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Efficiency of Italian Municipalities and Waste Regulatory Target

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Abstract

Due to increasing consumption and urbanization, urban waste collection has gained a lot of attention in recent years. One of the main problems in this field is the balance between management costs, proper waste collection, and regulatory target. Waste collection is critical to pursue a high recycling capacity. There are two main types of collection: sorted waste, which separates collection after recycling or composting, and unsorted waste, which does not. As a result, Italy's main concerns in recent years have been urban waste management and recycling. One of the main reform in the Italian waste collection was introducing the sorted collection target of 65% with the legislative decree no. 252/2006.

We analyze the efficiency and the effect of population, density, income and size on the sorted waste collection of 275 Italian municipalities from 2016 to 2019. We apply recently introduced smoothed approximations of nonparametric frontier models (Daraio and Simar, 2022) to estimate the coefficients of the cost efficiencies of sorted and unsorted waste. This approach does not assume any hypothesis on the efficient frontier's functional form and on the inefficiency's distribution. We analyze the effect of external and environmental factors, related to economies of scale (population served), territorial size, economies of density (population density) and economic development considering the municipalities that reached the regulatory target and those that did not.

Keywords: waste collection, Italy, FDH, smoothed approximations of nonparametric frontiers, waste economy.

Introduction

Municipal waste management has long been a key issue for Italy and the European Union (EU), with the need to find sustainable and efficient ways to dispose of waste generated by cities in a way that minimizes the impact on the environment and public health, while at the same time trying to minimize the costs of waste management. At EU level, municipal waste management is regulated by the Waste Directive 2008/98/EC, which sets targets for the prevention, reduction, recycling, and recovery of waste. In 2018, the EU adopted the Circular Economy Package, which aims to increase waste recycling and reduce the amount of waste produced. The Circular Economy Package includes several regulations, including strengthening recycling targets for municipal waste (65% by 2035), introducing recycling targets for plastic packaging (50% by 2025) and phasing out single-use plastic packaging. However, the EU still faces significant challenges in managing municipal waste, including the need to improve the quality of recycling, increase the energy efficiency of waste management processes and reduce overall waste generation. In addition, there are significant differences between EU countries in the management of municipal waste, with some countries having achieved high levels of recycling and others still needing to improve. One country in particular, Italy, has been working hard on this front in recent years, with various structural reforms of the entire waste management and waste collection process.

In Italy, the municipal waste problem was exacerbated in the 1990s and 2000s by the closure of several landfills and incinerators, leading to a national waste crisis with mountains of waste piling up on city streets. This crisis prompted Italy to radically reform its municipal waste management system, moving from one based mainly on landfill and incineration to one based on sorted collection and recycling. Italy's municipal waste management reforms began in 1997 with Law No. 94 on Sorted Collection, which established the obligation to differentiate organic and inorganic waste. To improve waste management in Italy, ATOs (Ambiti Territoriali Ottimali) were also initially introduced in 2003 with Legislative Decree No. 36 of January 13, 2003. ATOs are geographical areas defined at regional or provincial level, where the collection, treatment and disposal of urban waste is managed in an integrated manner. The ATO has the task of coordinating waste management between the various municipalities belonging to the territory, to ensure a homogeneous service tailored to the needs of the population. In 2006, Legislative Decree 152/2006 article 205 (Norms Concerning the Environment) introduced the obligation to achieve 65% sorted collection by 2012 (Subsequently, Law No. 221 of December 28, 2015, provided for an increase from 65 to 70 % by 2020), anticipating the European Union's 2018 regulations. To achieve this goal, several actions and tools were activated, including the implementation of door-to-door collection systems, the dissemination of recycling culture, the promotion of the circular economy, and the adoption of penalties for violators. The targets were not changed afterwards because many Italian cities did not reach the targets on time (Agovino et al., 2015). If at the level of the ATO the minimum targets for sorted collection are not achieved, a surcharge of 20% is levied on the landfill tax, sharing the burden among those municipalities within its territory that have not reached the required percentages. These reforms have led to a significant increase in the sorted collection in Italy, from 9.5% in 1997 to 64% in 2022 (ISPRA 2022). However, Italy continues to struggle to meet its targets, with significant regional disparities. The statutory sorted waste target does not consider a fundamental issue that municipalities need to keep under control: the cost of waste collection.

The management of municipal solid waste usually accounts for a significant share of the total expenditure of local governments (Sarra et al., 2017). Furthermore, the imposition of the same threshold for all Italian cities does not consider the territorial, socio-economic and technical characteristics that may affect the achievement of this target. Prioritizing sorted collection is fundamental to the entire waste management process. This is because waste management involves several stages with collection as the downstream stage of subsequent treatment. There are two main types of waste collection: sorted waste, which is collected separately and recycled or composted, and unsorted waste, which is not collected separately. The treatment of sorted waste collection basically consists of sending the different product fractions to recycling/recovery plants to produce new materials, after a possible sorting phase. Material recovery operations include biological treatment of the organic fraction (composting and anaerobic digestion). Biological treatment can produce soil improvers from organic waste. Anaerobic treatment can also combine the production of soil improver with the production of biogas, which can be used as an energy source. Unsorted municipal waste is mainly sent to pre-treatment plants, where the recyclable fractions are separated from the non-recyclable fractions destined for landfill.

The objective of this study is to assess the presence of economies of scale, economies of density and the effect of economic development on the municipal waste collection of Italian municipalities considering the achievement of the regulatory target on sorted waste collection. The decision to reach the target by increasing collection costs to implement the sorted collection system or to accept the 20% surcharge for landfilling is a trade-off that decision makers must consider. Although required by law, whether the sorted waste target is reached is closely linked to the policies adopted and the budget available to municipalities. For this reason, the study considers municipalities that have reached the target and those that have not, to understand whether, and to what extent, efficiency achievement in the two cases is different and what external factors influence efficiency in each case.

Literature Review

The topic of efficiency in municipal waste management and the balance between costs and waste collection is much discussed in the literature. This is because it directly influences the safety, hygiene, health, and welfare aspects of cities. Simões and Marques (2012) reviewed 107 studies from 1965 to 2010. They found that the most used method to assess efficiency in this sector is the non-parametric approach most often Data Envelopment Analysis (DEA). Most of the studies reviewed attempt to determine the relative efficiency of utilities in a specific country or region (e.g., Gonzalez-Garcia et al, 2018 in Spain, De Jaeger et al, 2011 for the Belgian case, Yang and Zhang, 2011 for Taiwan, Huang et al, 2018 for China and, Struk and Boďa, 2022 for the Czech Republic).

The literature on Italian urban waste management is quite rich. Antonioli and Filippini (2002) analyse the collection of municipal waste in Italy using a translog cost function. Their analysis focuses on the cost structure of 30 Italian utilities using data from 1991 to 1995. Findings showed that several firms in the waste collection and disposal industry are not scale efficient. Passarini et al. (2011) investigated the relationship between waste management and spatial characteristics for 341 municipalities in Emilia-Romagna in 2008. They found that municipalities having a population density between 150 and 500 inhabitants per square kilometre (km^2) are those where high performances and efficiency can be most easily achieved. Sarra et al. (2017) used a DEA-based model to calculate the service efficiency of 289 municipalities in the Abruzzo region between 2011 and 2013. They considered both the economic and environmental performance using the unsorted waste fraction as an undesirable output to minimise. Romano and Molinos-Senante (2020) used directional DEA to analyse 225 municipalities in Tuscany in 2016. They identify the presence of economies of scale and density: municipalities with more inhabitants have higher eco-efficient scores, smaller municipalities in terms of the size of the territory served and municipalities with higher population density are more efficient. The presence of economies of density is also in agreement with the review by Simões and Marques (2012). Romano and Molinos-Senante also identified other external factors that influence efficiency with a negative effect such as the age of the inhabitants and present tourism. Again, in the case of Tuscan municipalities, Romano et al. (2020) carried out an order-m analysis for 220 Tuscan municipalities to assess waste management efficiency. They identify the presence of economies of density in waste management and a negative effect of average annual income per capita on efficiency, as also found by Benito et al. (2011) in the Spanish case. Romano and Molinos-Senante found that an increase in the sorted collection rate beyond 50% reduces efficiency. The presence of economies of scale and density is discordant with what Greco et al. (2015) identify for the collection costs of 68 Italian municipalities. Using an Ordinary Least Square (OLS) stepwise they conclude that there is an increase less than proportionally with respect to the volume of waste collected. Guerrini et al. (2017)

used an order-m analysis and, as a second step, a truncated regression to analyse the efficiency in waste collection of 40 municipalities in the province of Verona (Italy). They found that integrating collection services in different small municipalities to exploit economies of scale is not very beneficial.

Another factor that influences efficiency according to the literature is tourism. Guerrini et al. (2017) found that the municipalities of Verona province with not very high tourist flows and with a relevant rate of non-residential customers highlight lower efficiency. Greco et al. (2018) with a regression analysis also found a negative effect of tourism on the cost of 67 Italian municipalities in 2011.

Lombardi et al. (2021) applied DEA to the case of 78 large Italian cities for the period 2014-2018. Compared to previous work, they identify a presence of density economies up to a population density of 1,500 inhabitants/km^2, identifying a positive correlation between the presence of the elderly and the amount of sorted waste, in contrast to what was observed by Romano and Molinos-Senante. Lombardi et al. (2021) state that a determining factor for efficiency concerns the Italian area analysed (Northeast, Northwest, Centre, South, and Islands), identifying municipalities in the South and Islands as less efficient. The differences in terms of geography and local management were previously explored by Agovino et al. (2018), which showed a high inefficiency in waste collection for Italian provinces in central Italy.

