Recycling and Waste Generation: An Estimate of the Source Reduction Effect of Recycling Programs

Recycling and waste generation: an estimate of the source reduction effect of recycling programs

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Abstract

Recent analyses maintain that recycling in developed countries, being mostly the result of costly policies, may be already above its socially optimal level. These analyses in fact underestimate such level if increasing recycling not only reduces residual waste, but also total waste. We find that this is the case: a 10% increase in recycling rate is associated with a 1.5-2% decrease of total urban waste. This effect is largely attributable to curbside collection programs, whose adoption increases recycling rates by 8-14% and reduces waste generation by about 4%. This paper contributes to the literature on the relations between waste and recycling by providing estimates of the source reduction effect of recycling policies and pointing out the important role played in it by curbside collection programs.

Keywords: Environmental policy, Waste management, Waste reduction, Socially optimal recycling rate, Curbside collection.

JEL Classification: C23, D61, R11, Q53.

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1. Introduction

Since the late 1980s, waste management has witnessed quite dramatic changes throughout the world (see, among others, Kinnaman, 2003; Kinnaman and Takeuchi, 2014; Mazzanti and Montini, 2009; Shinkuma and Managi, 2011). One of the most pervasive trends has been the increase of household recycling of urban solid waste. Recycling rates in developed countries of municipal waste has more than doubled in the last 20 years. In the US, the recycling rate increased from 10% in 1985 (16% in 1990) to about 35% in 2011 (US EPA, 2014). In the EU27, the average rate increased from 17% in 1995 to 42% in 2013 and three countries exceeded 50% in 2013, namely: Germany, 64.5%; Austria, 56%; Belgium, 55% (source: Eurostat).[1]

Such increase is largely attributable to government policies aimed at reducing landfilled waste: curbside recycling programs, unit-pricing ("Pay-As-You-Throw") programs (bag/tag programs, weight-based systems, can programs) and/or, to a lesser extent, other pricing policies (deposit/refund systems, advance disposal fees, recycling subsidies) (Abbott et al., 2011; Acuff and Kaffine, 2013; Bucciol et al., 2015; Fullerton and Kinnaman, 1996; Jenkins et al., 2003; Kinnaman, 2006; Kinnaman and Fullerton, 2000; Palmer and Walls, 1997). As discussed in Bucciol et al. (2015), curbside (door-to-door) collection and "Pay-As-You-Throw" programs are associated with recycling rates on average 30 percentage points (p.p.) larger.

Because of public worries over the lack of landfill spaces fanned by an upsurge of tipping fees in the mid 1980s (Jenkins et al., 2003) and the infamous "gar-barge" Mobro 4000 in 1987 (Kinnaman, 2006; Acuff and Kaffine, 2013), in the US many states started either mandating curbside recycling or setting recycling targets. In Japan, several recycling laws were enforced in the 1990s (Usui, 2008) (e.g., the Containers and Packaging Recycling Law, fully entered into force in April 2000). In the EU, the Directive 1994/62/EC obligated member states to meet specified targets for the recovery and recycling of packaging waste. More recently, the Directive 2008/98/EC (Waste Framework Directive), that has introduced the "polluter pays principle" and the "extended producer responsibility" in waste management, has set new recycling and recovery targets to be achieved by 2020 (50% for urban waste materials) and required EU member states to adopt waste management plans and waste prevention programs. This policy orientation is framed within the idea of circular economy (on this see EEA, 2016, 2017, 2018a,b).[2]

This notwithstanding, being the result of costly policies, high recycling rates

[1] According to the Waste Atlas (`http://www.atlas.d-waste.com/`, accessed: 07.20.18), a crowdsourcing database that hosts waste data for 164 countries together accounting for about 97% of the global waste generation, the first four countries in terms of recycling rates are: Singapore (59%), Slovenia (55%), South Korea (49%), Germany (47%). The four lowest are: Costa Rica (0.3%), Chile (0.4%), Brazil (1%), Antigua and Barbuda (1%).

