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Improving waste production and recycling through zero-waste strategy and privatization: An empirical investigation

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Abstract

Using a large 2012–2015 cross-sectional dataset for all 279 municipalities in Tuscany, Italy (the location of the first municipality in Europe to adopt a zero-waste strategy in 2007), this study investigates whether and how municipal waste production and re-cycling activities are related to two waste management policies of municipalities: the adoption of a zero-waste strategy and ownership type of the entity entrusted with urban waste management services. Population density, the municipal average age of inhabitants, municipality area, and the average taxable income of individuals per capita are considered as control variables in the panel data regression models. The study demonstrates the relevance of municipal policies on waste management performance. Specifically, the results show that municipal waste production is higher when urban waste services are managed by privately owned companies, as well as when the average taxable income of individuals per capita is lower. The adoption of a zero-waste strategy by municipalities significantly improves the separate collection rate in Tuscan municipalities. Municipalities that have entrusted solid waste collection and disposal services to mixed-owned firms have lower rates of separate collection than do municipalities that directly manage the service or entrust it to publicly owned firms. Furthermore, the separate collection rate is higher where population density and the average taxable income of individuals per capita are higher. The analysis helps policy and decision makers to identify policies with higher probabilities of reducing waste production and improving the separate collection rate, thereby reaching high standards of waste reduction and recycling.

Keywords: Waste; Urban waste management; Recycling; Separate collection; Local government policy; Ownership

1 Introduction

Municipal solid waste (MSW) collection and disposal is an extensively studied public service offered by local authorities, and is driven by three main factors: complexity, cost, and environmental concerns about MSW management (Pérez-López et al., 2016). There are two environmentally friendly strategies for dealing with MSW: waste reduction and recycling through waste separation (Struk, 2017). The prevention of waste, recycling, and reuse are the focus of the European Union (EU) strategy on waste since the 1997 Council's Resolution on a Community strategy for waste management (European Council, 1997) was delivered. In addition, the 2030 Agenda for Sustainable Development of the United Nations General Assembly confirms through Goal 12.5 (United Nations, 2015) the need for a substantial reduction of waste globally by 2030.

Waste management firms' performance, which is usually measured in terms of municipal waste production, rate of recycling, or cost efficiency, is influenced by demographic and socio-economic characteristics of the population served (e.g., Abbott et al., 2011; Czajkowski et al., 2017; Mazzanti et al., 2011; Sidique et al., 2010), geographical and structural features (e.g., Mazzanti et al., 2011), operational features (e.g., Guerrini et al., 2017), method adopted (curbside or street bin), maturity reached (e.g., Abbott et al., 2011; Guerrini et al., 2017; Sidique et al., 2010), and government characteristics (e.g., Gaeta et al., 2017; Plata-Díaz et al., 2014).

This study contributes to the literature by empirically investigating the determinants of the total municipal waste production and separation rate in the Tuscany Region, central Italy, through analyzing both the waste reduction and recycling results of municipalities. To the best of the authors' knowledge, it is the first study to include two variables that could impact the municipal waste production and separation rate: the ownership of the firm entrusted with the service and the adoption of a zero-waste strategy. These two issues have been deemed of significant relevance to urban waste management in the literature (Simões and Marques, 2012; Zaman and Lehmann, 2011) but the effectiveness of their impact on municipal waste production and the separation rate has not been previously investigated.

As highlighted by Mazzanti et al. (2011), the Italian context is relevant, with Italy being a main EU member, and offers important information for the evaluation of existing waste management policies. In the EU, waste

management is regulated by national legislation, based on the EU framework. However, waste policies and strategies are usually defined at the regional level; therefore, a high divergence in MSW management and results is detected even in the same country (Gaeta et al., 2017). The analysis is based on an original hand-collected 4-year panel dataset at municipal level for all Tuscan municipalities. The dataset was constructed by gathering data on a number of possible municipal-level covariates. While most previous studies have used cross-sectional analysis (Starr and Nicolson, 2015), panel data could offer more robust results. The focus of this study is the region where Capannori is located, which was the first municipality in Europe to adopt a zero-waste strategy in 2007 (i.e., sending zero waste to landfills by 2020). The first-mover status makes it particularly interesting to study this region to highlight if the adoption of a zero-waste strategy by municipalities (policymakers) is effective or mere political posturing. Moreover, differently from other Italian regions, such as Lombardy (Gaeta et al., 2017) and Veneto (Guerrini et al., 2017), the analyzed region has never been investigated with reference to MSW performance. After Emilia-Romagna, the Tuscany region has the second highest production of urban waste per capita at 608 kg per inhabitant per year versus a national average of 487 kg according to the ISPRA (2016). However, Tuscany's urban waste recycling rate of 46.1% is lower than the national average of 47.5% and the maximum attained in Veneto of 68.8% (ISPRA, 2016).