Agovino et al. (2016) analyse 103 Italian provinces from 1996 to 2012 showing an adverse relationship between city size and recycling rate and a strong difference in the percentage of sorted waste in Italian macro-areas. D'Amato et al. (2015) agree with that and identify as an important factor the presence of organized crime in local governments and illegal activities thriving in the sphere of waste management. The relationship between corruption and maladministration and inefficiency was further investigated by Romano et al. (2021) who using propensity score matching analysis identified corruption and maladministration in waste management in 66 Italian provinces in the period 2015-2017 as a decisive factor of inefficiency. Using data of municipalities in the Lombardy region, Gaeta et al. (2017) showed that the municipal waste recycling rate is affected by population and household size, population age, income, and municipality altitude.

The literature on the Italian case highlights several possible external factors that influence the efficiency of waste management and collection that can be summarised in:

Morpho-demographic Characteristics:

- Geographical characteristics (e.g., altimetry, Sarra et al., 2017, Agovino et al., 2018, Di Foggia and Beccarello, 2020).
- Population served and Population Density. (Passarini et al., 2011, Greco et al., 2015, Agovino et al., 2016, Guerrini et al., 2017, Fusco and Allegrini, 2020, Romano and Molinos-Senante, 2020, lo Storto, 2021, Lombardi et al., 2021);
- Geographical location (Greco et al., 2015, Agovino et al., 2016, Agovino et al., 2018)
- Household characteristics (Sarra et al., 2017, Guerrini et al., 2017)

Socio-economic Characteristics:

- Economic information like per capita income (Passarini et al., 2011, Sarra et al., 2017, Romano et al., 2021).
- Population seniority (Romano and Molinos-Senante, 2020).
- Corruption and criminal activities (Di Pillo et al., 2023, D'Amato et al., 2015, Agovino et al., 2018 and Romano et al., 2021)
- Tourist and non-residence presence (Sarra et al., 2017, Greco et al., 2018, Guerrini et al., 2017)

Technical caractheristics:

- Roads length (Sarra et al., 2017, lo Storto, 2021)
- Collection method (Guerrini et al., 2017)
- Load capacity (Guerrini et al., 2017)

The relationship between efficiency and the achievement of the DL no. 152/2006 target has not been explored yet at the municipal level. In addition, the literature is conflicting on the existence of economies of scale, economies of density, and on the influence of economic development factors.
The objective of this work is to estimate how various external factors influence the efficiency of Italian municipalities distinguishing those that reached the 65% sorted waste target from those that did not. The next section outlines the methodology applied.

Methodology

Starting from the seminal paper by Farrell (1957) in the efficiency analysis literature two main approaches have been developed to estimate the efficiency scores calculated on a set of units, based on the information of the inputs or resources used to produce the outputs or outcomes. The nonparametric approach is more general and flexible because does not specify any functional form for the efficient frontier and is based on envelopment estimators such as DEA (which assumes convexity and free disposability[1] of the inputs and outputs) and FDH (which assumes only free disposability). The parametric approach requires the strong hypothesis for the specification of a functional form for the efficient frontier and for the distribution of the inefficiency, but in turn allows estimating the coefficient of economic interest (for an overview, see Fried et al., 2008). To understand how municipalities achieve their efficiency and how external factors may influence their efficiency, we use the methodology proposed by Daraio and Simar (2022), hereafter DS, to which we refer the readers for more details. We apply for the first time, in the waste management sector, a flexible approximation of nonparametric frontiers to estimate a more robust coefficient of economic interest without having to assume a functional specification for the efficient frontier. Differently from previous literature, first, we estimate a nonparametric directional FDH efficient frontier and after that, we smooth this nonparametric frontier using a local linear regression to derive the coefficients of interest (e.g., marginal products).
Formally, let the set of technically feasible combinations of inputs (X) and outputs (Y), be defined as $\Psi = \{(x,y) \in R^{(p+q)} | x \; can \; produce \; y\}$. The efficient boundary (frontier) of this set is the set of efficient combinations of inputs and outputs such that:

$$\Psi^{\partial} = \{(x,y) \in R^{(p+q)} \big| (\gamma^{(-1)}x, \gamma y) \notin \Psi, \forall \gamma > 1\}.$$

There are several ways for measuring the efficiency of a production plan (x, y) as the distance from this boundary. In this article we adopted the directional distances measures (see Chambers et al., 1998), defined as $\delta(x,y) = \sup\{\delta \big| (x - \delta d_x, y + \delta d_y) \in \Psi\}$, where $d_x \in R_+^p$ and $d_y = R_+^q$. So, the distance is measured along a path determined by a direction vector $d' = (-d'x, d'y)$ in an additive way, where if (x, y) lies on the efficient frontier $\delta(x,y) = 0$.
The main steps of the method proposed by DS can be summarized as follows:

- From the sample of observations $X_n = (X_i, Y_i)_{i=1}^n$ compute the nonparametric estimators $\hat{\delta}_i$, I = 1. . .n of the directional distances. We use the FDH estimator (see Daraio et al., 2020, for more details and for the Matlab programs to make the computation). After that transform the data by the rotation $\begin{bmatrix} V_i \\ U_i \end{bmatrix}$=$R_d \begin{bmatrix} X_i \\ Y_i \end{bmatrix}$ where R_d is a fixed non-random rotation matrix. This is required for the multivariate case, see more details in DS.
- Project the observed U_i on the nonparametric frontier, providing $\widehat{U}_i^{\partial} = U_i + \|d\| \hat{\delta}_i$
- Use the sample $(V_i, \widehat{U}_i^{\partial})^n{}_{i=1}$ to find the best nonparametric approximation of the frontier function φ(v) available for all values of v (local linear approximation)[2]: Using $\widehat{U}^{\partial}$ as the

[1] Possibility of destroying or sparing goods/resources without costs.
[2] This allows us to have an estimate of the derivatives and other coefficients of interest at each point, in particular for each observation V_i, i=1…n

appropriate estimator of U^∂ the (local) values of $\theta(v) = [\alpha(v)\ \beta'(v)]'$ will be estimated from the sample $\left\{V_i, \widehat{U}_i^\partial\right\}_{i=1}^n$ by the weighted least squares problem:

$$\left(\hat{\alpha}_n(v), \hat{\beta}_n(v)\right) = argmin_{\alpha,\beta}\left[\sum_{i=1}^{n}\{\widehat{U}_i^\partial - \left(\alpha + \beta'(V_i - v)\right)\}^2 K_h(V_i - v)\right]$$

Where $\hat{\alpha}_n(v)$ is the estimated smoothed value of φ(v) and that $\hat{\beta}_n(v)$ provides an estimator of the first derivatives $\nabla\varphi(v)$ and $K_h(V_i - v)$ is a kernel weighting function localizing the values V_i in a neighbourhood of v and h is a vector of bandwidths determined by least-squares cross validation (LSCV), see e.g., Li and Racine (2007) for details.

The derivatives and coefficients of interest in terms of v can be transformed into the original unit x,y following DS (see DS for further details). In this paper, we applied this methodology in different contexts (by single year and distinguishing between cities that met the target and those that did not). In addition, we condition the efficient frontier estimation to several external factors (Z) once at a time.

Data

The study focuses on the urban waste collection of 275 Italian municipalities from 2016 to 2019. The choice of 2016 as the starting year is to have homogeneous data and the same data collection methodology, identified by the Decree of the Ministry of the Environment and Protection of the Land and Sea of 26 May 2016 (published in the Official Gazette of the Italian Republic, General Series, no. 146 of 24-6-2016). This methodology has some differences from the one adopted until 2015, so the data from 2016 onwards are not fully comparable with those of the previous historical series. Data were collected from the report on municipal waste of the Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA, 2022). The information collected refers only to those municipalities with at least 10000 inhabitants and with information available for the entire period considered. Data include the total cost of municipal waste collection[3], the tonnes of separated municipal waste and the tonnes of mixed waste in each municipality. Following Guerrini et al. (2017) we aggregate the collection cost items into a single cost value; this allows us to measure cost efficiency, since prices are the same among the observed units.

The choice of Italian municipalities as units of analysis is mainly related to the fact that individual municipalities are responsible for the collection of municipal waste, as opposed to the other phases of waste management, which are the responsibility of different entities.

To analyse the presence of economies of scale, density and the relationship with economic development, information was collected on population served, territorial size (in square kilometres, Km^2), taxable income (fiscal year prior to the year of analysis, e.g., for the year 2019 we refer to 2018 tax income). In addition, the cities were divided between cities that have achieved the targets set by dl 152/2006 (i.e., 65% of separated municipal waste) and those that did not. In Appendix A are presented the number of target and non-target municipalities per year and the main statistical information on the collected data. The dataset covers approximately 35 percent of the entire Italian population.

The question of balancing cost and target attainment is of primary importance for policy makers. To assess the efficiency of municipalities in balancing collection costs and sorted waste we use a model consisting of the total cost for waste collection as input (X), tonnes of unsorted waste as Bad Output (BY, treated as an input in the frontier estimation), tonnes of sorted waste as output (Y). In the analysis, all variables are scaled by their empirical standard deviation to improve the calculations.

[3] *ISPRA data of costs are per inhabitant served. The data considered are therefore the collection costs per inhabitant (provided by ISPRA) multiplied by the number of inhabitants served (Always ISPRA data available in the same dataset provided).*

We decided to use the direction vector d=*median*(x,y)= d =[-0.1173, -0.0982; 0.1995] as a balanced direction for each unit.

Results and discussion

The analyses carried out focus mainly on the estimation of the impact or effect of inputs or outputs on the efficient frontier and on the effect of external factors on the inputs used. In the following, all results in red in the figures refer to municipalities that did not reach the target for a specific year, while the results in blue refer to municipalities that reached the 65% target. The next section shows the base case, i.e., the efficiency estimation without external factors influencing the frontier. In the following sections there are the results which include the different external factors considering relevant by the existing literature analysed above.