[2] See also the 7th EU Environment Action Programme to 2020 "Living well, within the limits of our planet" adopted by the European Parliament and the European Council.

are not necessarily socially desirable (Kinnaman, 2006; Kinnaman et al., 2014). In fact, Kinnaman (2006) points out that disposal taxes levied at the landfill could effectively replace curbside recycling programs. By carrying out a cost-benefit analysis, Kinnaman et al. (2014) find that the recycling rate in Japan, equal to 19,44%, is almost double than the estimated optimal one (10%). Thus, one might easily conclude that also in EU and US recycling rates are in fact too high.

However, as observed by Kinnaman et al. (2014, p.57) themselves, their analysis underestimates the optimal level of recycling if recycling rates negatively correlate with total waste per capita, i.e. by increasing recycling both residual and *total* waste tend to decrease and there is therefore a source reduction effect of recycling programs.

By analyzing data on municipal solid waste generation and recycling rates for the Italian capital cities at the Province level (116) in the 2000s and early 2010s (13 years), we show that this is indeed the case. We observe a robust negative association between changes in recycling rates and waste generation: an increase of 10 p.p. in recycling is associated with a decrease of 1.5-2% in total urban waste. In 2012 in Italy this amounted to more than 500 thousand tons. Moreover, we find that curbside collection programs play an important role in such effect: the adoption of a curbside collection program increases recycling rate by roughly 10% and also significantly strengthens the marginal impact of recycling on waste minimization. The total effect is a reduction of waste generation of roughly 4%.

A number of studies have already discussed the connections between recycling and waste generation. Ebreo and Vining (2001) investigate subjects' self-reported behavior on recycling and waste reduction, showing that respondents' propensity to engage in waste minimization behavior is not related to their propensity to recycle. By using survey data, Barr et al. (2001) analyze the effect of environmental values, situational and psychological factors on waste minimization and waste recycling, finding that the motivations behind the two are different. By monitoring households behavior over a 16-week period, Tonglet et al. (2004) conclude that waste reduction and recycling identify different dimensions of waste management and show that waste reduction behavior is not correlated with recycling intentions and attitudes. D'Amato et al. (2016) put forward a theoretical model which considers intrinsic and extrinsic motivations to recycling and waste reduction, and allows for complementarity/substitutability relations between recycling and waste minimization.[3] By estimating a structural equation model based on survey data reporting individual opinions and stated behaviors on a wide range of environment-related activities, the authors find that recycling and waste reduction reveal a complementarity relation and they affect each other.

Our contribution to the literature is twofold. First, by using data on the

[3] D'Amato et al. (2016) show that the social norms affect recycling behavior while environmental values tend to enhance waste reduction. On the effect of motivations on waste management behavior see also Cecere et al. (2014) and Gilli et al. (2018)

actual amount of (total and recycled) waste, we provide an estimate of the marginal impact of recycling on expected urban waste reduction. Second, we show that curbside collection programs not only positively affect recycling rates (see Bucciol et al., 2015; Kinnaman, 2006; Kinnaman and Fullerton, 2000), but they also increase the marginal impact of recycling on waste reduction, thus further reducing landfilled waste and the exploitation of virgin raw materials (Abbott et al., 2011). In this respect, our results differ from Kinnaman and Fullerton (2000), who do not find any statistically significant impact of curbside recycling on waste generation, and are in line with D'Amato et al. (2016), who indeed find a positive effect of the presence of bottle/recycling banks in the area of residence on waste reduction, although they do not quantify this effect.