Tuscany also provides a valuable environment for examining the influence of different ownership types of urban waste management firms on urban waste production and the separation rate among other variables considered in the literature, because the region has different types of waste operators—from the municipalities themselves to firms with different ownership models. Contracting public services, such as urban waste, is still the focus of debates worldwide and the literature has not provided conclusive results on the optimal model (Petersen et al., 2018). Thus, this research provides a better understanding of the potential role of ownership on the performance of urban waste firms by extending the literature on this issue. The results also deepen emerging findings of previous empirical studies (Simões and Marques, 2012), which highlighted that, in the wealthiest countries, public provision of waste management services seems to yield better results in terms of cost efficiency than private provision and that privatization loses its advantages over time. Moreover, this study sheds light on the impacts on MSW performance of managerial and policy decisions, such as the introduction of curbside collection and Pay-As-You-Throw tariffs that are usually included in a municipality's zero-waste strategy.

The rest of the paper is structured as follows. The next section reviews the literature on the public–private conflict in public service provision and the impact of zero-waste principles in MSW service provision. Sections 3 describe the data and method applied. Section 4 presents and discusses the results. Finally, Section 5 concludes.

2 Literature review

Several theories investigate the role of private operators in delivering public services, such as waste management services: public choice theory, property rights theory, organizational theory (Simões et al., 2012a; Villalonga, 2000), and the new public management (NPM) approach (Zafra-Gómez et al., 2013). These theories support the notion that publicly owned firms and their managers perform worse than their private counterparts (Villalonga, 2000), owing to their self-interested conduct, politicians' influence on decision making, and different organizational characteristics, such as culture and control mechanisms (Villalonga, 2000). Thus, publicly owned firms and their managers need strong supervision to prevent and overcome inefficiency and even corruption. The NPM approach encourages the adoption of the management principles of the private sector in the public sector (Hood, 1991). Moreover, the reasons for privatization are usually based on an investigation of differences in efficiency and costs. Bel and Fageda (2006) argued that the development of scale economies through privatization is a topical argument to support privatization of local public services. Thus, the authors focused on small municipalities and their use of inter-municipal cooperation instead of privatization to develop scale economies and reduce transaction costs. Their empirical results show that the cost of collection is lower when inter-municipal cooperation happens. Furthermore, Bel and Fageta (2008) found that both politics and ideology influence the privatization decisions of municipalities even if the former has more influence. For an Italian region, Guerrini et al. (2017) showed that integrating collection services is not useful if the confederation of municipalities remains quite small.

Simões et al. (2012a) showed that, in refuse collection services in Portugal, public operators with in-house service provision are less efficient than private ones owing to competition and economies of scale. Similarly, Chifari et al. (2017) found that municipalities can diminish waste management costs through privatization and even more so with a waste management association in the Japanese context.

However, Zafra-Gómez et al. (2013) questioned the NPM postulates by showing that public management forms, through both public provision by a single local authority and shared delivery by a consortium of local authorities, are more efficient than private management provision in reducing the cost of waste collection and disposal. Their results, based on data on small and medium municipalities (below 50,000 inhabitants), suggest that adopting policies that encourage joint (inter-municipal cooperation) and public management has a significant effect on reducing costs.

For Italy, based on regional data for 2002–2004, Lombrano (2009) found no correlation between privatization policies and cost efficiency. Thus, the preference for public versus private MSW service delivery and the choice of contracting out public services are still unanswered questions (Petersen et al., 2018) that require further investigation to support policy and decision makers.

Along with the decision on the privatization of MSW services, other relevant policies implemented by policymakers at local level could affects municipal waste production and the recycling rate. A recent empirical study found that policy measures that support the improvement of the infrastructural conditions of household recycling, such as curbside collection and a high density of recycling drop-off stations, explain why some municipalities have higher recycling rates than others (Hage et al., 2018). Similar results were found by Callan and Thomas (2006), who studied cross-sectional data on cities in Massachusetts. The authors found that the availability of curbside recycling services (measured as the number of pick-ups per month) is a negative and significant determinant of disposal demand. The same results were identified by Kinnaman (2005) for US municipalities in that the increasing ratio of the population

served by curbside recycling significantly increases the recycling rate. Moreover, Starr and Nicolson (2015), focusing on the US context, found that the Pay-As-You-Throw tariff method is the most relevant recycling determinant, even more when it is paired with curbside collection. In addition, Starr and Nicolson (2015) identified that easy access to a recycling facility is relevant for increasing recycling rates.