Basic case: no external factors considered

As a first analysis, the frontier was estimated to be unconditioned by any external factor. The analysis performed identifies as outliers Rome for the years 2016, 2018 and 2019, Brescia for 2017 and Reggio Emilia for 2017. We estimate the derivatives of the efficiency with respect to cost (X) for each municipality. Figure 1 shows the details of the derivatives with respect to cost distinguishing between municipalities that reach the 65% target (bottom section of Figure 1) from those that did not reach the target (upper section of Figure 1) and reporting the variation across years by column, from 2016 on the left to 2019 on the right.

We estimate the derivatives of the efficiency with respect to the unsorted waste (bad output BY, Figure 2). Finally, we estimated the derivatives of efficiency with respect to the output (sorted waste, Y, Figure 3). In Figures 1, 2 and 3 there is a black dotted line in correspondence to zero. The closer the values are to the dotted line, the closer the unit is to the efficient frontier. A positive coefficient (above 0) implies a negative effect on efficiency, because when the input X increases also the inefficiency increases (remember that an efficiency score equal to zero identifies units on the efficient frontier, while efficiency score higher than zero implies inefficiency) vice versa in the case of a negative value (coefficients below zero means that when X increases the inefficiency decreases and the units are closer to the efficient frontier). Figure 1 shows that the two groups of target units differ in the increase of costs and the attainment of efficiency: in the case of non-target municipalities (bottom section of Figure 1), as costs increase, they move away from efficiency. Target units instead (upper section of Figure 1) show a mixed effect, with the units that seem to approach the efficient frontier in the first year of analysis. Figure 2 shows that the increase of unsorted waste BY) plays a positive role in approaching the frontier for non-target and target units up to a certain threshold, and after that it has a negative impact on the efficiency. Figure 3 shows an almost constant effect of sorted waste on efficiency that brings all analysed units closer to the frontier.

These first results show that the two groups have differences in the attainment of efficiency mainly attributable to costs: those on target seem to have efficiency benefits. The opposite is true for those who are not on target. It seems that those who are not on target try to keep their collection costs as low as possible to be efficient in their group.

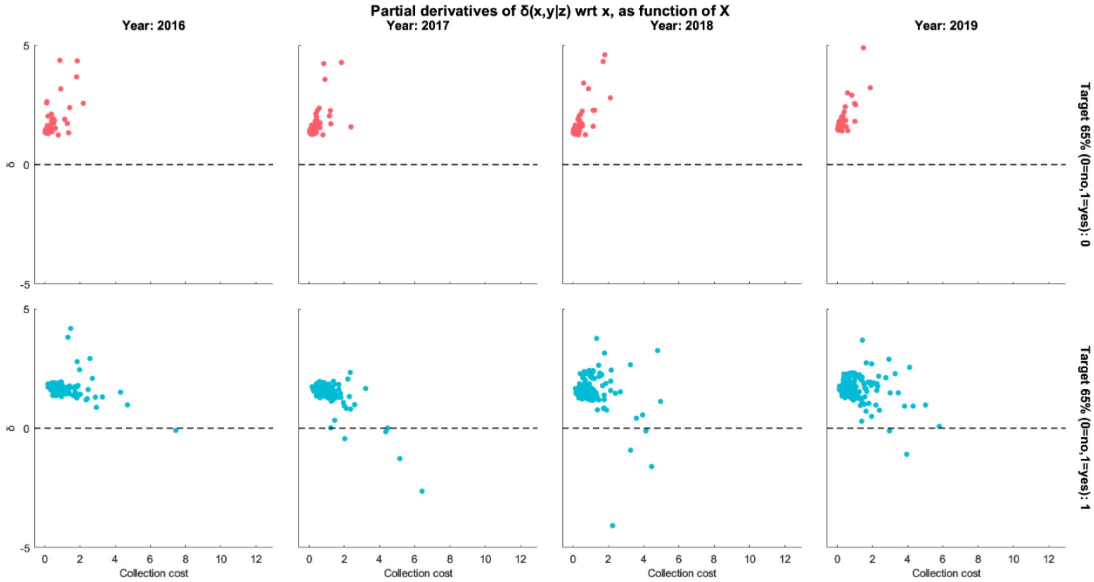

Fig 1 Derivatives of the efficiency (one for each municipality) with respect to X (cost). Each point represents a municipality.

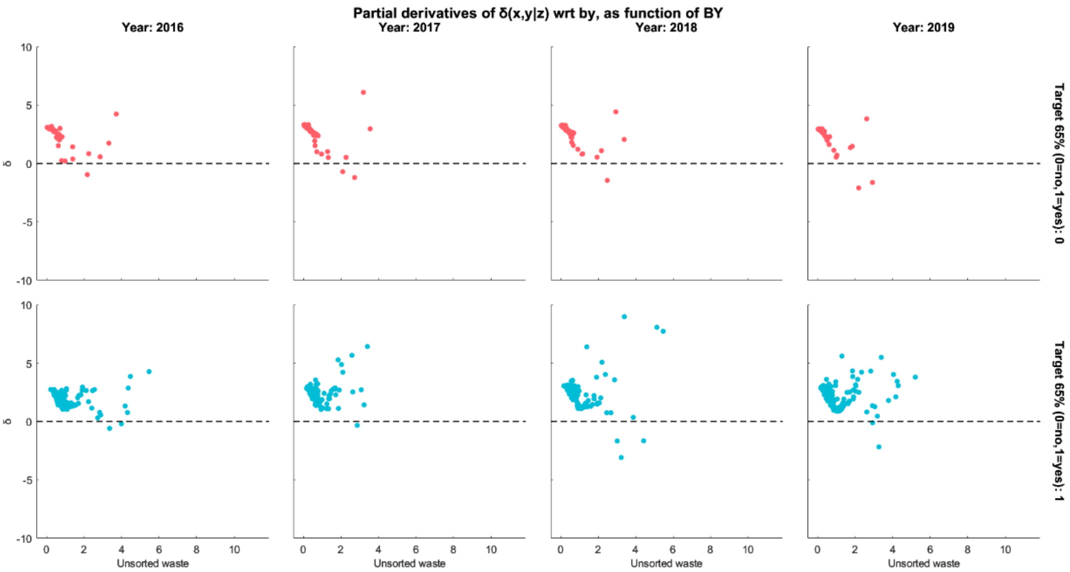

Fig 2 Derivatives of efficiency (one for each municipality) with respect to BY (bad output). Each point represents a municipality.

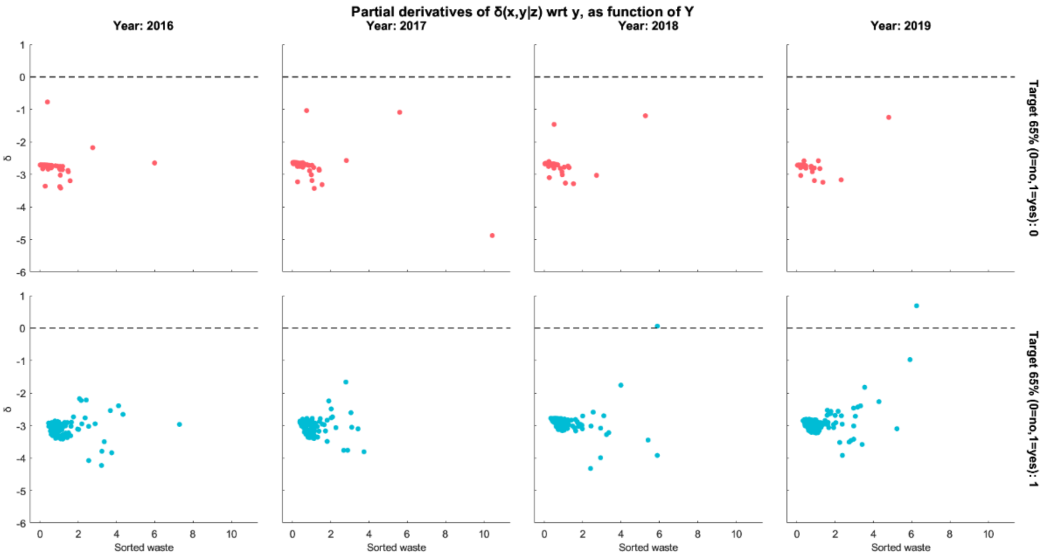

Fig 3 Derivatives of efficiency (one for each municipality) with respect to Y. Each point represents a municipality.

Population case

In this section, we analyse efficiency by including an external factor, i.e., by conditioning the estimate on the population served in the various municipalities.

Figure 4 shows the partial derivatives of the efficiency conditioned to population (δ (x,y|z)) with respect to collection cost (X). Again, it reports in the upper section the non-target municipalities and in the bottom section the target ones: by columns there are the years starting with 2016 on the left to 2019 on the right.

Figure 5 reports the partial derivatives of the efficiency conditioned to population (δ (x,y|z)) with respect to unsorted waste (BY). Again, it reports in the upper section the non-target municipalities and in the bottom section the target ones: by columns there are the years starting with 2016 on the left to 2019 on the right.

Figure 6 illustrates the partial derivatives of the efficiency conditioned to population (δ (x,y|z)) with respect to sorted waste (Y). Again, it reports in the upper section the non-target municipalities and in the bottom section the target ones: by columns there are the years starting with 2016 on the left to 2019 on the right.

Figures 4, 5 and 6 show the difference between target and non-target municipalities in the achievement of efficiency. Figure 4 shows how rising costs bring target municipalities closer to the frontier, while non-target municipalities show the opposite trend. Figure 5 shows that municipalities not in target have an improvement in efficiency if they produce a lot of unsorted waste (high values of BY). In Figure 6 is possible to visualize that the increase of sorted waste has a positive effect on the efficiency when its amount increases.

