z}^g \geq y^g, Y_{j,Z=z}^u \leq y^u\} \quad (6)$$

In applicative analysis, however, the multitude of exogenous conditions being conditioned for, may not fully capture the socio-economic and/or political dependencies among evaluated municipalities. For instance, the set of background conditions selected for the analysis may be unsuccessful in encapsulating the institutional setting and administrative constraints of higher level authorities at least partially constraining the flexibility for municipalities in defining their waste policies. As an alternative to the conditional version of the BoD-model, to address the issue of spatial proximity/dependence, a recent extension of Fusco et al. (2018) is implemented. The notion is to compare and evaluate municipalities with local potential competitors in a way such that the BoD-model accounts for the underlying spatial point pattern process. So, municipalities are only compared and assessed relative to the group of neighbours belonging (with similar background conditions) to S_j, with S_j denoting a generic portion of territory. In formal notations, the spatial version of the model (6) is as follows:

$$\vec{\Psi}_{m_S} = \bigcup_{j=1}^{m} \{(\mathbb{1}, y^g, y^u) \in \mathbb{R}_+^{1+g+u} | Y^g_{j,j\in S_j} \geq y^g, Y^u_{j,j\in S_j} \leq y^u\} \tag{7}$$

and, referring to equations (4) and (5), the spatial directional Robust BoD-model in the presence of undesirable outputs scores can be calculated by solving the equation (8) first:

$$\vec{D}^b_{m_S}(\mathbb{1}, y^g, y^u; d^g, d^u) = \sup\{\beta | (\mathbb{1}, y^g + \beta d^g, y^u - \beta d^u) \in \vec{\Psi}_{m_S}\}, \forall \quad b = 1, \ldots, B. \tag{8}$$

and, then, as a result, the equation (9):

$$\vec{D}_{m_S}(\mathbb{1}, y^g, y^u; d^g, d^u) = \mathbb{E}\left[\vec{D}^b_{m_S}\right] \tag{9}$$

Finally, the spatial version of the robust order-m directional distance BoD-model is adjusted to address two final issues: (perfect) compensability among performance indicators and the possibility that the BoD-method could assign zero or too low importance weights to one or more indicators implying that these performance criteria are (nearly) ignored in the construction of the composite performance score. The first issue has been addressed in Fusco (2015) (denominated *DBoD* method), by introducing a "directional" penalty using a directional distance function, with the aim to consider a preference structure among the performance indicators and to penalise municipalities that are far from this chosen direction. However, the Fusco (2015) proposed approach does not allow for undesirable criteria (negative directions). Therefore, we follow Zanella et al. (2015) and Rogge et al. (2017) and specify the directional vector by the current value of the performance indicators, *i.e.* $d = (d^g, -d^u) = (y^g, -y^u)$ in order to have a directional distance function comparable to Shephard (1970). This choice for the directional vector implies that desirable and undesirable indicators will be expanded and contracted, respectively, proportionally to the original indicator performance levels.[7] The second issue is avoided by limit the proportional or relative importance of each performance indicator to be situated between certain bounds in the construction of the composite performance score using the proportional *virtual weight restrictions*.[8] Thus, the restricted BoD-model offers some flexibility in the determination of the BoD weights for the performance indicators and as such allows a certain degree of "specialisation" in the MSW-policies of municipalities. This avoids that municipalities will be punished for a successful pursuit of relatively strong performances on some waste performance indicators (*e.g.*, recycling rate) at the acknowledged expense of relatively weak performances on some other waste performance indicators (*e.g.*, a high land-filling rate). However, the restricted BoD-model avoids that municipalities are rewarded for exclusively focusing on improving the performance in one or a subset of waste performance indicators while continuing to perform very poorly on the other waste performance indicators (for more on the issue of undesirable specialisation in the construction of composite indicators, see Rogge, 2012).

4. An application to the Italian waste sector

4.1. The Italian MSW sector among different levels of governance

Waste management in Italy (ISPRA, 2016) concerns a sector whose annual production is 29.6 million tonnes of waste, down 8.7% over the four-year period 2010-2014. The most significant decreases were recorded in the South (-10.5%) and in the Centre (-9.8%) as a result of the economic recession and a trend towards generating less waste in production and consumption. The average national per capita production of waste amounts to 488 kg per inhabitant (496kg in the North, 547kg in the Centre and 443kg in the South) compared to an average EU production in 28 countries of 481 kg/inhabitant (with waste production per capita ranging from 249 kg/inhabitant per year in Romania to 758 kg/inhabitant in Denmark, data from year 2014).

[7]Remark that other choices of direction vectors are also possible. Färe et al. (2008) discussed several examples of possible formats.

[8]For more on weight restrictions in BoD, see, *e.g.*, Cherchye et al. (2007) and Wong and Beasley (1990).