In Europe, focusing on small communities in the Czech Republic, Struk (2017) showed a relevant impact on the waste separation rate of drop-off sites and curbside collection, and its incentives. An incentive program can significantly increase the standard separation rates, meaning that municipalities planning to increase their rates can do so without high investments. Moreover, Struk (2017) showed there was less recycling in the smallest municipalities, owing to generally worse separation options due to the lower accessibility of drop-off and civic amenity sites. Abbott et al. (2011) found that, in the UK, lowering the frequency of residual waste collection was effective in increasing the recycling rate. Consequently, defining the timing for residual waste collection seems relevant for increasing the recycling rate, to incentivize households' sorting of waste and to decrease the amount of landfill household waste.

The literature review highlights that recent empirical studies demonstrate that the principles underpinning the zero-waste strategy are effective for reducing waste production and increasing the recycling rate (Connet, 2013). According to Connet (2013), there are 10 steps toward a zero-waste community (i.e., zero-waste strategy), including door-to-door collection systems, recycling and waste reduction programs, and economic incentives. The Zero Waste International Alliance and the Italian Zero Waste Research Center in Capannori have both outlined the principles and some of the practical steps being taken in both large urban and small rural communities in the pursuit of zero waste (ZWIA, 2018), including curbside collection and Pay-As-You-Throw taxes. Notwithstanding growing scientific and political attention on the impact of the introduction of curbside recycling, recycling drop-off stations, incentives to reduce and recycle more, and incentivizing tariff methods, to the best of the authors' knowledge, no previous empirical studies have investigated the role of the formal adoption by a municipality of a zero-waste strategy, which would commit the municipality to sending zero waste to landfills, increasing attention to the sustainable design of communities and products, as well as stakeholder engagement in waste reduction and recycling activities. Including this variable in empirical analyses would enable checking whether such political decision is effective.

As most empirical investigations focus on US municipalities, a deeper focus on European countries' municipalities, including Italian ones, is still needed.

3 Data and method

Data collection started with the list of all 279 Tuscan municipalities in 2015. Since waste reduction behavior differs from recycling behavior, the recycling approaches are not always linked to waste-reduction attitudes (Cecere et al., 2014). Therefore, both the total waste produced per inhabitant (TOTW, kg/y) and the separate collection rate (SW), measured as municipalities' share of waste recycling to total waste generated, were used as dependent variables. These data were retrieved from the database of the Tuscan regional agency, Agenzia Regionale Recupero Risorse S.p.a. (ARRR). Furthermore, building on the literature and available data, in the regression analyses, some municipal-level covariates were introduced by collecting publicly available data from multiple sources (Table 1); the covariates investigate demographic characteristics, socio-economic features, and policies adopted by municipalities.

Table 1 Variables.

alt-text: Table 1

Variable group	Variable	Data source
Dependent variables	Total waste produced per inhabitants (kg/y) (**TOTW**) % separate collection (**SW**)	ARRR S.p.a. ARRR S.p.a.
Independent variables: Demographic and geographical characteristics of the municipalities	Population density (**DENS**) Average age of inhabitants (**AA**) Size of municipality in km^2 (**SIZE**)	ISTAT and www.comuni-italiani.it ISTAT and www.comuni-italiani.it www.comuni-italiani.it (retrieved from ISTAT)
Independent variables: Socio-economic features of the municipalities	Average taxable income of individuals per capita (**AI**)	www.comuni-italiani.it (retrieved from ISTAT)
Independent variables: Policies adopted by the municipalities	Ownership of the waste utility that manages the urban waste management services of each municipality (**OWN**) Adoption of zero-waste strategy (**ZW**)	Official enterprise websites, AIDA Database (Bureau Van Dijk), direct contact with municipalities or local waste authorities (ATO). Data were cross-checked with ARRR data and Ato Costa data. Zero Waste Research Center

Regarding demographic and geographical characteristics, three covariates were included in the model: size of the municipality (SIZE); population density (DENS); and average age of residents (AA).

For socio-economic features and to check for the impact of income, the authors collected information about the average taxable income of individuals per capita (AI).

Finally, two variables concerning the policies adopted by the municipalities with regard to local waste management were considered. These variables, as highlighted in the literature review, were assumed to have a relevant

impact on performance in terms of waste production reduction and recycling rate. First, information on the institutions that manage the urban waste management services of each municipality were collected and then checked against ARRR and ATO information, creating a classification based on the ownership (OWN) of waste firms, with the variable taking the value 0 for municipalities that directly manage the service or entrust it to wholly publicly owned waste firms, 1 for mixed-owned ones, and 2 for wholly privately owned ones. Moreover, the information about the adoption of a zero-waste strategy by the municipality was retrieved from the Zero Waste Research Center in Capannori, which registers strategy adoption.