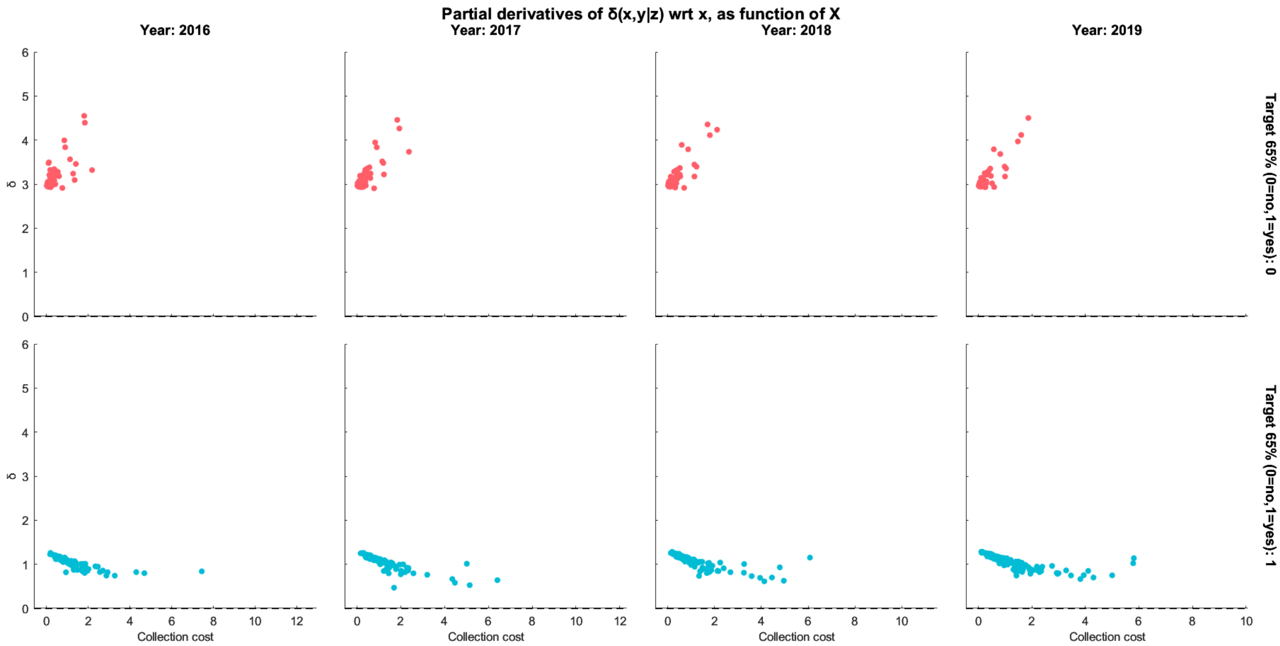

Fig 4 Partial derivatives (one for each municipality) of the efficiency scores conditioned to z=population (δ (x,y|z)) with respect to X (collection cost) as function of X. Each point represents a municipality.

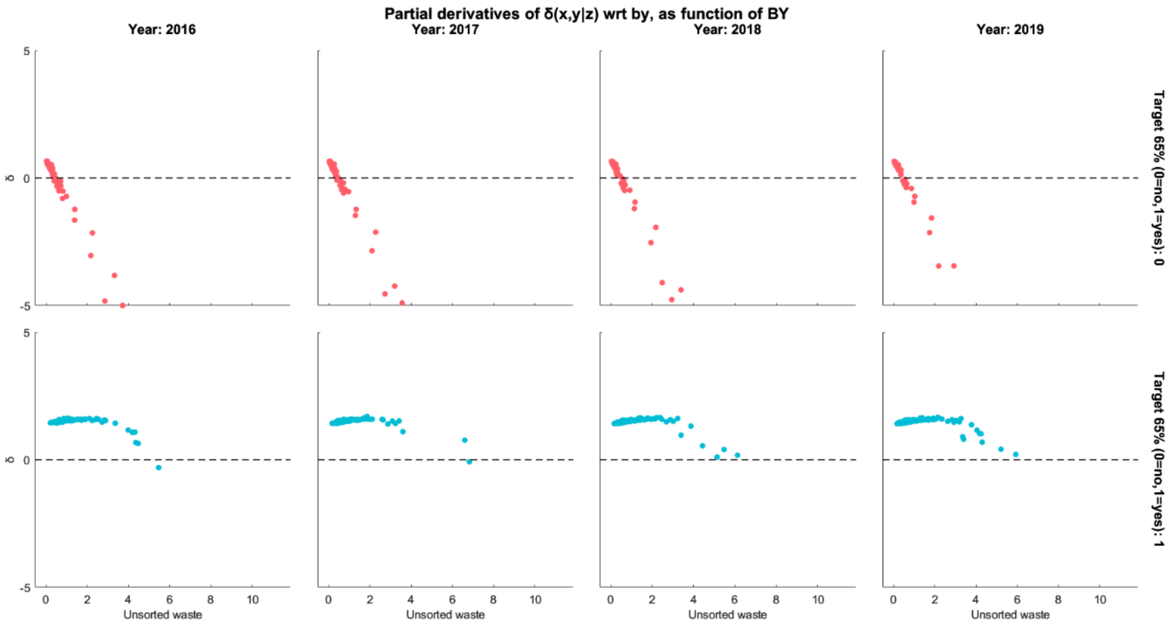

Fig 5 Partial derivatives (one for each municipality) of the efficiency scores conditioned to z=population (δ (x,y|z)) with respect to BY (unsorted waste) as function of BY. Each point represents a municipality.

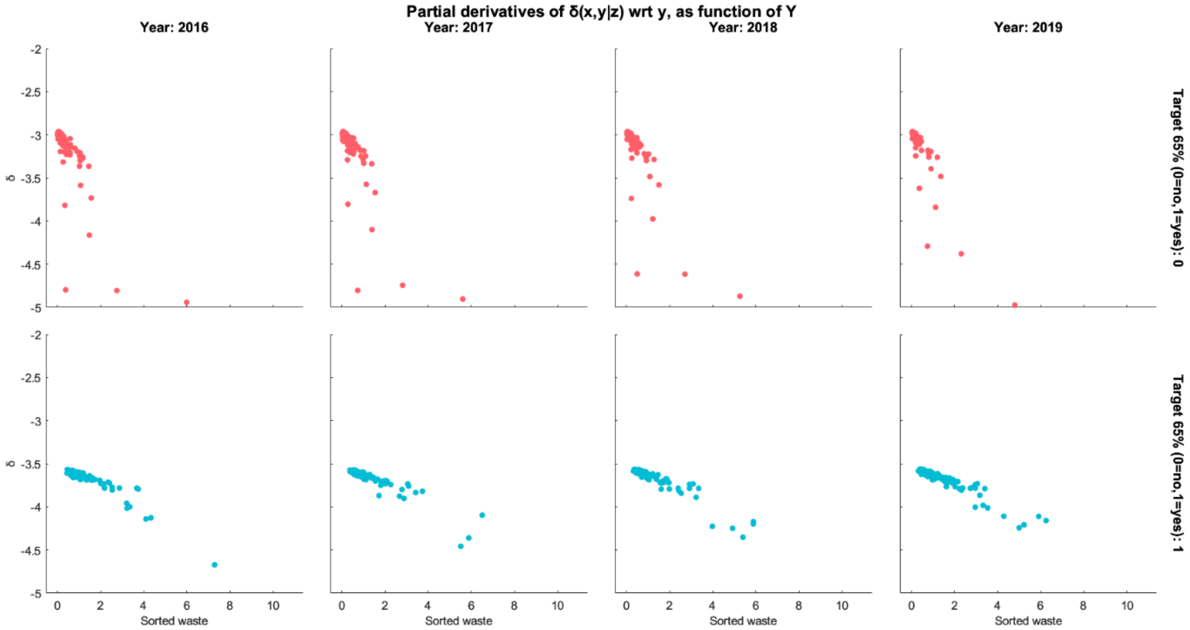

Fig 6 Partial derivatives (one for each municipality) of the efficiency scores conditioned to z=population (δ (x,y|z)) with respect to Y as function of Y. Each point represents a municipality.

Focusing on the effect of the population on the production factors, as the population increases, the cost of collection decreases (Figure 7), the tonnes of unsorted waste decrease (Figure 8) and the increase in sorted waste increases (Figure 9). In all cases for the non-target municipalities (Blue boxplots in the figures) the effect of increasing population is more evident. However, it must be considered that the non-target municipalities are on average municipalities with fewer inhabitants than the non-target municipalities. The results obtained therefore show an important effect of population on costs and quantities, highlighting the presence of economies of scale.

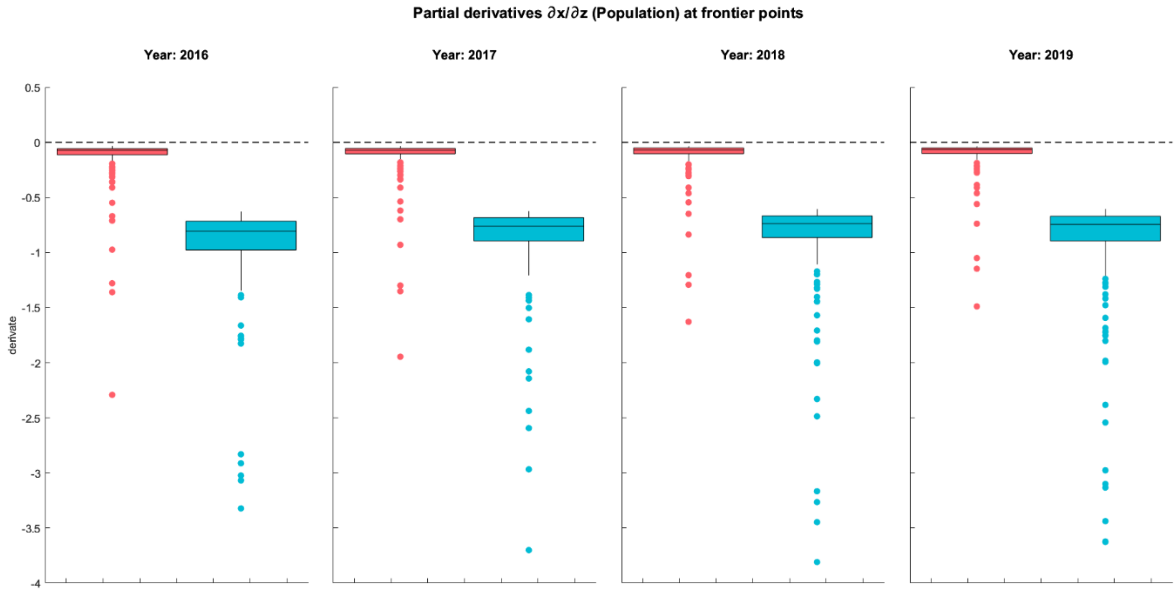

Fig 7 Partial derivatives dx/dz (population) at frontier points. Red boxplots show target municipalities, blue boxplots non-target municipalities. Each point represents a municipality.