In Italy, the general principles, guidelines and legal framework are stipulated at a higher policy level.[9] The most important waste legislation (Legislative Decree 22/97) has been issued in Italy in 1997. This legislation defined the framework for the national waste management system, thereby specifying responsibilities of the different stakeholders and actors involved in the waste sectors. This waste legislation also set out milestones and targets about separate collection of municipal waste. Other elements of this legislation were the progressive implementation of a new waste tariff (which replaced the old waste tax) and the establishment of a National Packaging Consortium. In 2006, this legislation was replaced by a new waste legislation (Legislative Decree 152/2006) which, however, included most of its elements. The decree 152/2006 also regulates the management of the waste according to the precautionary principles, of prevention, proportionality, accountability and cooperation of all the subjects involved in the production, in the distribution, use and consumption of goods from which they originate waste. Priority is given to the prevention of waste production and waste recovery (intended as reuse, recycling and recovery), two pillars of the EU and Italian legislation. Quantity and type of disposal are, therefore, the two main aspects to be taken into consideration when assessing the performance at municipal level. The total amount of generated waste per capita measures the quantity of the waste services offered. The percentage of separate collection can be interpreted as a proxy for the quality of the service.

In spite of defining a fixed national landfill tax rate that applies to all Italian regions, the Italian law merely defines an upper bound and lower bound rate level for the tax, which is applied at the regional level. The regional application of the tax rate makes that the heterogeneity in the tax levels is quite high. Some regions define very low landfill tax rates whereas others have a landfill tax rate that is much higher. Nevertheless, in general, the national average level of the landfill tax is very low as compared to how other European countries tax land-filling. This low landfill tax rate explains why Italy has traditionally land-filled most of its MSW. In spite of recent efforts to reduce land-filling rates (as stipulated in the Landfill Directive), almost half of the regions in Italy still have landfill rates of 50% or higher. There are however large differences between regions. Whereas some regions such as Lombardy, Trentino Alto Adige, and Friuli-Venezia Giulia are land-filling only a small percentage of MSW, other regions such as Sicily, Molise and Puglia are still land-filling most of its MSW. Whereas the rates of separate collection of waste are generally increasing in all Italian regions, Italy as a whole is still far from realising

[9] EU targets have been stipulated for each EU Member State by the Waste Framework Directive, the Landfill Directive and the Packaging Directive.

its national target for separate waste collection as stipulated by Legislative Decree 152/2006.

As to the responsibilities of the different actors, for Italy, broadly speaking there is a shared responsibility between regions and municipalities. In particular, regions are responsible for defining the waste management plans that have as particular aim promoting waste reduction. The municipalities are responsible for organising the collection and management of MSW.[10] At local level, the public services involving the collection and treatment of waste absorb a considerable amount of public financial resources (in Italy, on average, approximately 20% of the total municipal budget in 2015 equivalent to EUR 10.3 billion). Moreover, the waste sector is one of the sectors in which concurrence among the different levels of government (EU, central state, regions, provinces and municipalities) is great, both from a legislative and administrative point of view.

The operating environment and background conditions under which municipalities have to organise their waste policies and waste-related public services vary considerably among Italian municipalities. More in particular, whereas some municipalities are characterised by socio-economic and demographic conditions that are more beneficial for being successful in organising the processing and collection of waste (and, hence, realising a high efficiency score), other municipalities have to operate under conditions that make it more difficult to organise their waste collection and processing proficiently.[11]

4.2. Data

The main source of statistical information in Italy in the waste sector is the Italian National Institute for Environmental Protection and Research (ISPRA - *Istituto Superiore per la Protezione e la Ricerca Ambientale*), the statistical office which collects the waste data for Italy. The dataset used for the present study includes waste data for the Italian municipalities (LAU level 2, formerly NUTS level 5). Data have been collected from the municipal waste generation and treatment dataset, year 2015. More in detail, the ISPRA dataset includes data on factors which mea-

[10] Rogge et al. (2017) noted that it general holds, for EU Member States, that waste policy competencies are not restricted to the national level. In most EU Member States regional and local (*i.e.* municipal) competencies play a vital role at both the strategic and the operational level of waste management.

[11] For instance the distance from the disposal plants, the typology and number of plants at the provincial level, the level of economies of scale.

sure both desirable (*e.g.* recycling rate) and undesirable (*e.g.* total municipal waste generation) outputs of waste management for about 8,000 municipalities.[12]

As discussed in the subsection 4.1, the waste quantity and type of waste disposal are the two main aspects to be taken into consideration when assessing the performance of the waste policies and services at municipal level. As to the waste generation, the database includes two undesirable performance criteria: the 'undifferentiated waste collection' (*Rifiuti Urbani -'Raccolta indifferenziata'*) and the 'differentiated waste collection' ('*Raccolta Differenziata*'). Data for these two undesirable indicators is available in 'tons' and 'kilos per inhabitant', respectively. The differentiated waste collection is further disaggregated in: organic, bulky waste, paper and cardboard, wood, metal, plastic, electrical and electronic equipment, selective collection, textiles, and glass. The dataset also includes data on some structural variables of the disposal plants at provincial level. It concerns information on composting, aerobic and anaerobic integrated treatment, anaerobic digestion, organic mechanical treatment (TMB), incineration, coincineration and land-filling.[13] Finally, the dataset also includes information on the population, economic and exogenous characteristics as well as the municipal expenditures on MSW.