During the observation period (2012–2015), eight new municipalities were constituted by merging two pre-existing municipalities. In these cases, data for the period before the merger were collected separately and then merged by sum (SIZE) or average (other variables). Both ZW and OWN were identical for the merged municipalities.

The dataset comprises longitudinal data with repeated measurements on the same municipality over a 4-year period from 2012 to 2015. The time trends within municipalities and between municipalities were identified. The dataset comprises the response variable, time covariate, indicator of the municipality for which the measurement took place, and other covariates (Table 1).

This study modeled both the TOTW and SW as a function of the characteristics of the municipalities and waste policies adopted (Sidique et al., 2010), as follows:

$$TOTW_{it} = ß_0 + ß_1\,DENS_{it} + ß_2\,AA_{it} + ß_3\,SIZE_{it} + ß_4\,AI_{it} + ß_5\,OWN_{it} + ß_6\,ZW_{it} + a_i + u_{it}, \quad \textbf{(1)}$$

$$SW_{it} = ß_0 + ß_1\,DENS_{it} + ß_2\,AA_{it} + ß_3\,SIZE_{it} + ß_4\,AI_{it} + ß_5\,OWN_{it} + ß_6\,ZW_{it} + a_i + u_{it}, \quad \textbf{(2)}$$

where i ($i = 1 \ldots N$) represents the municipality and t ($t = 1 \ldots T$) the year. $ß_k$ is the coefficient on the independent variables, a_i represents the unobserved municipality-level effect, and u_{it} is the idiosyncratic error. The other variables are as per Table 1.

The models were estimated using both fixed- and random-effect methods (Sidique et al., 2010). Fixed-effect models consider the unit of analysis as a unique effect, checking for dissimilarities between units and analyzing changes within units over time, while random effects consider the units of analysis as if they were randomly taken from a broader population and investigate the variations across units and within units over time (Starr and Nicolson, 2015). Hence, the difference between the two models is that in the first model, the individual-specific effect is a random variable allowed to be correlated with the covariates, whereas in the second model, the individual-specific effect is a random variable that is uncorrelated with the covariates.

To select the most appropriate method, the Hausman test was applied. This test compares fixed and random models to assess endogeneity by testing whether the errors u_{it} are correlated with the covariates. The Hausman test was computed through the integrated procedure of Stata (Tantau et al., 2018). The test results ($p = 0.0025$ for Model 1 and $p = 0.0001$ for Model 2) revealed endogeneity and confirmed the fixed-effects model as the proper specification for municipality-specific unobserved effects.

4 Estimation results and discussion

Tables 2 and 3 report the statistics of the analyzed variables. The panel nature of the dataset allows an analysis of cumulative effects over the time period.

Table 2 Statistical features of variables used.

alt-text: Table 2

YEAR		Average income AI (Euro)	Average age AA (y)	Size of municipality SIZE (km^2)	Population density DENS (inh/km^2)	Separate collection rate SW (%)	Total waste produced per inhabitant TOTW (kg/y)
2012	Average	18,095.21	46.06738	82.39086	219.648	37.28833	593.2941
	Max	27,604	57	473.5532	3,492.206	88.79754	1,759.387
	Min	13,133	41	5.8591	7.000054	6.388066	245.9808
	SD	2,377.942	2.525747	67.73823	359.9983	17.64314	202.7168
2013	Media	18,589.8	46.25735	82.39444	221.1343	39.11894	582.8508
	Max	35,211	57.4	473.5532	3,577.44	89.53265	1,619.619

	Min	13,560	41.1	5.8591	7.045313	7.67189	276.7013
	SD	2,508.135	2.545261	67.73615	364.6189	18.8874	196.9478
2014	Media	18,841.37	46.34731	82.39803	224.6098	40.957	578.3657
	Max	31,261	57.4	473.5532	3,686.589	88.59258	1,620.155
	Min	13,546	2.1	5.8591	7.000054	7.54114	263.2252
	SD	2,457.268	3.695864	67.73411	374.2818	19.07984	177.5104
2015	Media	19,189.97	46.74194	82.40161	224.8075	42.27398	575.4603
	Max	30,225	58	473.5532	3,724.021	87.41069	1663.576
	Min	13,644	41.6	5.8591	6.962339	11.63277	327.0291
	SD	2,477.521	2.58806	67.73213	375.8232	19.07708	181.2376
Total	Media	18,679.09	46.35349	82.39623	222.5499	39.90956	582.4927
	Max	35,211	58	473.5532	3,724.021	89.53265	1,759.387
	Min	13,133	2.1	5.8591	6.962339	6.388066	245.9808
	SD	2,484.629	2.888256	67.64397	368.25	18.7512	189.7597