Our sample is suitable to analyze the relation between recycling and waste generation. First, we consider Italy over a period of pretty radical changes in waste management.[4] Second, in Italy urban waste management is highly decentralized and municipalities exhibit large differences in terms of waste generation, disposal and recycling across units and periods.[5] Finally, the absence of (strictly defined) unit-pricing programs in place in the municipalities and the periods we consider allows us to partly rule out illegal dumping and burning as possible explanations of the decrease in waste generation associated with increased recycling.[6] Unless the introduction of a fee completely crowds-out the (intrinsic) motivations behind the source reduction effect of recycling activities,[7] at least part of the decrease of unsorted waste associated with increased recycling promoted by unit-pricing programs discussed in Kinnaman and Fullerton (2000) and Allers and Hoeben (2010) can be accounted by the source reduction effect

[4]In Italy, the percentage of landfilled municipal waste decreased from 93% in 1995, well above the EU27 average (64%), to 37% in 2013 (EU27: 31%). Such decrease was due to a larger fraction of incinerated waste — from 5% (EU27: 14%) to 20% (EU27: 26%) —, but also to a significant increase in material recycling — from 3.5% (EU27: 11%) to 25% (EU27: 27%) — and composting and digestion — from 1% (EU27: 6%) up to 15% (EU27: 15%). The recycling rate of municipal waste — which, according to the Eurostat definition, includes material recycling, composting and anaerobic digestion, — therefore increased from 5% in 1995 (EU27: 17%) and 14% in 2000 (EU27: 25%) up to 39% in 2013 (EU27: 42%). Source: Eurostat.

[5]As noted by Mazzanti and Montini (2014), decentralization is a prime factor behind the heterogeneity in waste management performance exhibited by Italian provinces and the recurrence of the North-South divide in waste generation and management (on this, see Mazzanti et al., 2008, 2012). The high decentralization resulted also in infamous "waste emergencies" occurred in some municipalities over the years, such as the waste crisis in Milan (1995), Naples (1994-2009) and, more recently, Rome and Palermo (2014) (D'Alisa et al., 2010).

[6]Since recycling generates opportunity costs and there are monetary sanctions in case recyclable waste is thrown in the garbage or non-recyclable waste is put in the wrong bin, one might argue that illegal dumping and burning are plausible explanations even in the absence of unit-pricing programs. In fact, since these illegal activities stem even higher opportunity costs and sanctions than those associated with incorrect recycling, and the implementation of sanctions in case of incorrect recycling is particularly difficult because of monitoring costs, source reduction seems a much more plausible explanation than illegal dumping/burning.

[7]Since the existing literature highlights a role of intrinsic motivations in explaining waste reduction behavior and of extrinsic motivations in explaining recycling behavior, we cannot exclude this possibility.

of recycling.

In fact, although up to 1998 the waste tax (TARSU) in Italy was determined by considering only the size of household living spaces, with no reference to the actual amount of waste generated/recycled, Law No. 22/1997 introduced a waste management tariff (TIA) based on the principle of full-cost pricing, where a part of the total payment is actually connected with variable management costs. Although these costs are variously determined in general on the basis of past trends of waste generation in the place where the household lives,[8] and therefore the tariff is not unit-pricing in a strict sense, this new tariff might have induced some of the effects of unit-pricing programs (in this respect, D'Amato et al., 2018, find some evidence of a positive effect of the new tariff regime on illegal waste disposal). To account for them, we control for the tariff system in place in the municipality in each year. This is possible because Law 22/1997 provided for a gradual transition phase (see also Mazzanti et al., 2008) and different municipalities have adopted the new system in different periods.[9] We find no evidence that the waste management tariff affects the expected level of urban waste (thus finding no support of its effect on illegal waste disposal), although there is some evidence that it tends to increase recycling.

The paper is organized as follows. In Section 2, we describe the data and carry out some preliminary analysis. In Section 3, we present and discuss the empirical methodology and the results: the effect of recycling on waste generation, and the effect of curbside collection programs on recycling rates and waste generation. Section 4 concludes by summing up the main results and discussing the main limitations of the present analysis and the possible venues of future research.