4.3. Choice of the measurement model

The multiplicity of waste collection and treatment services provided by the Italian municipalities makes that a comprehensive performance evaluation requires the aggregation of the performance values on multiple performance indicators into a composite waste policy performance indicator. Following Rogge et al. (2017), the composite waste policy performance indicator is calculated taking into account a mixture of desirable and undesirable performance indicators:

- **Undesirable indicators**:

    1. *Waste generation (tonnes per capita)*: total amount per capita of the collected waste for each single municipality (NUTS5).
    2. *Tons of waste managed in landfills and in TMB plants (% of total)*: provincial (NUTS3) average percentage of land-filling or biological mechanical treatment.

[12]The presence of missing data - especially for variables describing the typology of waste disposal plant - has reduced our application sample to 5,532 units.

[13]http://www.catasto-rifiuti.isprambiente.it/index.php?pg=gestimpianto&aa=2015&regid=1&impid=01&imp=Piemonte

- **Desirable indicators**:

    1. *Differentiated waste collection (% of total)*: municipal (NUTS5) percentage of the differentiated on the total of the collected waste.
    2. *Tons of waste managed in co-incinerators, composting, aerobic and anaerobic digestion and incinerators plants (% of total)*: provincial (NUTS3) average percentage of co-incinerators, composting, aerobic and anaerobic digestion and incinerators plants.

The former type of indicators measure undesirable outcomes of a municipality's waste policy with higher performance values indicating a worse performance on that performance criterion. The latter type of performance indicators measure desirable outcomes of a municipality's waste policy. For these indicators, higher values indicate a better performance for the municipality on that performance criterion. The upper part of Table 1 reports the descriptive statistics for the 5,501 Italian municipalities that presented reliable performance values for the mix of desirable and undesirable performance indicators.[14]

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
Undesiderable indicators							
Waste per capita (*tonnes per capita*)	5,501	0.670	1.761	0.0003	0.102	0.586	42.407
Waste landfill or TMB plants (*% of total*)	5,501	0.523	0.287	0.038	0.299	0.768	0.997
Desirable indicators							
Differentiated waste (*% of total*)	5,501	0.339	0.110	0.002	0.283	0.420	0.493
Waste in (co-)incinerators plants, ... (*% of total*)	5,501	0.477	0.287	0.003	0.232	0.701	0.962
Personal income (*Euro per capita*)	5,501	16,711	3,495	8,233	14,021	19,149	43,737
Population density (*number per km^2*)	5,501	307.464	710.860	0.747	44.116	268.122	12,272.880
Beds in tourist accommodation (*per 1000 inhabitants*)	5,501	238.782	2,274.234	0.402	11.641	98.988	89,469.140

Table 1: Descriptive statistics: undesirable and desirable waste performance indicators and population and economic characteristics

Three versions of the composite indicator are constructed to measure the waste policy performance of the Italian municipalities. A first version of the composite policy score is constructed using the *Robust BoD-model (RBoD)*. This robust composite index score is constructed using the aforementioned mix of desirable and undesirable performance indicators using a robust order-*m* version of the directional distance function model as discussed by (Zanella et al., 2015; Rogge et al., 2017). This version of the composite score is robust in the sense that it corrects

[14] 31 municipalities (0.6%) have been excluded from the analysis because of missing data or inconsistency among the variables under consideration; the presence of out of scale municipalities (large cities) has been controlled through the use of robust estimation methods.

for the (potential) presence of municipalities with outlying and/or extreme performance data values (see also Vidoli et al., 2015).

In order to get a more accurate picture of the municipalities' performance in the waste sector, a version of the composite waste policy performance indicator is constructed correcting for differences in the population and economic conditions of municipalities.[15] The reasons justifying this approach can be identified on the empirical findings by previous studies and the practical experience of stakeholders and local policy makers about the operation environment (proxied by a selection of exogenous variables). In particular, similar to Rogge et al. (2017), in the evaluation of the municipalities' waste policy performance, we use a *Conditional Robust BoD-model (Cond. RBoD)* which corrects for the following exogenous variables:

- **Population and economic characteristics**:
    1. *Personal average income*, municipal level (NUTS5).
    2. *Population density*: inhabitants for km^2, municipal level (NUTS5).
    3. *Number of beds in tourist accommodations per capita (*1000)*, provincial level (NUTS3).

The lower part of Table 1 reports the descriptive statistics for economic and demographic characteristics of the 5,501 Italian municipalities in the sample set.