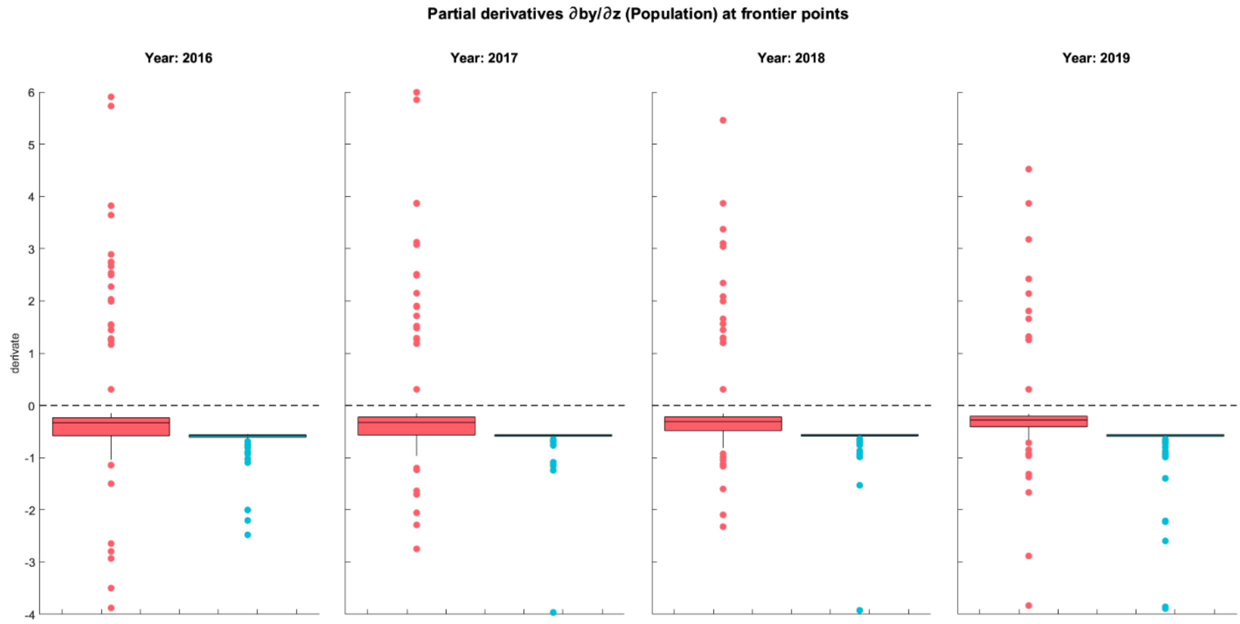

Fig 8 Partial derivatives dby/dz (population) at frontier points. Red boxplots show target municipalities, blue boxplots non-target municipalities. Each point represents a municipality.

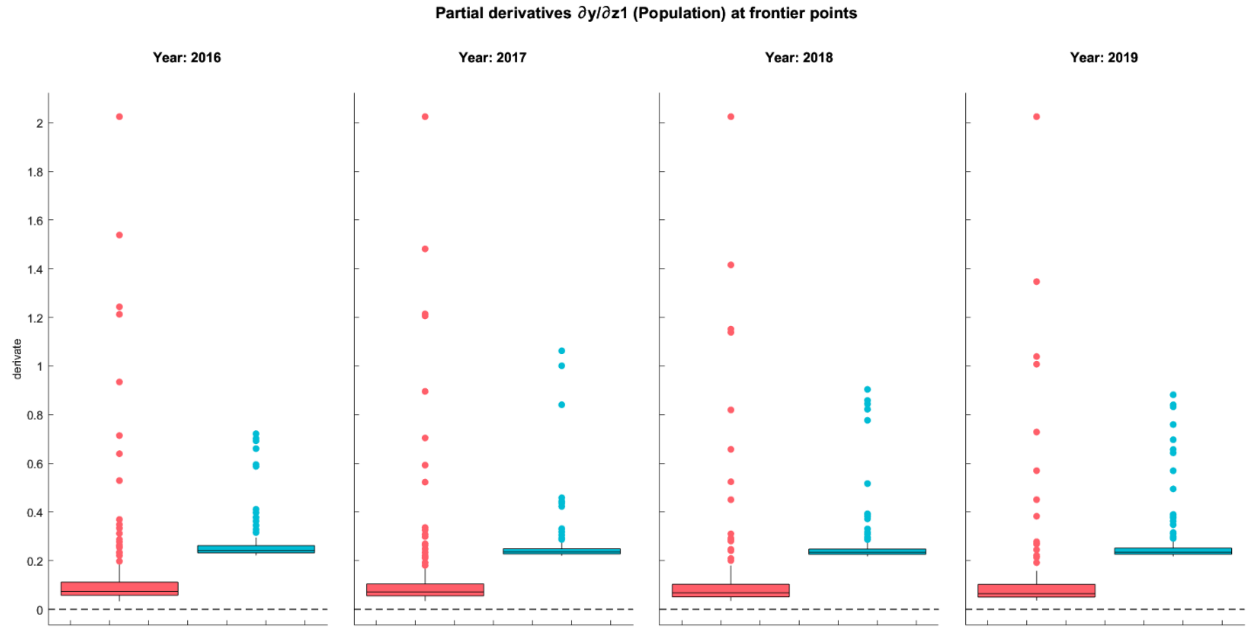

Fig 1 Partial derivatives dy/dz (population) at frontier points. Red boxplots show target municipalities, blue boxplots non-target municipalities. Each point represents a municipality.

Size of municipalities case

This section presents the analysis conditioned on the size of the municipalities in km^2. Three outliers were identified: Rome (2016); Rome (2019) and Brescia (2017).

Figure 10 shows the partial derivatives of cost (X) with respect to size of municipalities (Z) at frontier points.

Figure 11 reports the partial derivatives of the bad output (BY) with respect to size of municipalities (Z) at frontier points.

Figure 12 illustrates the partial derivatives of output (Y) with respect to size of municipalities (Z) at frontier points.

Considering the effect of size of municipality (Figures 10, 11 and 12) only to a small extent the target municipalities see a decrease in costs with increasing size (of municipality), a decrease in unsorted waste with increasing size and an increase in sorted waste with increasing size. No decisive role of size of municipalities on costs and quantities collected is evident (see Figures 10, 11 and 12).

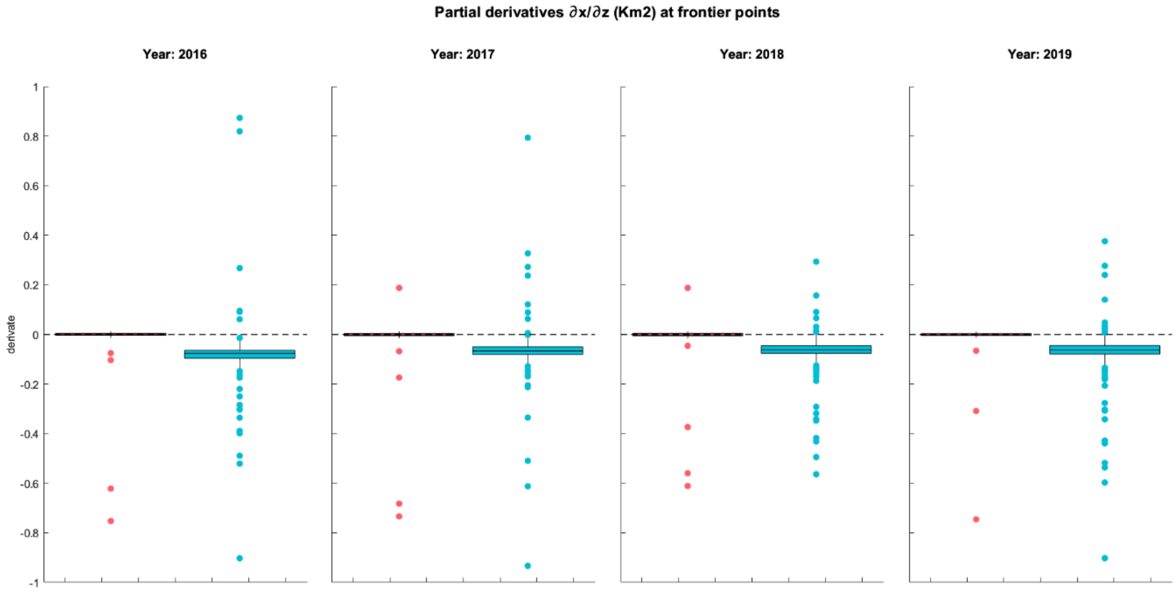

Fig 2 Partial derivatives dx/dz (km²) at frontier points. Red boxplots show target municipalities, blue boxplots non-target municipalities. Each point represents a municipality.

