Productivity Analysis of Municipal Solid Waste Collection in Italy using SBM DEA Malmquist Index

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Abstract. This paper presents a productivity analysis of municipal solid waste collection in Italian provinces from 2010 to 2019. Particularly, the total factor productivity was measured by computing the non-parametric Global Malmquist Productivity Index implementing Slack Based Measure Data Envelopment Analysis (SBM-DEA). Findings show that the productivity of the sorted waste collection service slightly grew from 2010 to 2019. Such growth was due to an increase of the technical efficiency and an improvement of the service technology. However, in some years the efficiency changes and productivity increase were affected by the rise of the per capita production of waste.

1. Introduction
Municipal solid waste (MSW) management is an essential public service which includes the collection, transport, recovery, and disposal of waste. Since time, the agenda of the European Union (EU) has given attention to policies aimed at improving waste management and resource recovery to reduce the negative impact on the environment, economy, and human health. Particularly, the EU policies focus on the reduction of the per capita quantity of produced waste and the expansion of the quantity of recycled materials [1]. Waste minimization, reuse, and recycle, together with energy recovery help to deal with the waste management problem meeting economic and environmental sustainability goals. In Italy, although significant progress has been done in the last 15 years, much still needs to be done as the recent urban waste report published by ISPRA highlights [2]. Indeed, while the per capita production of waste is diminishing, the average percentage of selectively collected waste is slightly higher than 61% and this figure falls to about 50% in the Southern regions of Italy, below the target value of 65% set by law for year 2012.

Since time benchmarking and efficiency analysis have been employed to compare the performance between municipalities, regions, and countries, and monitor the progress of waste management policies. They both may help to achieve more efficient municipal resource management cutting avoidable expenditure. Solid waste collection (SWC) is an important part of waste management, as it is the transfer of solid waste from the place where it is generated and disposed to the point where it is treated or landfilled. It also includes the curbside or door to door collection of recyclable materials.

This paper presents a productivity analysis of municipal solid waste collection in Italian provinces from 2010 to 2019. Specifically, the non-parametric Malmquist Index was calculated using Slack Based Measure Data Envelopment Analysis (SBM-DEA).

2. Literature
Several scholars employed DEA to estimate the efficiency of MSW management and, specifically, of the SWC service. Indeed, Campitelli and Schebek [3] performed a literature review analyzing 366
research papers focusing on municipal solid waste management. One of their objectives was to gain a better knowledge of the different approaches and methods adopted to assess the municipal solid waste service. They found that DEA is a commonly used method.