Table 3 Statistical features of variables used.

alt-text: Table 3

	Ownership of waste utility OWN				Adoption of zero-waste strategy ZW		
YEAR	Public	Mixed	Private	Total	No	Yes	Total
2012	163	93	23	279	269	10	279
2013	171	91	17	279	261	18	279
2014	130	131	18	279	258	21	279
2015	136	125	18	279	253	26	279
Total	600	440	76	1,116	1,041	75	1,116

The data show that the average TOTW decreased during the observed period. This is in contrast to the predictions of Hoornweg and Bhada-Tata (2012) but in accordance with national and regional trends highlighted by ISPRA (2016). According to the latter, in Tuscan municipalities, the percentage of separate collection (SW) increased over the observed period, even if it was still far from the minimum level of 65% fixed by the law (Decree. 3 April 2006, n.152) to avoid penalties. The data also show that more than 85% of Tuscan municipalities were under the threshold of 65% in 2015. Moreover, the average values of the observed covariates increased during the analyzed period, with an improvement for Tuscan municipalities that adopted a zero-waste strategy.

Both TOTW and SW have a wide range. The highest values of TOTW are registered in highly touristic municipalities and while the minimum value of SW increased (from 6.39 in 2012 to 11.63 in 2015), the maximum decreased (from 88.80 in 2012 to 87.41 in 2015). Gaeta et al. (2017) observed such high cross-municipality variability in waste recycling in another Italian region (Lombardy). Among the observations, 55% represents municipalities that manage services directly or use publicly owned firms, 39% municipalities whose services are entrusted to mixed-owned firms, and 7% municipalities that contracted out urban waste management to privately owned firms. Of all observations, 7% are for municipalities that adopt a zero-waste strategy.

The results from the panel estimates are presented in Tables 4 and 5.

Table 4 Panel regression estimates (fixed effects)—Total waste produced per inhabitant (kg/year) (TOTW) in Tuscan municipalities.

alt-text: Table 4

TOTW	Coef.	Std. err.	t	P > |t|	[95% conf.	interval]
AI	**−0.01193**	**0.003193**	**−3.74**	**0.000*** **	**−0.01819**	**−0.00566**
AA	−0.14365	1.442509	−0.1	0.921	−2.97504	2.687743
SIZE	−21.9895	22.76739	−0.97	0.334	−66.678	22.69891
DENSITY	−0.09299	0.198051	−0.47	0.639	−0.48173	0.295747
ZW	−10.4989	14.48892	−0.72	0.469	−38.9381	17.94034
OWN						
Mixed	−10.4297	6.932299	−1.5	0.133	−24.0366	3.177242
Private	**43.11335**	**22.10816**	**1.95**	**0.051***	**−0.28113**	**86.50784**
_cons	2,646.364	1,875.814	1.41	0.159	−1035.53	6,328.26

Significance level: *** p < 0.01, * p < 0.1.

Table 5 Panel regression estimates (fixed effects)—Percentage of separate collection (SW) in Tuscan municipalities.

alt-text: Table 5

SW	Coef.	Std. err.	t	P > |t|	[95% conf.	interval]
AI	**0.002869**	**0.000333**	**8.62**	**0.000*** **	**0.002216**	**0.003522**
AA	0.167287	0.150362	1.11	0.266	−0.12785	0.462421
SIZE	0.596769	2.373192	0.25	0.802	−4.06139	5.254932
DENS	**0.044017**	**0.020644**	**2.13**	**0.033** **	**0.003496**	**0.084537**
ZW	**3.631763**	**1.510273**	**2.4**	**0.016** **	**0.66736**	**6.596167**
OWN						
Mixed	**−1.6305**	**0.722598**	**−2.26**	**0.024** **	**−3.04884**	**−0.21217**
Private	−2.83435	2.304476	−1.23	0.219	−7.35764	1.688931
_cons	−79.8126	195.5281	−0.41	0.683	−463.6	303.9751

Significance level: *** p < 0.01, ** p < 0.05.

In Model (1), which includes the **TOTW** as the dependent variable (Table 4), the results reveal that one of the two variables concerning the policies adopted by municipalities appears to be statistically significant. The ownership of firms that manage urban waste management services in Tuscan municipalities matters, since municipalities that entrusted the service to wholly privately owned waste companies register a higher production of per capita waste.

The adoption of a zero-waste strategy by a municipality does not affect the amount of waste produced per inhabitant, even if the data show that, on average, this amount is lower for zero-waste municipalities than for others (570.99 kg/y vs. 583.32 kg/y).