For the organisation of their waste policies and services, Italian municipalities take into account the policy and management decisions (landfills, TMB or composting plants) set out at the provincial level. This makes that the waste policy performance of municipalities is at least partially determined by the waste policy choices made by higher-level regulatory administrations (*i.e.*, provinces). As such, in the evaluation of municipal waste policy performances, one should not only correct for differences in population and economic characteristics but also for territorial/administrative constraints. As noted above, the set of background conditions selected for the conditional BoD-analysis may not fully capture the socio-economic and/or political dependencies among evaluated municipalities (*i.e.* the institutional setting and administrative constraints of higher level authorities at

[15]The granularity of the present analysis (NUTS5 level) has led to the choice of a smaller number of conditional variables compared to those highlighted *e.g.* by NarbonPerpina and De Witte (2018) affecting municipal performance. A more detailed analysis of the effects of the exogenous conditions of local demand and supply can certainly be subject of further study.

least partially constraining the flexibility for municipalities in defining their waste policies). Therefore, as an alternative to the conditional version of the BoD-model, to address the issue of spatial proximity/dependence, a recent extension of Fusco et al. (2018) is implemented.
In the computation of the composite waste performance indicator for the Italian municipalities, the *Conditional Robust BoD-model (Conditional RBoD)* and the *Spatial Robust BoD-model (Spatial RBoD)* are used to measure municipalities' waste policy performance. The first one accounting for a set of exogenous variables (characterising the operation environment for the municipalities' waste sector) and the second one for spatial proximity/dependency among municipalities (which capture the territorial regularities related to the organisational and/or administrative form).[16]

All three versions of the BoD-weighted composite indicators have been computed using the R *Compind* package v.2.0, which includes among other things the new spatially constrained Robust BoD function. Note that in order to avoid that the BoD-model would select (quasi) zero weights, in the computations of the composite indicators, additional weight restrictions were included which imposed that BoD-weights for each performance indicator should be at least 0.05 or 5 percent.[17] Ideally, such a lower weight bound value should be specified by experts and/or stakeholders. However, practical experience teaches us that strong consent, even between experts thoroughly acquainted with the object of study, is unlikely to come about on this matter. In the current application we lack such expert information, but still defined the lower weight bound value of 5 percent so as to avoid (quasi-) zero BoD-weights. Stated otherwise, we take it that the composite performance score cannot be constructed while disregarding at least one of its constituent performance indicators, a minimalist position which we take to reflect the underlying idea that all performance indicators are considered as providing at least some valuable information to the municipalities' waste policy performance.

[16] More in particular, a contiguity structure is required to calculate the composite index in the case of spatial dependence: the neighbourhood criteria and the relative spatial matrix has been set using a k-nearest neighbours algorithm with $k = 30$, the average number of neighbours in each province.

[17] Obviously, in the proposed model, this additional weight restriction can be included or not: from our point of view it remains an additional possibility given to the researcher in order to jointly evaluate all the indicators considered; it is also clear that, in the absence of additional information (opinion of experts), this constraint can be considered subjective.

5. Results

Table 2 reports the descriptive statistics for the three versions of composite indicators for measuring Italian municipalities' waste policy performance as computed by three versions of the BoD-model: (*i*) *RBoD*, (*ii*) *Cond. RBoD*, and (*iii*) *Spatial RBoD*. There are some interesting points to be taken away from these statistics. On such interesting point is that the mean values and the standard deviation values for the three versions of the composite scores vary between 0.711 and 0.893 and between 0.199 and 0.222, respectively.[18] The relatively high mean scores demonstrate that on average Italian municipalities are evaluated to be rather well-performing in waste policy when favourable BoD-weighting is applied. The low standard deviations allude to the fact that the disparity between the majority of the Italian municipalities in their waste policy performances is modest in BoD-based evaluations. Nonetheless, the difference between the maximum and minimum estimated BoD-weighted composite index scores suggests that the disparity between the best and worst-performing municipalities is significant. Note also that the standard deviation values for the BoD-weighted composite scores decreases as exogenous characteristics and spatial dependencies are being corrected for.

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
RBoD	5,501	0.711	0.222	0.000	0.537	0.894	1.496
Condit. RBoD	5,501	0.762	0.199	0.000	0.612	0.940	1.452
Spatial RBoD	5,501	0.893	0.158	0.000	0.844	0.977	1.479