A short list of research contributions employing DEA is reported as follows. Bosh et al. [4] calculated the technical efficiency of the waste collection service in 75 municipalities in Catalonia (Spain) using several parametric and non-parametric DEA based techniques. Variables used include the amount of waste, the numbers of trucks and containers, and the number of workers. Although they obtained different efficiency measurements, results were consistent implementing the various techniques. De Jaeger et al. [5] implemented bootstrapped DEA and a matching technique to estimate the cost efficiency of waste collection and processing in 299 municipalities in Flanders for year 2003. They also investigated the effect of different policy instruments on municipality cost efficiency. Rogge and De Jaeger [6] used an adjusted “shared-input” DEA model to measure the efficiency of 293 municipalities in Flanders (Belgium) to deliver the waste collection and processing service. This model allowed sharing costs among multiple urban waste fractions. Agovino et al. [7] applied DEA to measure the efficiency of Italian provinces from 2004 to 2011. They also investigated the spatial interdependencies in the waste management performance of governments and citizens and the persistence of good/bad performance in waste management distribution. Giannakitisidou et al. [8] measured the performance of 26 EU countries developing a DEA model which includes the produced urban waste and three components of the Social Progress Index as inputs and the amount of recycled material as output. Their study shows that new EU members perform better than old members. Romano and Molinos-Senate [9] adopted two stage meta-frontier DEA to identify factors that affect the efficiency of Tuscan municipalities in the management of urban solid waste. Results showed that efficiency is higher when public owned companies are entrusted the management of urban waste service and there is a large population. Rtós and Picazo-Tadeo [10] implemented DEA to develop a composite efficiency measurement which accounts for desirable and undesirable waste management operations. This indicator was used to evaluate the EU-28 member states in the delivery of the municipal waste service. They also found that there is a positive strong association between efficiency and economic development. Llanquileo-Melgarejo et al. [11] used DEA to evaluate the impact of urban waste selective collection and recycling on the performance of 298 Chilean municipalities. They found that selective collection and recycling urban waste had a significant impact on the municipalities’ performance. Some scholars specifically investigated how efficiency changes over a period of time by calculating the Malmquist Productivity Index (MPI) to measure the SWC total factor productivity. Worthington and Dollery [12] evaluated the productivity dynamics of domestic waste management and recycling services, and planning and regulatory services in New South Wales municipalities between 1993 and 1996. Results indicated that there was almost no productivity growth, but there was an increase of the relative efficiency. Simões and Marques [13] performed a benchmarking study to analyze the influence of regulation on the efficiency of the waste management operators in Portugal from 2011 to 2008. The scholars estimated the MPI decomposing it in two indexes, evaluating the usage of resources with respect to quality and quantity. They found that the sunshine regulatory model has a positive effect when the objective is the improvement of service quality. De Jaeger and Rogge [14] employed the non-parametric MPI to measure efficiency changes in MSW in Flanders after the introduction of a novel payment scheme for service provision based on weight-based billing system. The scholars found that the new billing system did not increase the MSW efficiency. Tüzün and Alp [15] employed DEA to measure the solid waste management efficiency in Turkey and EU countries. Particularly, they computed the MPI adopting two model specifications, privileging each time the environment and the economic perspective, respectively. Marques et al. [16] implemented DEA to measure the static efficiency and the Törnqvist index to measure dynamic efficiency of a sample of 278 Portuguese municipalities in the refuse collection. They performed three different DEA models to compute the efficiencies for the different waste management activities regulated by the authority, i.e. treatment of waste from refuse collection, selective collection, and treatment of waste from selective collection. The scholars found that the regulatory scheme based on the adoption of a tariff setting
mechanism triggered on a productivity X factor associated to a revenue cap had a positive effect in the waste management industry.

3. Empirical setting

3.1. Method
DEA is a non-parametric technique that is commonly employed to generate efficiency measures of units which perform production processes converting some inputs into outputs. These units are denominated as decision-making units (DMUs). The efficiency of a DMU can be computed as the maximum of a ratio of weighted outputs to weighted inputs subject to the condition that similar ratios calculated for the other DMUs under evaluation cannot be higher than one. The ratio optimization problem is transformed into an ordinary linear programming problem. The efficiency scores are computed based on the distance of every DMU from a benchmarking frontier obtained by enveloping efficient DMUs.

For the purpose of modeling dynamic changes of efficiency measurements, scholars have introduced a method to calculate the Malmquist productivity index under the DEA framework \[17\]. The conventional approach to compute the MPI suffers from infeasibility and lack of circularity problems. Pastor and Lovell \[18\] have proposed the Global Malmquist Productivity Index (GMPI) in which the output distance is measured against a global benchmarking frontier to overcome these problems. The GMPI for DMU \(k\) is defined as follows:

\[
M_k^G \left( x^{\ast+1}, y^{\ast+1}, x', y' \right) = \frac{D_k^G \left( x^{\ast+1}, y^{\ast+1} \right)}{D_k^G \left( x', y' \right)} \tag{1}
\]