2. Preliminary analysis

The data on per capita municipal waste generation[10] and recycling rates for 116 provincial capitals in Italy from 2000 to 2012 come from the Italian National Institute of Statistics (ISTAT).[11]

As it appears from Figure 1, that reports the box plots with means by year, the distribution of urban waste per capita (p.c.) over provincial capitals in Italy changed over time. In particular, the mean and median increased by about 10% from 2000 to 2007 and then started decreasing, with the levels in 2012 rather similar to the initial ones. Linear and rank correlation coefficients between municipal waste p.c. in 2000-2002 and 2010-2012 are both equal to 0.83, hinting

[8] The variable part of the tariff is reduced by 10% to 20% if domestic composting and/or join garden waste door-to-door collection programs are implemented (ISPRA, 2013).

[9] In fact, in 2012, only around 17% of municipalities in Italy had adopted the TIA (ISPRA, 2013; Mazzanti et al., 2008), although the percentage is greater for the provincial capitals in our sample, where 38% had actually adopted the TIA up to 2012.

[10] Municipal waste is mainly waste generated by households, although it also includes waste generated by small businesses and public institutions collected by the municipality.

[11] The data cover all the provincial capitals in Italy except Urbino.

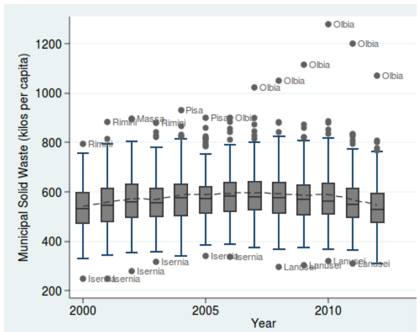


Figure 1: Box plots with means (dashed line) of municipal waste

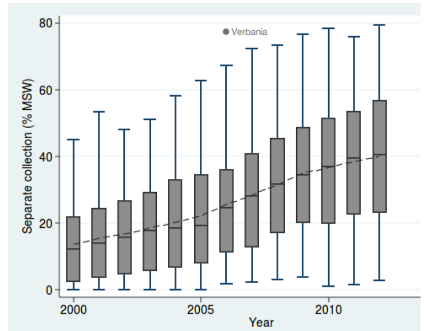


Figure 2: Box plots (dashed line) of recycling rates of municipal waste

Table 1: Mobility of municipalities in terms of recycling rates 2000-2012

Recycling rate quartile		Mean 2010-12				
		1st	2nd	3rd	4th	Total
Mean 2000-02	1st	17	4	3	5	29
	2nd	12	10	2	5	29
	3rd	0	10	11	8	29
	4th	0	5	13	11	29
	Total	29	29	29	29	116

at no significant intra-distribution dynamics.[12]

Figure 2 reports the same info for recycling rates of municipal waste.[13] Average recycling rates (mean and median) exhibit a linear increasing trend: the mean (median) recycling rate increased by 26.4 (28.2) p.p. from 13.7% (12.3%) in 2000 to 40.1% (40.5%) in 2012. The spread of the distribution increased over time (the standard deviation doubled), indicating the absence of a process of convergence across municipalities, although the rank correlation coefficient between the recycling rates in 2000-2002 and in 2010-2012, equal to 0.48, hints at some intra-distribution dynamics, i.e. processes of catching-up and leapfrogging involving a subset of municipalities.

[12]The decreasing averages since 2007 are consistent with the overall patterns at the EU15 level. This is only partly accounted by the reduction in the final consumption expenditure of households associated with the crisis, hinting at a possible phenomenon of "decoupling" in urban waste generation (on this see, for instance, ISPRA, 2014). On the issues of (absolute and relative) "decoupling" in waste generation and the estimation of "waste Kuznets curves" for Italy see also Mazzanti and Zoboli (2009) and Mazzanti et al. (2012), who however find no evidence of decoupling as they cover the period 1999-2006.