Table 2: Composite indicator summary by method

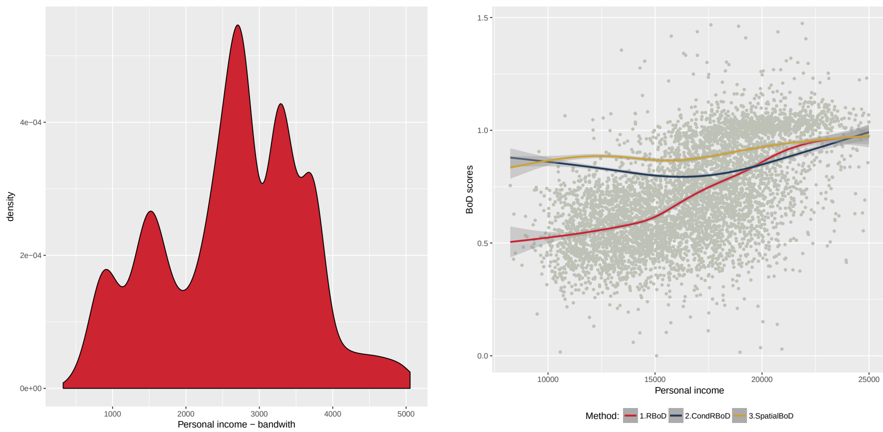
To estimate the effect of the population and economic characteristics on the municipalities' waste policy composite performance scores, we use local linear regression that smooths both continuous and discrete variables (Racine and Li, 2004). The estimated bandwidths and the partial regression plots for the exogenous variables "*Personal average income*", "*Population density*", and "*Number of beds in tourist accommodations per capita*" are visualised in Figures 1, 2 and 3, respectively. The partial regression plots visualise the distributions of the three versions of the composite scores (*RBoD*, *Cond. RBoD* and *Spatial RBoD*) with respect to each single exogenous variable. In the reading of these plots, negative (positive) slopes denote

[18] Please note that, unlike the traditional non-parametric framework, in the order-*m* approach some units may present efficiency score greater than 1; these "super-efficient" (Andersen and Petersen, 1993) units, showing a higher composite output level than the frontier, may suggest out of scale data.

a negative (positive) relationship with the municipalities' waste policy composite performance scores.

The partial regression plot in Figure 1 shows that for the robust order-*m* evaluations (*RBoD*), average income relates positively to the municipalities' composite waste policy performance scores. For the evaluations using the conditional robust (*Cond. RBoD*) and the Conditional Spatial Robust BoD-model (*Spatial RBoD*), it can be easily noted that there is no relation between the average income and the municipalities' composite waste policy performance scores. In fact, though the plot shows a slight negative relation for the lower average incomes and a slight positive association for the higher average income levels, these minor patterns seem to be statistically non-significant. In Figure 2, the partial plot suggests a positive relation between population density and municipalities' composite waste policy performance scores. This relationship is less strong (and, in fact, largely disappears) when looking at the municipalities' composite waste policy performance scores as computed by the conditional robust (*Cond. RBoD*) and the Conditional Spatial Robust BoD-model (*Spatial RBoD*). As regards the exogenous variable measuring the number of tourist accommodations, the partial regression plot in Figure 3 demonstrates a negative, albeit moderately, relation to municipalities' composite waste policy performance scores computed using the robust order-*m* BoD-model. For both the conditional (*Cond. RBoD*) and the spatial robust order-*m* scores (*Spatial RBoD*), this association is not present. In general, whereas the partial regression plots show significant associations between the municipalities' performance scores according to the robust (non-conditional and non-spatial) order-*m* BoD-model, these relations are no longer present for the Conditional RBoD and the spatial RBoD composite scores.

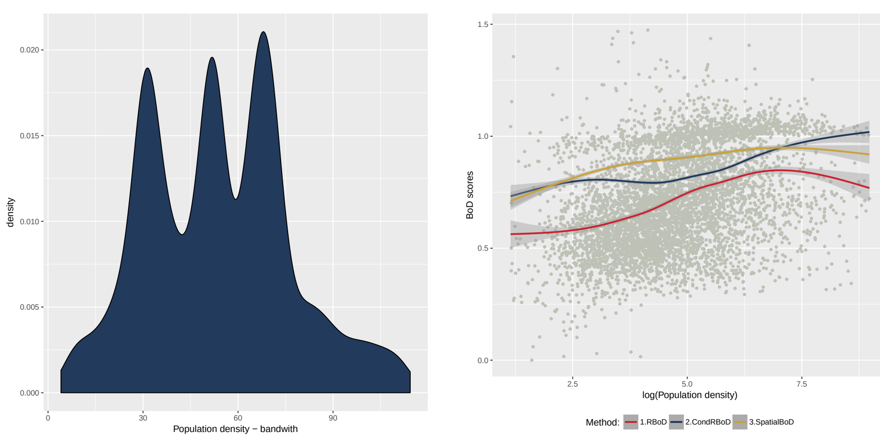
More specifically, the inclusion of the demand side variables (Income, Population and Tourist accommodation) as conditional factors in the Robust BoD model significantly impacts on the estimated indicator. This result could be checked both applying non-parametric significance tests as suggested by De Witte and Kortelainen (2013) (all the Individual Significance Test based on non-parametric Kernel Regression with IID Bootstrap (100 replications) show p-values $< 2.22e^{-16}$ for both the conditional and the spatial conditional model) and by analysing the relationship between conditioned and unconditioned efficiency (Q_z) as a function of the individual conditional variable. Figure 4 highlights two main findings: *(i)* the Q_Z ratio average trend is significantly dependent on the variation of each conditional variable and *(ii)* these trends are substantially similar to the variation of the conditional method.
As regards the spatial dependencies (*i.e.*, effect of local variables - both at the ad-