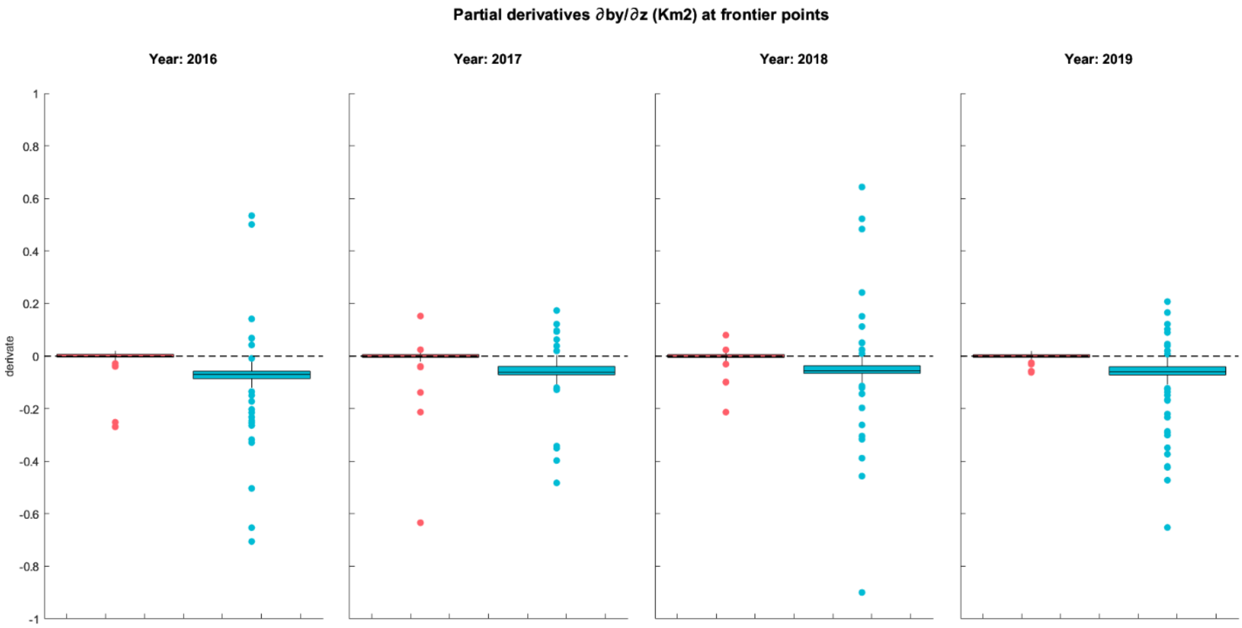

Fig 11 Partial derivatives dby/dz (km²) at frontier points. Red boxplots show target municipalities, blue boxplots non-target municipalities. Each point represents a municipality.

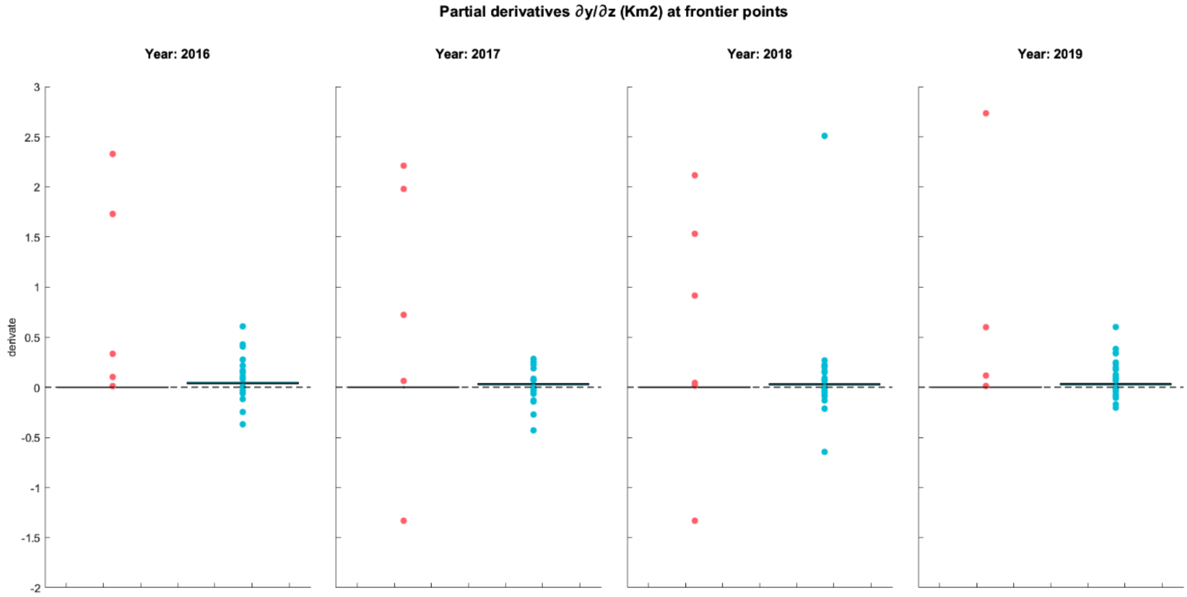

Fig 12 Partial derivatives dy/dz (km^2) at frontier points. Red boxplots show target municipalities, blue boxplots non-target municipalities. Each point represents a municipality.

Population density case

This section shows the analysis carried out on the frontier conditioned on the population density of municipalities measured as population per km^2 of municipal territory. Six outliers were identified: Rome (2016, 2017 and 2019), Parma (2016), Reggio Emilia (2017) and Brescia (2017).
Figure 13 shows the partial derivatives of cost (X) with respect to population density of municipalities (Z) at frontier points.
Figure 14 reports the partial derivatives of the bad output (BY) with respect to population density of municipalities (Z) at frontier points.
Figure 15 illustrates the partial derivatives of output (Y) with respect to size of municipalities (Z) at frontier points.
Considering the effect of density of municipality (Figures 13, 14 and 15) the results show an adverse effect of density on costs (X) for the group of target municipalities (as density increases, costs increase), while a zero effect for non-target municipalities. It can be seen for the target municipalities that as density increases, the amount of unsorted waste increases and the amount of sorted waste decreases. This result contrasts the presence of economies of densities that was found in previous literature. On the contrary, we found evidence of diseconomies of density for Italian municipalities. Furthermore, by combining the results of the analysis in the case of population and in the case of size of municipality, considering only size, this does not have a decisive effect, but combined with population, small and highly populated cities are disadvantaged. For municipalities that have not reached the target, on the other hand, population density does not have an important impact on the production factors considered (X, BY and Y).

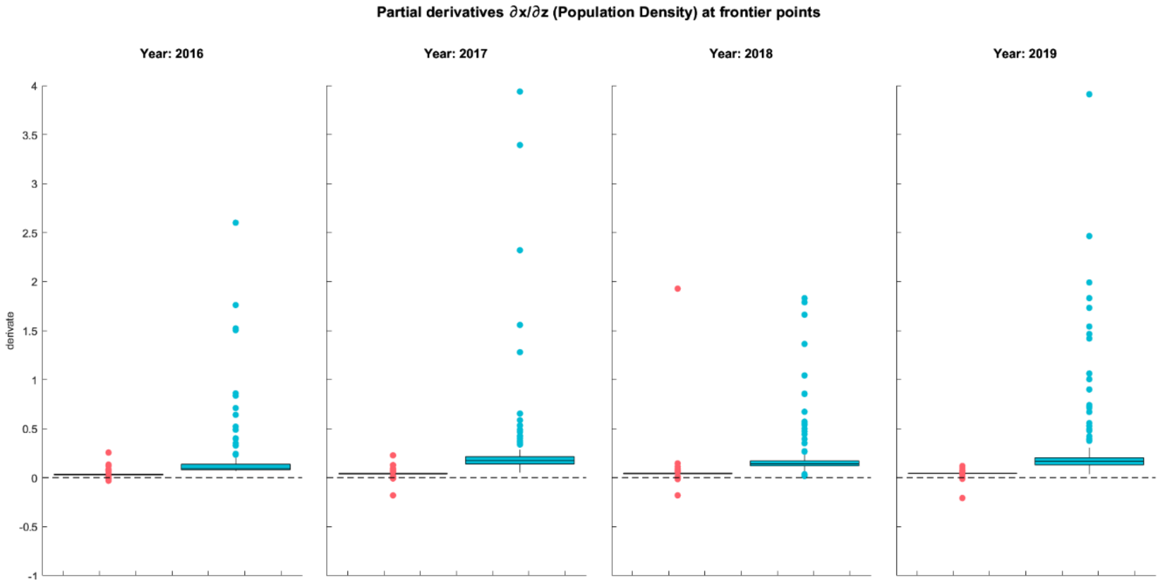

Fig 13 Partial derivatives dx/dz (population density) at frontier points. Red boxplots show target municipalities, blue boxplots non-target municipalities. Each point represents a municipality.