Moreover, TOTW is significantly correlated with the average taxable income of individuals per capita (AI), but not as expected: in contrast to Abbott et al. (2011) and Hoornweg and Bhada-Tata (2012), MSW production levels in Tuscan municipalities are lower as the income level of residents increases. This result could be because economic wellbeing is linked to environmental concerns, such as waste reduction. Since income is usually correlated with education level, higher education levels are expected to induce more pro-environmental behavior (Gaeta et al., 2017).

The variables used to observe the demographic characteristics of the analyzed municipalities are not statistically significant, highlighting that population density, age of inhabitants, and size of municipality do not affect the amount of waste produced. These results are in contrast to the literature, that is, there is more waste per capita in the smallest municipalities of the Czech Republic (Struk, 2017) and lower waste production for older people than younger residents (Kinnaman and Fullerton, 2000). These empirical differences could be due to the different geographical and temporal contexts. Struk (2017) focused on small municipalities, among which the smallest are often in the countryside, and locations for second homes or holiday homes. Thus, in these smallest municipalities, people are mainly not permanent residents. By contrast, the dataset of this study includes all Tuscan municipalities, not only small ones. Kinnaman and Fullerton (2000) used data of US municipalities from 1991, showing that the behavior of younger and older residents has become more similar in recent decades; that is, no statistically significant differences in behavior have been highlighted. However, the empirical results of the present study are consistent with previous works that have found that population density is not significantly correlated with waste generation per person per year (Callan and Thomas, 2006; Kinnaman and Fullerton, 2000).

Table 5 reports panel regression estimates using the percentage of separate collection (**SW**) as the dependent variable. Overall, recycling is significantly correlated with average income and population density, as well as with the observed policies adopted by municipalities (privatization and adoption of zero-waste strategy).

SW is positively correlated with the adoption of a zero-waste strategy, thereby supporting the concept that political input derived from a formal decision of the mayor or municipal council can significantly and positively influence citizens' behavior and the environmental performance of municipalities through the SW. Moreover, SW could have a relevant effect on the influencing strategies and policies of firms entrusted with waste management services. Even the ownership of the entity entrusted with the waste management service matters: mixed-owned firms perform a significantly lower rate of separate collection than do municipalities where the service is managed directly by the municipality or publicly owned firms. Thus, SW is negatively affected by the partial privatization choice of municipalities (i.e., a PPP) that register lower environmental results when the waste management service is not entrusted to public entities (the municipalities themselves or publicly owned firms). This result is confirmed even if the entity entrusted with the waste management service is represented by a dummy taking 1 for both mixed and privately owned firms, and 0 otherwise.

Moreover, the results show that the rate of separate collection is positively correlated with **population density**, so that an increase of 100 in./km^2 improves the SW by more than 4%. This result is consistent with those of previous studies (Abbott et al., 2011; Lakhan, 2014). Gaeta et al. (2017) also demonstrated the existence of this relationship for municipalities with more than 5000 and less than 15,000 inhabitants in Lombardy region, as this cluster of municipalities accounted for around 23% in Lombardy and 35% in Tuscany.

Population age does not exercise a significant effect on the recycling rate, which is a different result to most existing studies (Callan and Thomas, 2006; Kinnaman, 2005; Kinnaman and Fullerton, 2000; Lakhan, 2014; Starr and Nicolson, 2015), since AA is not statistically significant. The results show that the coefficient is positive, so that an increase of the average age of residents in municipalities corresponds to an increase in the SW; older people seem to be more sensitive to social norms that support recycling, and have more time to devote to recycling activities (Kinnaman, 2005). Another variable that is traditionally related to the opportunity cost of time (usually linked to citizens' age) is **income**, which exerts a statistically significant positive effect on the recycling rate (Kinnaman, 2005). Specifically, an increase of 1000 euros in the average income of the municipality, keeping the other variables constant, yields an increase of 2.8% in its SW. This result could be linked to the fact that higher earners can purchase more recyclable goods, owing to their greater financial flexibility, in accordance with Callan and Thomas (2006). Moreover, higher earners can pay more for a healthier environment (Abbott et al., 2011), considering that economic welfare incentivizes pro-environmental concerns (Gaeta et al., 2017).