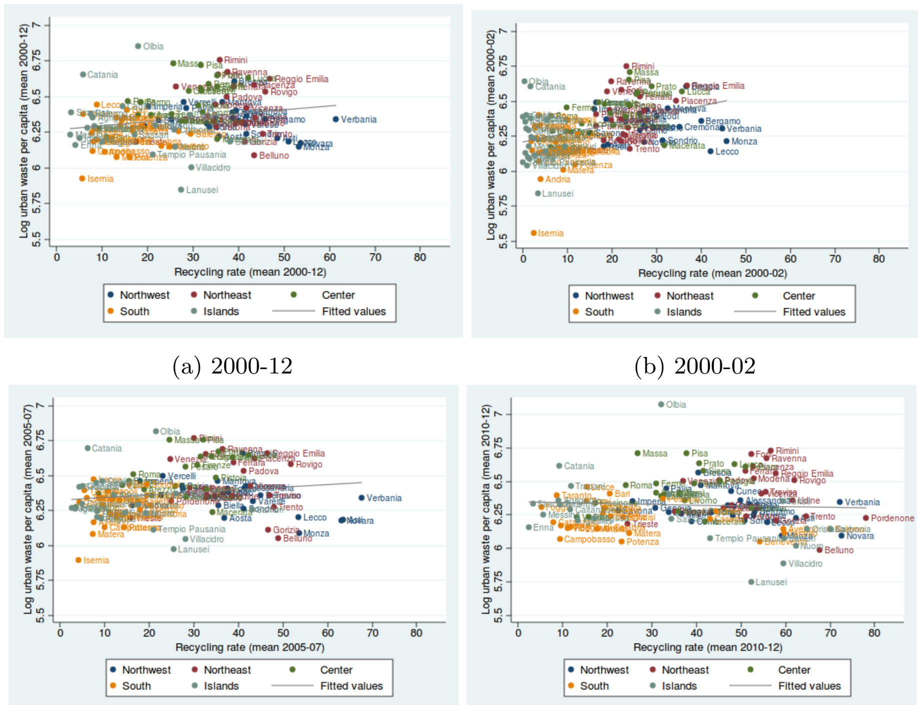
[13]The variable actually records the percentage of separate collection of municipal waste (paper and paperboard, glass, plastics, metals, hazardous waste, yard and organic waste). A kilogram of separate collection of municipal waste is made up on average (across units and periods) of: 27.8% yard and organic waste, i.e. waste to be treated via composting or anaerobic digestion; 14% glass; 5.7% plastics; 4.8% metals; 0.4% hazardous waste; 10% other materials (bulky waste, electrical devices, inert materials to recovery, textile, other packaging).

Figure 3: Municipal waste per capita (mean 2000-12)

Figure 4: Recycling rates of municipal waste (mean 2000-12)

Table 1 analyzes more in depth the evidence on the 10-year mobility of municipalities in terms of recycling rates. The table is a discrete transition matrix and is built as follows: for each municipality we computed the mean recycling rate in, respectively, 2000-02 and 2010-12; each municipality is counted in a different cell on the base of the quartiles it belongs to in the distribution of recycling rates in 2000-02 and 2010-12, respectively. If there were no changes in the relative performance, all municipalities were counted in the main diagonal of the matrix. The cases of catching-up and leapfrogging appear below the main diagonal: these are municipalities that started from relatively low levels and ended up in higher rankings. In this respect, a significant catching-up process occurred in the provincial capitals of the regions of Sardinia and Campania, with the important exception of Naples, whose relative position got even worse (it appears therefore among the municipalities above the main diagonal), while the majority of the other municipalities in the South remained stacked at the lower end of the distribution.