(a) *Estimated bandwidth*

(b) *Condit. effect*

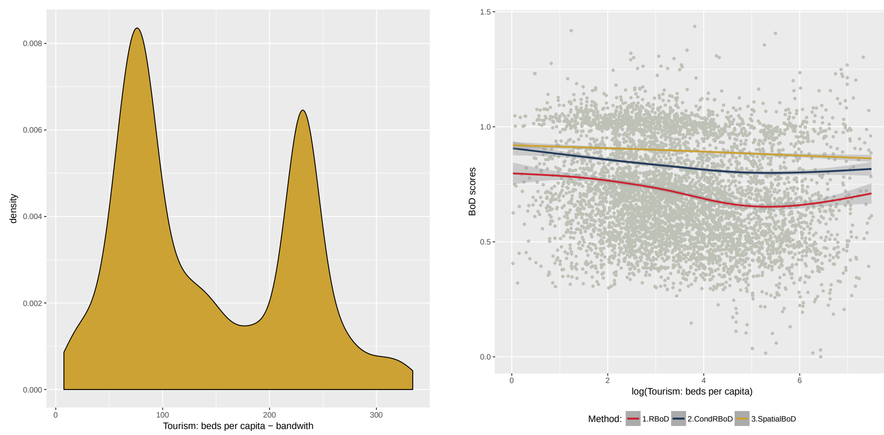
Figure 1: BoD scores and average personal income: comparing the conditional effect by method



(a) *Estimated bandwidth*

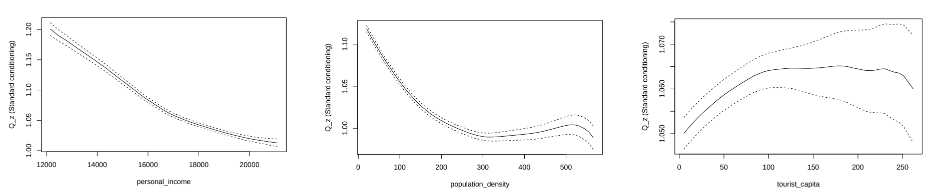
(b) *Condit. effect*

Figure 2: BoD scores and population density: comparing the conditional effect by method

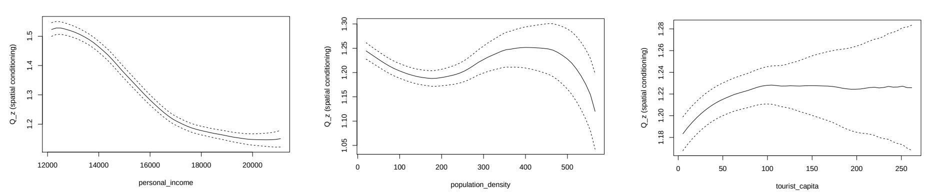


(a) *Estimated bandwidth* (b) *Condit. effect*

Figure 3: BoD scores and beds in tourist accommodation: comparing the conditional effect by method



(a) *Income - Condit.* (b) *Population - Condit.* (c) *Tourist - Condit.*



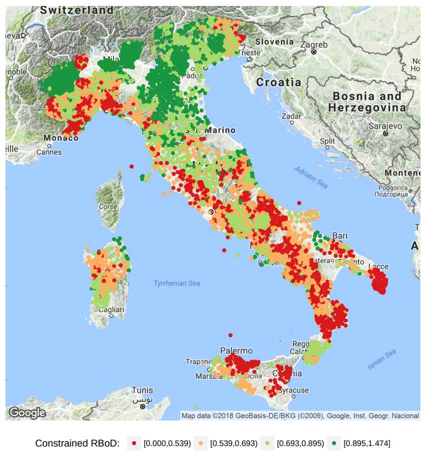
(d) *Income - Spatial condit.* (e) *Popul. - Spatial condit.* (f) *Tourist - Spatial condit.*