Finally, to compare the results with other municipalities in Italy and thus, to control for geographical characteristics, we extend our analysis to compare the results registered for Tuscany municipalities with those registered for other Italian municipalities. To this end, we collect data for a sample of 52 municipalities located in different Italian regions and we apply them to the two models described in Section 3. We estimate models (1) and (2) using the random-effect method, as the Hausman test results indicate that unobserved effects are adequately modeled by random effects (Sidique et al., 2010). The results from the panel estimates obtained for these municipalities are presented in Tables 6 and 7. According to the results shown in Table 6, the TOTW is significantly correlated with the average taxable income of individuals per capita, and the sign of the slope coefficient is positive. This result conflicts with the Tuscany results (which show a negative sign) but is in line with those of other studies (Abbott et al., 2011; Hoornweg and Bhada-Tata, 2012). With regard to waste policies adopted by these municipalities, the results reveal that the ownership of firms that manage urban waste management services has a significant impact on the waste produced per capita; however, in this case, the impact is negative, since municipalities that entrust the service to mixed-owned waste companies register a smaller production of per capita waste.

Table 6 Panel regression estimates (random effects)—Total waste produced per inhabitant (kg/year) (TOTW) in other Italian municipalities.

alt-text: Table 6

TOTW	Coef.	Std. err.	t	P > |t|	[95% conf.	interval]
AI	**0,015342**	**0,003323**	**4.62**	**0.000*** **	**0,008829**	**0,021855**
AA	**−10.0613**	**3.71452**	**−2.71**	**0.007****	**−17.3416**	**−2.78098**
SIZE	**1,265129**	**0,333815**	**3,79**	**0.000*** **	**0,610864**	**1,919394**
DENSITY	0,012609	0,032057	0,39	0,694	−0,05022	0,075439
ZW	−48,785934,78196	1,40,161	−48,7859	34,78196	−1,4	0,161	−116,957	19,38547
OWN						
Mixed	**−106,725**	**55,17016**	**−1,930,053* −1,93**	**0,053***	**−214,856**	**1,406752**
Private	10,2778	23,81224	0,43	0,666	−36,3933	56,94893
_cons	588,7035	169,7395	3,47	0,001	256,0201	921,3869

Significance level: *** p < 0.01, ** p < 0.05, * p < 0.1.

Table 7 Panel regression estimates (random effects)—Percentage of separate collection (SW) in other Italian municipalities.

alt-text: Table 7

SW	Coef.	Std. err.	t	P > |t|	[95% conf.	interval]
AI	0.002699	0.000578	4.67	**0.000*** **	0.001567	0.003831
AA	0.05967	0.643034	0.09	0.926	−1.20065	1.319993
SIZE	−0.068410.054093	1.260.206	−0.06841	0.054093	−1.26	0.206	−0.17443	0.037612
DENS	**−0.00868**	**0.005216**	**−1.660.096* −1.66**	**0.096***	**−0.0189**	**0.001543**
ZW	**12.00734**	**5.681526**	**2.11**	**0.035****	**0.871753**	**23.14292**
OWN						
Mixed	9.622144	9.027014	1.07	0.286	−8.07048	27.31477
Private	0.251378	4.199412	0.06	0.952	−7.97932	8.482074
_cons	−0.2719429.81648	0.010.993	−0.27194	29.81648	−0.01	0.993	−58.7112	58.16729

Significance level: *** p < 0.01, ** p < 0.05, * p < 0.1.

Meanwhile, as registered for Tuscany municipalities, the adoption of a zero-waste strategy does not affect the amount of waste produced per inhabitant. Moreover, for this sample of municipalities, the age of inhabitants and the size of municipality are statistically significant and affect the amount of waste produced. Even though these empirical results conflict with those from Tuscany, they are consistent with those of previous studies (Kinnaman and Fullerton, 2000; Struk, 2017).

With regard to Model (2), we find that the average taxable income of individuals per capita and the adoption of a zero-waste strategy are important determinants of SW (Table 7), which is in line with both our expectations and the Tuscany results.

However, two contradictions with the Tuscany results are noted. First, population density does not exert a significant effect on the waste recycling rate: this result is in contrast to those of previous studies (Abbott et al., 2011;

Lakhan, 2014). Moreover, the ownership of the waste utility that manages urban waste management services does not significantly influence the SW. Finally, as for Tuscany municipalities, the results confirm that population age is not statistically significant.

Table 8 summarizes the comparison of panel regression estimates using TOTW and SW as dependent variables for both Tuscan municipalities and municipalities from other Italian regions. Data about other municipalities in different regions seem to confirm that AI, DENS, ZW and OWN are relevant determinants of environmental performance of municipalities.