In fact, as shown in the proportional symbol maps in Figures 3 and 4, that report the time averages of municipal waste p.c. and of recycling rate for the provincial capitals, data on municipal waste and recycling rates exhibit quiet evident spatial dependence (for seminal analysis of the spatial patterns for municipal waste generation and landfill disposal in Italian provinces see Mazzanti et al., 2012; Mazzanti and Montini, 2014). In particular, the very large positive spatial autocorrelation for recycling rates provides a striking picture of the Italian north-south divide, where the North is the hot spot of recycling and the South



(a) 2000-12

(b) 2000-02

(c) 2005-07

(d) 2010-12

Figure 5: Scatter plots of log municipal waste p.c. vs. recycling rate (with least squares fit)

the cold one.[14]

The fact that the South of Italy is characterized on average by lower levels of both urban waste per capita and recycling rates in the 2000s is the main driver of the positive correlation between the two variables (Figure 5a).[15] In fact, this

[14]The Moran's I and the Getis-Ord G are two (global) indexes of spatial autocorrelation (Fischer and Getis, 2010). The former measures the overall degree of similarity/dissimilarity between spatially close regions within a given study area: a positive and statistically significant Moran's I entails that similar values (high or low) occur among close regions more often than what is to be expected under the null of no spatial dependence. The Getis-Ord statistic is useful instead to understand whether high or low values are spatially concentrated over the study area. When we compute these two statistics for recycling rates (using the Queen-contiguity weights matrix based on the province areas, where two municipalities are neighbors if the respective Province areas share a common edge or vertex), the Moran's I is as high as .72, while the Getis-Ord standardized G^* statistic is equal to 7.36 (p-value = .000), indicating the prevalence of hot spots, i.e. the clustering of high values. As far as municipal waste p.c. is concerned, the Moran's I is also statistically greater than zero (I = .352, p-value = .000) and G^* greater than what is to be expected under the null ($G^* = 2.58$, p-value = .005). The results are fairly similar using an inverse distance-based weights matrix with a friction coefficient in the range 2-5.

[15]The partial correlation between the two variables including macro-regional dummies is

correlation was not stable and significantly decreased over time (Figures 5b-d) for recycling rates and urban waste generated per capita across municipalities moved in opposite directions.[16] This phenomenon started well before the crisis (Figure 5c) and cannot be explained by it, as in fact the crisis hit harder the regions showing the smallest decreases in urban waste per capita.[17]

The changes in the relationship between municipal waste per capita and recycling rates resulted in changes in the correlation between recycling rates and total urban waste from positive (0.2 in 2000-02) to negative (-0.2 in 2010-12), with eight out of the ten largest municipalities in Italy (Rome, Milan, Naples, Palermo, Genoa, Bologna, Bari and Catania) showing recycling rates below the average.

In the next section, we shall analyze more in depth the relation between recycling and source reduction by estimating the marginal impact of recycling on expected waste reduction and the possible differential impact of curbside collection on recycling and source reduction.

3. Methodology and results

3.1. Recycling and source reduction

In order to quantify the marginal impact of recycling on source reduction, we exploit the multi-level structure of the panel data and estimate the following specification:

$$\ln w_{ijt} = \beta_{0i} + \tau_{jt} + \beta_1 r_{ijt} + \boldsymbol{\beta}_2 \, \mathbf{Z}_{ijt} + \epsilon_{ijt} \tag{1}$$

where w_{ijt} is the solid urban waste per capita, in terms of kilos per year, in municipality i in region j (NUTS2) and year t, r_{ijt} is the recycling rate (the fraction of separate collection on total municipal waste), $\mathbf{Z}_{ijt}$ is a vector of controls at the municipality level, τ_{jt} are region and time-specific unobserved factors (to control for the fact that in Italy, regions set different policy frameworks and may provide different policy signals), β_{0i} is aimed at capturing unobserved time-invariant municipality-specific factors and ϵ_{ijt} is the (possibly serially correlated) error term.[18]

nearly null.

[16] The sample correlation between the average values in 2000-02 is 0.41, while the same correlation computed between the averages in 2010-12 is -0.05.

[17] Since 2007, the average yearly rate of decrease of household expenditure has been 1.56% in the islands, 1.21% in the South, 0.31% in the Northeast, 0.22% in the Center and the Northwest (source: Istat).