The GMPI can be decomposed into efficiency change (\(EC\)) and technology change (\(TC\)) as follows:

\[
M_k^G \left( x^{\ast+1}, y^{\ast+1}, x', y' \right) = \frac{D_k^{\ast+1} \left( x^{\ast+1}, y^{\ast+1} \right)}{D_k \left( x', y' \right)} \times \frac{D_k^G \left( x^{\ast+1}, y^{\ast+1} \right)}{D_k^{\ast+1} \left( x^{\ast+1}, y^{\ast+1} \right)} \times \frac{D_k \left( x', y' \right)}{D_k^G \left( x', y' \right)} \tag{2}
\]

where

\[
EC = \frac{D_k^{\ast+1} \left( x^{\ast+1}, y^{\ast+1} \right)}{D_k \left( x', y' \right)} \tag{3}
\]

\[
TC = \frac{D_k^G \left( x^{\ast+1}, y^{\ast+1} \right)}{D_k^{\ast+1} \left( x^{\ast+1}, y^{\ast+1} \right)} \times \frac{D_k \left( x', y' \right)}{D_k^G \left( x', y' \right)}
\]

In this study, the constant returns to scale (CRS) and output-orientation assumptions, and the slack based measure (SBM) suggested by Tone \[19\] were adopted to calculate the distance functions \(D_k, D_k^{\ast+1}, D_k^G\). Under the output-oriented assumption, the level of outputs is maximized keeping constant the inputs amount because these latter cannot be easily changed.

We have \(n\) DMUs with the input and output matrices \(X=(x_{ij}) \in \mathbb{R}^{m \times n}\) and \(Y=(y_{ij}) \in \mathbb{R}^{p \times n}\). The values \(s^- \in \mathbb{R}^m\) and \(s^+ \in \mathbb{R}^p\) indicate the input surplus and output shortage, respectively. For DMU \(k\) the distance measurements can be calculated using the following linear program:
\[
\min \rho = \frac{1}{1 + \frac{1}{p} \sum_{r=1}^{p} s^r_k}
\]

\[
st \quad x_k - X\lambda - s^r = 0
\]

\[
Y\lambda - y_k - s^s = 0
\]

\[
i = 1, 2, \ldots, m \quad r = 1, 2, \ldots, p
\]

\[
j = 1, 2, \ldots, k, \ldots, n \quad \lambda_j, s^r_k, s^s_k \geq 0
\]

3.2. Sample

Sample includes all the Italian provinces. Provinces are territorial bodies which have the responsibility for planning of wide areas. They are recognized as administrative entities at the intermediate level between the Regions and the municipalities. After regional Law no. 2 of 4.02.2016, the Province of South Sardinia was established in place of the Provinces of Carbonia-Iglesias and Medio Campidano. The same law suppressed the Provinces of Ogliastra and Olbia-Tempio. As data were collected from 2010 to 2019, the sample is unbalanced, including 110 units for the interval between 2010 and 2016, and 107 units for the interval between 2017 and 2019.

3.3. Input, outputs and data sources

Input and output data were retrieved from the Italian National Institute of Statistics (ISTAT) and the Italian Institute for Environmental Protection and Research (ISPRA) databases, respectively. Following other studies on the productivity of the municipal waste management, the sorted and unsorted waste fractions were used as outputs in model specification [7, 9]. Because the unsorted fraction is an undesirable output, the linear monotonic decreasing transformation suggested by Seiford and Zhu [20] was employed to convert it into a desirable output to run the DEA linear programming model. After this transformation, a higher value of the new variable is associated to a better performance of the province with respect to the waste management service. The territorial extension and the resident population of the province were included in the model as inputs [21]. As data relative to the total cost of the waste management service were unavailable for all provinces, the previous input variables were considered acceptable proxies of the consumption of resources used to deliver the service.