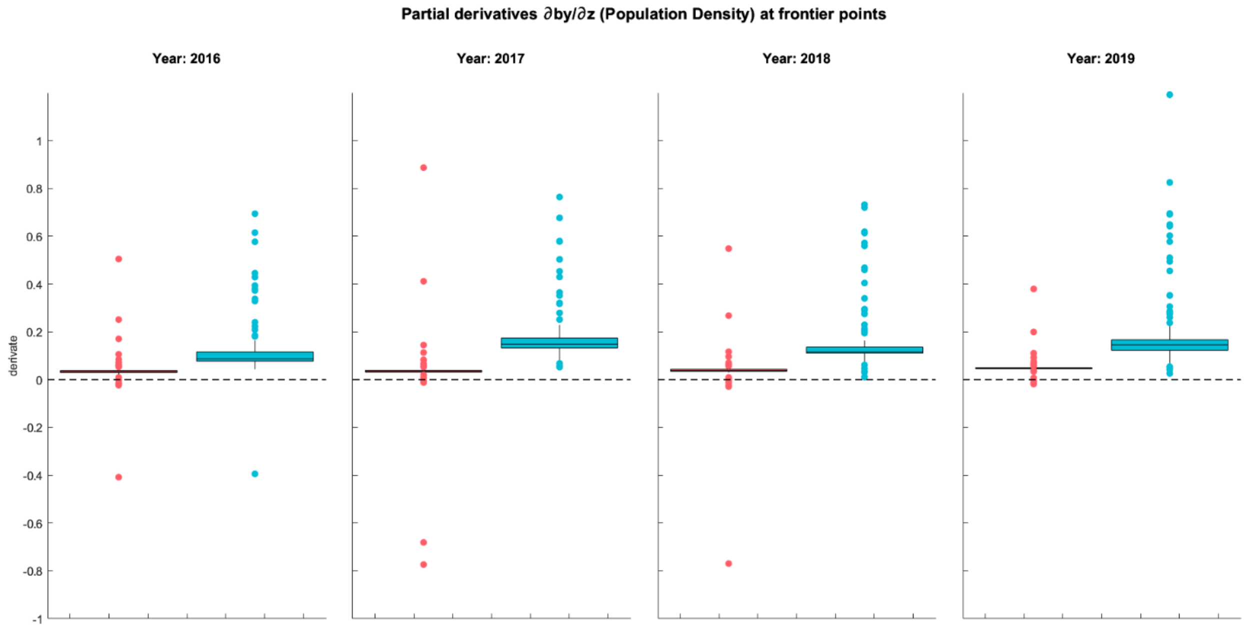

Fig 14 Partial derivatives dby/dz (population density) at frontier points. Red boxplots show target municipalities, blue boxplots non-target municipalities. Each point represents a municipality.

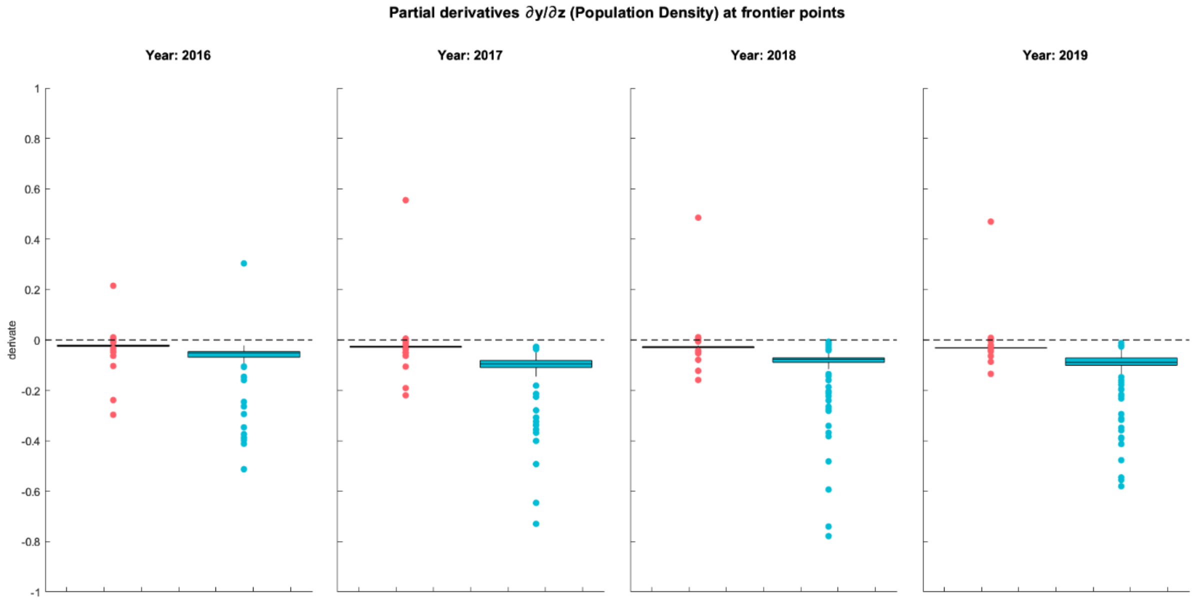

Fig 15 Partial derivatives dy/dz (population density) at frontier points. Red boxplots show target municipalities, blue boxplots non-target municipalities. Each point represents a municipality.

Total income case

This section shows the analysis carried out on the frontier conditioned on the total income as a proxy of the economic development of the municipalities.

Figure 17 shows the partial derivatives of cost (X) with respect to population density of municipalities (Z) at frontier points.

Figure 18 reports the partial derivatives of the bad output (BY) with respect to population density of municipalities (Z) at frontier points.

Figure 19 illustrates the partial derivatives of output (Y) with respect to size of municipalities (Z) at frontier points.

Considering the effect of economic development of the municipality (Figures 17, 18 and 18) it is possible to see that the increasing of the total income has a negative effect on the cost and the unsorted waste while have a positive effect on the sorted waste. The results show that the economic development of a municipality have a decisive impact on the sorted collection and cost sustained. Considering the income per capita as external factor Z we obtain similar results that we do not report to save space.

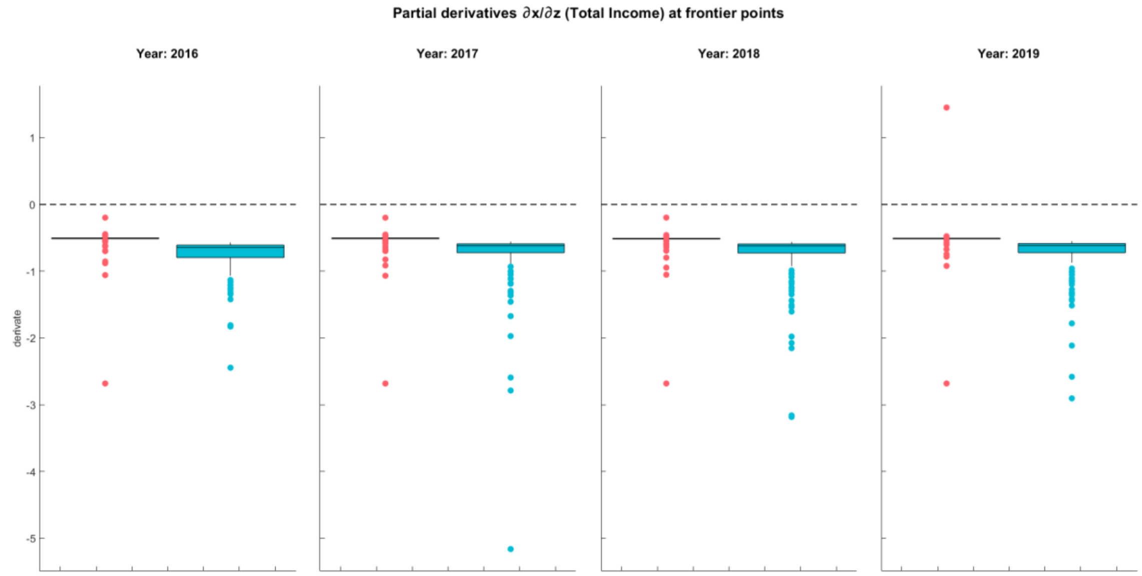

Fig 16 Partial derivatives dx/dz (total income) at frontier points. Red boxplots show target municipalities, blue boxplots non-target municipalities. Each point represents a municipality.

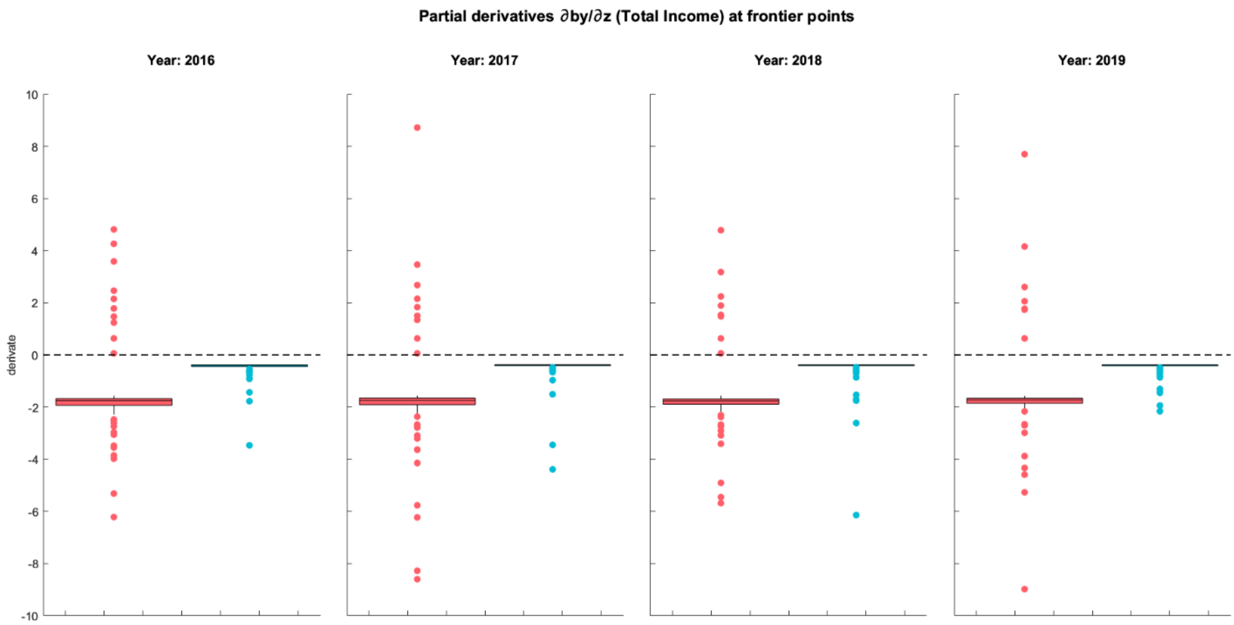

Fig 17 Partial derivatives dby/dz (total income) at frontier points. Red boxplots show target municipalities, blue boxplots non-target municipalities. Each point represents a municipality.