Figure 4: Conditional effects vs base model by method

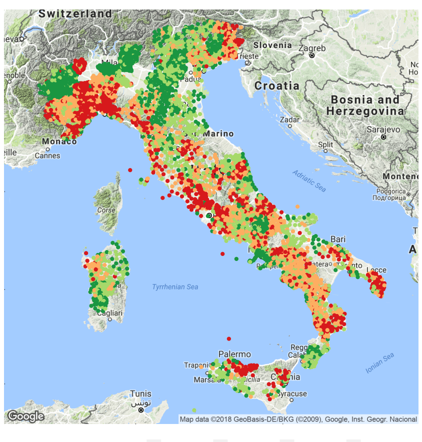
ministrative level and linked to omitted territorial variables), Figure 5 shows the maps for the Italian municipalities with the composite waste policy performance scores as computed using the three versions of the BoD-model (*i.e.*, *RBoD*, *Cond. RBoD* and *Spatial RBoD*).[19] The map in *Figure 5.a* with the visualisations of the municipalities' composite waste policy scores as computed using the robust order-*m* method (*RBoD*), highlights clear provincial regularities both locally - failing to isolate the municipal performance from the constraints on the plants at the provincial level - and globally due to the difference between Northern and Southern regions. In particular, *Figure 5.a* clearly shows that Italian municipalities in the Northern of Italy are obtaining higher waste policy performance scores as compared to their counterparts in the South of Italy. *Figure 5.b* shows the map with the *Cond. RBoD*-scores. Though the North-South divide is somewhat less outspoken, on average, municipalities in the North of Italy are still outperforming the municipalities in the South, even when taking into consideration differences in population and economic characteristics. The maps also show that the *Cond. RBoD*-scores do not fully correct for territorial constraints/dependencies linked to organisational and administrative choices. This result confirms our point made earlier that the set of background conditions selected for the construction of the *Cond. RBoD*-scores may not fully capture the socio-economic and/or political dependencies among evaluated municipalities. Finally, *Figure5.c* shows the map with the *Spatial RBoD*-scores for the Italian municipalities. As compared to the previous two maps with the *RBoD*- and *Cond. RBoD*-scores, this map no longer demonstrates significant territorial regularities/dependencies. Note also that this map does no longer show any North-South divide. This confirms that the spatial, conditional robust order-*m* version of the BoD-model is able to capture and correct for both differences in exogenous variables as well as spatial dependencies.

The global and local Moran measures as in Figure 6 and 7 confirm the evidence outlined in Figure 5. The three plots in Figure 6 display the spatially lagged *Spatial RBoD*-scores versus the *RBoD*-scores, *Cond. RBoD*-scores and *Spatial RBoD*-scores, respectively. Figure 7 shows the corresponding local Moran values. The three plots show a decreasing correlation pattern, with the lowest correlation being observed in the right plot for the *Spatial RBoD*-scores. Correspondingly, Figure 7 shows local Moran values which are situated closer to zero for the *Cond. RBoD*-scores and *Spatial RBoD*-scores, with the local Moran value for the *Spatial RBoD*-scores being situated most closely to zero. The combination of both these results

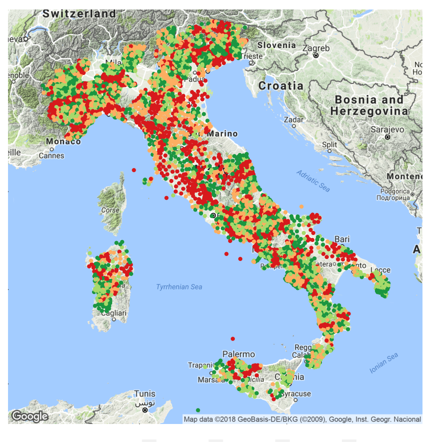
[19] In the figures, the colour scale has been kept specific for each map in order to maintain the variability of each method.



(a) *RBoD*



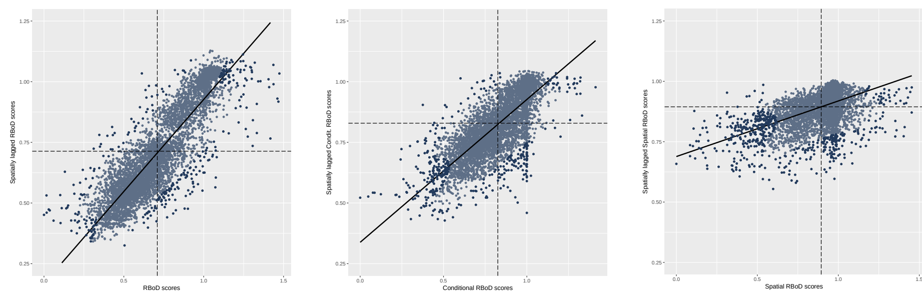
(b) *Cond. RBoD*



(c) *Spatial RBoD*

Figure 5: Comparing the composite waste policy performance scores by method

shows that the *Spatial RBoD*-scores is most successfull in capturing the differences between Italian municipalities in population and economic characteristics as well as the territorial constraints/dependencies linked to organisational and administrative choices.