4. Results

Figure 1 displays the average annual SWC efficiency (E) measurements from 2010 to 2019. In this period, the average SWC efficiency of the Italian provinces has risen from slightly more than 44% to 53%, increasing by a rate of 18.4%. The growth trend has been generally positive, except between 2010 and 2011. Indeed, in this time frame there was a small decrease by about 2.6%. During the first years of the period covered in the study, innovative models for the collection of separate fractions of waste have been experienced by the majority of provinces. Hence, both traditional and innovative models and schemes for the collection of waste coexisted side by side. These first years have been a period of transition towards a new industry setting. During the 2010-2012 three-year period, the consolidation of the implementation of the EU policies and norms aimed at reducing the production of landfilled waste decreased the quantity of urban waste disposed in an authorized landfill by about 11.3% as the ISPRA report indicates [22]. Figure 1 also shows the measurement of the per capita waste quantity (pcW). For each province, this value was obtained calculating the ratio of the quantity of waste annually produced to the number of resident inhabitants living in the province. Between 2010 and 2011 the efficiency reduction was associated to the reduction of the per capita production of waste. However, from 2011 to 2013 these indicators are negatively correlated, as while the SWC efficiency was growing, the average per capita production of waste diminished. Starting from year 2013, the average per capita production of waste remained approximately the same, slightly increasing from 2015 to 2019. This latter behavior of this variable suggests that part of the efficiency improvement was likely due to a new rise in the production of waste.
Figure 1. Efficiency measurements of the waste collection service from 2010 to 2019.

Figure 2. EC, TC, GMPI and pcWC measurements of the waste collection service from 2010 to 2019.

Figure 2 displays the outcome of the productivity analysis relative to the SWC service during the period 2010-2019. Specifically, the graphics of the efficiency change (EC), technology change (TC), and the Global Malmquist Productivity Index (GMPI) are reported. The value greater than one indicates increasing productivity, whereas the value lower than one implies diminishing productivity from year $t$ to year $t+1$. Instead of presenting results for each province, a summary description of the average productivity growth of the waste collection service over the entire period 2010-2019 is presented considering the mean value. In this figure the biennial change of the per capita waste production (pcWC) is displayed, too. The mean values of GMPI change range from 1.0088 to 1.0737 for the whole period, while the average is 1.0490, implying that the overall GMPI measuring the total factor productivity growth over the whole period was 4.9%. As it is always greater than unity, the total factor productivity growth was positive from 2010 to 2019. Changes occurred in the per capita production of waste are indicating that periods in which the average production of waste decreases prevailed over periods in which it increased. There was generally a positive correlation between pcWC and GMPI, indicating that the increase of the total factor productivity in the collection of waste was induced by the increase of the per capita production of waste. Spearman correlation is positive and statistically significant, being equal to 0.246 (Table 1).
Table 1. Spearman correlations among EC, TC, GMPI, and pcWC.

|     | EC | TC  | GMPI | pcWC |
|-----|----|-----|------|------|
| EC  | 1  |     |      |      |
| TC  | -0.341** | 1 |      |      |
| GMPI| 0.637** | 0.363** | 1 |      |
| pcWC| 0.010 | 0.269** | 0.246** | 1 |

**correlation is significant at the 0.01 level (2-tailed)

The GMPI (hence, the total factor productivity growth) can be decomposed in two components, the first one measuring the efficiency change (EC) and the second one measuring the technical progress (TC). EC provides a measurement of the relative deviation of each province from the benchmarking frontier, while TC provides a measurement of the movement of the frontier over the period covered in the study. Particularly, from 2010 to 2019 the efficiency change and the technology progress were on average greater than the unity, indicating that both of them contributed to the total factor productivity growth over the period. Spearman correlations are positive and significant, too. However, the efficiency change and the technology progress were negatively correlated. From 2012 to 2013 and from 2016 to 2017 there was a slight regress of the production technology by about 1.8% and 3%, respectively with a deterioration in catching up with the frontier.

5. Conclusion

Results from this study indicate that the productivity of the sorted waste collection service in Italian provinces slightly grew from 2010 to 2019. Such growth was due to an increase of the technical efficiency and an improvement of the technology of the service. However, in some years the efficiency changes and productivity increase are influenced by the rise of the per capita production of waste. Further research is necessary to identify more factors which affect the GMPI measurement. Potential factors that should be investigated include income, education, the capacity of the waste treatment facilities, and population density.

6. References

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