Table 8 Comparison of estimates for municipalities located in Tuscany and in other regions.

alt-text: Table 8

	Tuscany		Other regions	
TOTW	Coef.	Sign.	Coef.	Sign.
AI	-***+***AA-**SIZE-	***	+	***
AA	-		-	**
SIZE	-		+	***
DENSITY	-+ZW-		+	
ZW	-		-	
OWN				
Mixed	--		-	*
Private	+	*	+	
_cons	+		+	

	Tuscany		Other regions	
SW	Coef.	Sign.	Coef.	Sign.
AI	+	***	+	***
AA	+		+	
SIZE	+		-DENS+**-	
DENS	+	**	-	*
ZW	+	**	+	**
OWN				
Mixed	--	**	+	
Private	-+_cons-		+	
_cons	-		-	

5 Policy implications and conclusions

This study investigates the effect of policies adopted by 279 Tuscan municipalities on environmental performance, measured in terms of the total waste produced per capita and rate of separate collection, along with the relevant demographic and socio-economic characteristics of the municipalities during the 4-year observation period (2012–2015).

Cross-municipality differences in waste production and recycling are identified within Tuscany. In 2015, the total waste produced ranges from 327 to 1663 kg per year per inhabitant, while the municipal share of recycled waste

ranges from 11.63% ~~to~~ 87.41% and an average of 42%, with more than 85% of municipalities far from the legal threshold of 65% of the share of recycled waste. Since the national average production of urban waste per capita is 487 kg per inhabitant per year and the national average recycling rate is 47.5%, there is a need to introduce new policies to encourage the sustainable behavior of Tuscan citizens in terms of reducing waste production and household waste sorting activities, at least to align regional and municipal performances to the national average. The empirical results could help policy and decision makers to identify policies that have higher probability of encouraging waste reduction and recycling activities. First, adopting a zero-waste strategy helps improve the SW; thus, a formal policy decision adopted by the municipality is an effective way to encourage citizens' pro-environmental behavior. Citizens that elect their representatives as mayors or as members of the municipal council may consider such political input as an effective encouragement to be committed to the environmental problems related to waste reduction and recycling. Citizen participation in household waste separation is essential for waste management firms' performance and further utilization of recyclable waste (Stoeva and Alriksson, 2017). Thus, Tuscan municipalities should communicate to their citizens their commitment to reduce waste and improve the SW. To this end, the compulsory introduction of curbside collection and separate collection of waste could be effective instruments, even given their economic and financial constraints, since larger amounts of recycled waste overcome the higher costs of curbside collection (Guerrini et al., 2017). Recycling programs can reduce disposal costs and even produce revenue from selling recycled material, but this holds only if these advantages overcome the cost of collecting and treating the recycled materials (Kinnaman, 2005).

Moreover, the adoption of a zero-waste strategy through the four categories of mechanisms of policy diffusion (coercion, imitation, competition, and learning) (Ruiz-Villaverde et al., 2018) could impact the strategies and policy of waste firms, forcing managers to be more committed and have better recycling rates and waste production reduction. The municipal decisions of policymakers about zero-waste strategy are able to influence managerial decision-making in both publicly and mixed-owned firms through shareholder meetings, investment in communication, stakeholder engagement, and adoption of zero-waste principles (ZWIA, 2018).

Urban waste management services managed by municipalities or publicly owned firms induce lower production of waste and higher SWs than privately or mixed-owned firms. This result advances the literature on public versus private MSW management, demonstrating that public management is better in terms of municipal environmental performance (measured by TOTW, public provision is better than totally private provision, and measured by SW, public provision is better than total or partial privatization).

Policy and decision makers should introduce awareness-raising actions and exchanges of good practices to encourage pro-environmental behavior among younger generations, people living in low-density areas, and citizens with lower incomes, which all have less clear attitudes on separate collection and waste production reduction. This could be achieved by fostering, for example, education and communication campaigns on how to reduce waste and carrying out effective waste separation and incentive programs.

The study has some limitations. First, it focuses only on one Italian region; the comparison with a sample of municipalities located in other Italian regions confirmed some results but also highlighted some differences. Future studies could compare a broader dataset of municipalities in other regions as well as undertake international comparisons between countries to control for more geographical and regulatory characteristics. Moreover, it would be useful to extend the investigation period, adding more data as soon as they become available, to include other factors that affect municipality performance to obtain more robust results, and to introduce other performance indicators along with waste production and the separation rate, such as the waste disposal rate.

Declaration of interest

None.

Uncited references

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Giulia Romano wrote the Introduction and Sections 1,2,4, and ~~5~~5; Agnese Rapposelli wrote Section 3; Lorenzo Marrucci built the dataset and collaborated with Giulia Romano on the study design.

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Highlights

- We study the links between municipal waste/recycling and a zero waste strategy.
- We analyze the link by ownership type in Tuscany, Italy.
- Waste production is higher when waste services are wholly privately owned.
- It is higher when the average taxable income of individuals per capita is lower.
- A zero waste strategy significantly improves the separate collection rate.

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