(a) *RBoD* (b) *Cond. RBoD* (c) *Spatial RBoD*

Figure 6: Comparing the Moran plot by method

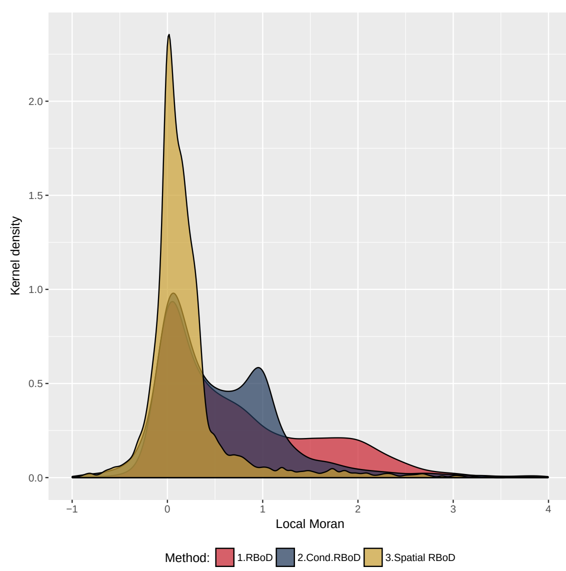


Figure 7: Comparing the local Moran value by method - kernel distributions

Finally, the correlation matrix in Figure 8 describes the correlations among the three BoD-based municipalities' composite waste policy scores (*i.e.*, *RBoD*-scores, *Cond. RBoD*-scores and *Spatial RBoD*-scores) and the constituting sub-indicators.

The correlation results show that: *(i) RBoD*-scores and *Cond. RBoD*-scores are more correlated with the provincial variables (Bad manag. waste % and Good manag. waste %) than the *Spatial RBoD*-scores; *(ii)* at the same time all three composite waste policy scores are equally correlated with variables at the municipal level. Again, this suggest that the *Spatial RBoD*-model is able to better clean the provincial effect, and so administrative constraints, allowing to analyse the specific municipal performance as desired.

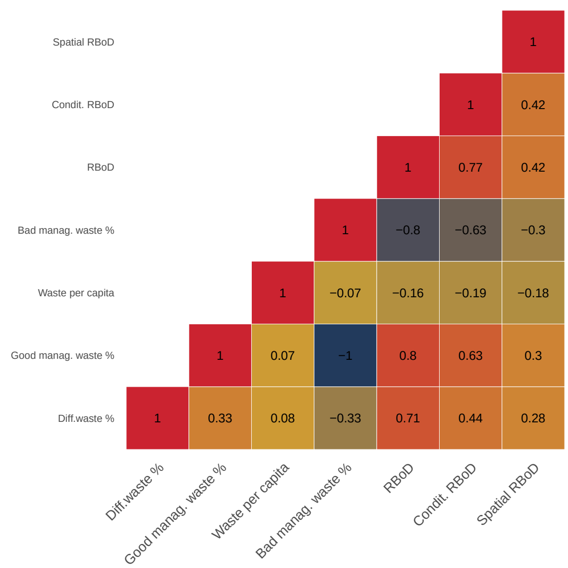


Figure 8: Correlation matrix - simple and composite indicators

6. Final remarks

This paper introduces a new type of BoD-weighted composite indicator that allows to account for: *(i)* the (potential) presence of observations with extreme and/or outlying performance data, *(ii)* a mix of desirable and undesirable performance indicators, *(iii)* differences in potentially influential background characteristics and *(iv)* the presence of spatial dependence. A spatial directional distance robust order-m BoD-model is used to construct this new type of CI. This extended version of the BoD-model defines the conditioning of exogenous variables as a random process that manifests itself in space assuming that the phenomenon under analysis is locally subjected to the same external conditions. The need to develop spatial techniques in the field of constructing composite policy indicators is crucial to correctly evaluate the performance of local administrations in the public sector, given the (practical) importance of evaluating these administrations as uniformly as possible, separating their policy performance from the influential regional characteristics and different resilience of the territories.

The new extension of the BoD-method has been tested on a very extended dataset on the MSW performance data of Italian municipalities. The waste section is a crucial public sector in Italy where the administrative and organisational constraints of the different levels of governance significantly impact the waste policy performance of municipalities. Given the specific nature of waste treatment, with approved and less-fitting ways of treating waste being used, the evaluation of the local waste policy performance involves a mixture of both desirable and undesirable performance indicators. Three versions of BoD-weighted composite performance indicators are constructed for the Italian municipalities to examine the effectiveness of the new version of the BoD-method at capturing differences in background characteristics and spatial constraints/dependencies: the *Robust BoD*-model, *conditional Robust BoD*-model and the *Spatial Robust BoD*-model. For the Italian waste sector, the results show the effectiveness of the new *spatial Robust BoD*-method in identifying and counteracting the provincial conditioning due to the technological constraints related to waste plants and highlighting the advantages of the proposed approach compared to the traditional and conditional robust BoD specifications.

The proposed method opens some interesting streams for further research either linked to the specific procedure or more generally to the BoD composite indicators class; more specifically, the proper spatial bandwidth identification is one of the most promising issue especially in the presence of a non-stationary spatial process. Another promising research field can be the extension of these models to panel data. Finally, joining the conditional and the spatial models may be another analytical point of interest in order to identify the elements most closely linked on the one hand to tangible characteristics and on the other hand to intangible spatial spillovers.

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