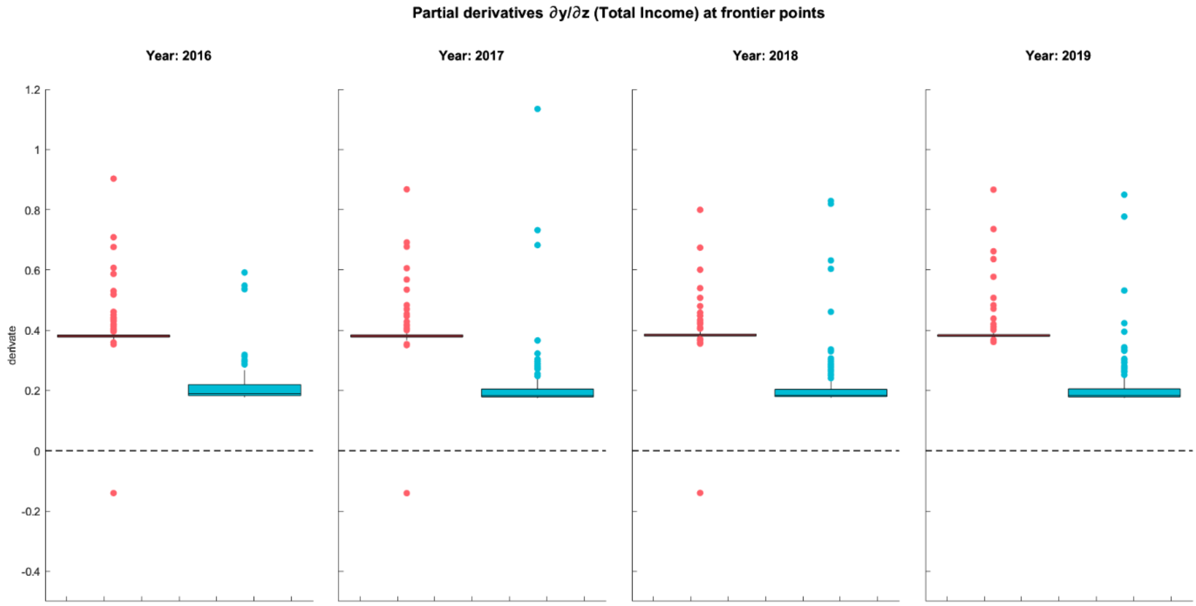

Fig 18 Partial derivatives dy/dz (total income) at frontier points. Red boxplots show target municipalities, blue boxplots non-target municipalities. Each point represents a municipality.

Conclusion and policy implications

The present article analysed the efficiency of municipal waste collection in Italy, considering municipalities that reached the regulatory target and those that did not. We assess the impact of several conditioning factors on the efficiency of municipalities, their costs, and their sorted and unsorted waste.

We found that the collection costs of Italian cities that did not reach the 65% separate waste target have a negative impact on efficiency, as when collection costs increase their efficiency decreases, unlike cities that reached the target, which see efficiency increase as costs increase. This different effect on the efficiency frontier suggests us that the policies adopted by the cities that did not reach the target try to keep their collection costs as low as possible to be efficient in their group and thereby try to compensate for the 20% landfill penalty.

The results of the conditional analysis, including population as an external factor, show the presence of economies of scale (as when the population increases, costs and unsorted waste decrease, and the amount of sorted waste increases) for the municipalities. The effect of the population is more evident for target municipalities than for non-target municipalities. However, it should also be considered that on average, over the years considered, the non-target municipalities are more populous. This could indicate saturation of the economies of scale, or at least a smaller effect, for the larger municipalities. At the policy level, this result indicates a possibility for municipalities that have already reached the target to expand their collection activities to neighbouring non-target municipalities (in the ATO they belong to) benefiting from a reduction in costs and at the same time helping their neighbours and the ATO itself in reaching the target. Furthermore, the possibility to cooperate as a “neighbourly solidarity” should be encouraged in cases of target municipalities with few inhabitants next to larger municipalities. We would like to emphasise that the evidence and implications made in this study are only in the area of waste collection and not in waste disposal (which in Italy is managed by the ATO and not at municipality level).

At the same time, the results show that the economic development of cities is very relevant for success in waste collection. Policymakers should be then more careful in setting targets and penalties that burden municipalities that are not very well developed, as this would risk in a vicious spiral: the less economic development the city has, the less collection costs can sustain and consequently the less sorted waste collection will be able to carry out. In addition, if the target is not reached, the waste disposal penalty will be added. In this latter case, our suggestion is to incentivise cooperation between less economically developed and more developed municipalities by sharing means or common investments for joint collection works. Our results of per capita analyses in fact show a joint positive effect of population and wealth on efficiency.

Contrary to previous literature, we found that population density and city size are not key factors for success in sorted collection, showing only a minimal effect on costs: as size increases, collection costs decrease while they increase in the case of density.

The results therefore suggest that, in the Italian case, there is scope for economies of scale and a strong effect of economic development in achieving the targets. To help Italian cities in the development of sorted waste collection, it is therefore necessary that the expected targets are also calibrated in relation to the economic development of the city and that a process of closer collaboration between municipalities that reach the target and those in their neighbourhood that do not reach the target is encouraged. To do that, the policy makers should work on additional targets beyond the percentage of sorted waste, which therefore does not consider the population size and wealth of the cities. A possible alternative target could be the consideration of the tonnes per capita and kg per income, by setting compensation targets for those municipalities which, below a threshold of tonnes per euro and/or tonnes per population (i.e., smaller municipalities), have not reached the expected targets. One proposal could be, for example, a 5% reduction in the case of sorted tonnes per capita that are below the median of non-target municipalities (e.g., in the analysed case for the year 2019 it is 0.359 tonnes per capita) and a further 5% in the case of municipalities below the median of income/ sorted waste ratio (0.0247 Kg per euro in 2019). The choice of the median would make it possible to have a measure that is more robust to the average in the case of particularly virtuous cities. This would avoid further aggravating the cases of small municipalities, which therefore cannot fully exploit economies of scale, and of municipalities that are not very economically developed and can afford to bear a reduced amount of penalisation compared to other municipalities. This is only a preliminary proposal, which needs further investigation and study before it can be used, but it is an initial cue for policymakers to deepen the study of regulatory targets that should not be equal for all municipalities but may be fairer for all Italian municipalities, without exacerbating the socio-economic differences already present in Italy. As a future development, is it possible to expand the analysis considering other environmental or external variables to evaluate their effects. It will be also possible to apply the same methodology to other factors already proposed in the literature to assess their impact (like tourism or population seniority). Without the current data limitation and with enough observations, it will be also possible to further extending the analysis grouping municipalities into zones, considering altitude or geographical localization.

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Appendix A

Tab. A1 Number of observations that reached and not reached the 65% target of sorted waste and descriptive statistics of the external factor analyzed.

			Collection Cost			Unsorted waste			Sorted waste		
Year	**Target Reached**	**nObs**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**
2016	No	165	382792,25	6911585,95	293326267,52	2661,30	31235,03	979780,02	202,64	23893,73	709426,09
2016	Yes	110	314731,04	2091754,07	13228132,68	958,16	5287,08	23991,61	4989,33	14272,09	81769,83
2017	No	150	382567,68	7393326,69	290353896,00	2778,11	31443,80	957966,92	646,88	25803,59	729050,32
2017	Yes	125	314128,15	2189447,44	12629638,98	933,35	5353,44	38037,21	5039,50	14963,45	87129,91
2018	No	130	397623,17	8118130,18	296489623,47	3057,62	33888,79	973084,93	1888,57	28050,50	755180,76
2018	Yes	145	310952,40	2461580,98	14419870,99	975,37	5935,46	36937,88	5115,90	16662,25	91612,60
2019	No	99	374633,49	9451417,30	300964760,81	3013,44	38314,66	926757,22	1947,97	32919,09	765130,10
2019	Yes	176	276325,84	2798475,82	15350144,65	1030,34	6224,03	36091,07	4973,30	17492,77	98790,11

			Population			**Size (Km2)**			**Density**		
Year	**Target Reached**	**nObs**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**
2016	No	165	20359	100487,92	2873494	3,94	123,28	1287,39	71,52	1376,39	7439,31
2016	Yes	110	19930	40308,10	194417	3,38	61,64	402,88	72,77	1408,15	7771,11
2017	No	150	20003	105259,71	2872800	3,38	126,59	1287,39	71,50	1443,68	7763,42
2017	Yes	125	20019	41739,14	196745	3,94	65,06	383,64	72,01	1323,38	6008,68
2018	No	130	19879	111169,37	2820219	5,13	129,72	1287,39	69,57	1425,09	7683,80
2018	Yes	145	19938	44148,08	198606	3,38	70,74	449,61	72,55	1335,50	7786,19
2019	No	99	19743	128781,31	2808293	5,13	138,96	1287,39	69,10	1497,45	7740,29
2019	Yes	176	20038	46213,50	200455	3,38	75,94	449,61	72,07	1313,11	7798,01

			Total Income			**Income Per Capita**		
Year	**Target Reached**	**nObs**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**
2016	No	165	139137007	1510755665,61	48352040323	5347,49	12701,71	24104,98
2016	Yes	110	163618451	629236331,51	3613025351	7319,72	15177,36	21613,29
2017	No	150	143078822	1631918273,73	49314358907	5528,67	13004,39	24708,37

2017	Yes	125	170196810	666090379,76	3758157596	7647,80	15512,20	23091,08
2018	No	130	145619154	1751600071,22	49195511468	5838,80	12931,89	23633,29
2018	Yes	145	171290748	696446607,97	3743244332	6718,89	15573,34	25023,80
2019	No	99	151193589	1990104619,02	47903317182	6014,95	12432,29	22679,50
2019	Yes	176	146830957	703541157,46	3699997944	6369,55	14902,10	24457,89