[18] In Equation (1), we implicitly assume that these municipality and time-specific random changes in urban waste per capita, ϵ_{ijt}, are not systematically related with recycling rates, computed as the ratio of recycling to urban waste, which is in turn the sum of recyclable volumes plus the volumes of residual waste. In fact, random changes generated by measurement errors can cause $\hat{\beta}_1$, the estimator of β_1, to be biased. The size and the direction of the bias actually depends on the relative size of measurement errors in recycling vs. residual waste: if measurement errors on volumes are larger (smaller) for recycling than for residual waste, this entails a positive (negative) correlation between r_{ijt} and ϵ_{ijt}, and this in turn upwardly (downwardly) biases $\hat{\beta}_1$, leading to underestimate (overestimate) the marginal effect of recycling

We estimate Equation (1) by means of a Fixed-Effects (FE) estimator with HAC-robust standard errors. The results are summarized in Table 2. Column (1) shows the results of a FE regression of $\ln w_{ijt}$ on r_{ijt} and time-dummies. In column (2), we include region and time-specific dummies (a different dummy for each pair of region and year). The point estimate of β_1 in column (2), -0.19, implies that a 10% increase of recycling rate is associated with a 1.9% decrease in expected waste generation.

In column (4), we re-estimate Equation (1) by including a dummy (TIA) equal to 1 in year t and municipality i if i moved from TARSU to TIA and 0 otherwise, to control for a possible effect of the new waste management tariff on the production of (legal) urban waste.[19] In fact, results show no evidence of such effect.

In columns (5), (6) and (7), we control also for income per capita and tourism.[20] We include the log of income per capita in the municipality (column 5),[21] along with the log of the total number of nights spent in tourist accommodation establishments in the tourist district (column 6) (source: ISTAT). In our sample, tourist districts mostly overlap with municipalities; nonetheless, the dimension and composition of some districts have changed in the period we consider. To account for this, in the specification reported in column (7), we include interaction terms between the log of the total number of nights spent in tourist accommodations and dummies capturing such changes. The inclusion of these terms do not change the results obtained in column (6).[22]

The intra-distribution dynamics in recycling rates across municipalities highlighted in Section 2 might hint at the presence of municipality-specific trends in recycling correlated with waste generation. In order to control for them, as a

on source reduction. It is worth stressing that these issues do not arise in Equation (5), where we estimate the source reduction effect of curbside collection programs (see Section 3.3).

[19]The variable has been created starting from the report Osservatorio prezzi e tariffe di Cittadinanzattiva (2013) and cross-checking and collecting information through the web or direct contacts, via email or phone, with the administrative staff of the municipalities included in the dataset. Data available upon request.

[20]Income per capita and tourist arrivals are in fact municipality-specific factors omitted in Equation (1) as they vary in time. These factors are allegedly positively associated with waste generation (e.g. the larger the tourist arrivals, the larger the waste in the municipality, *ceteris paribus*). As long as they also correlate with recycling, their omission produces an omitted variable bias. The likely sign of the bias in this case is decided by the sign of the correlation between each one of them and the recycling rate (this is in fact strictly valid only when each omitted variable is uncorrelated with the other regressors) (Wooldridge, 2010, p. 65-67). Since income per capita is positively correlated with recycling rate, omitting it should upwardly bias $\hat{\beta}_1$, thus underestimating the marginal effect of recycling on source reduction; on the contrary, as far as tourist arrivals negatively correlates with recycling (for tourists on average recycle less than locals), not controlling for tourists downwardly biases $\hat{\beta}_1$, leading to overestimate the source reduction effect of recycling.

[21]Income per capita at the municipality level is computed using personal income tax data from the Italian Ministry of Economy and Finance.

[22]The same result is obtained also by simply dropping from the sample the observations where touristic district and municipality do not coincide.

further robustness check, we also estimate the following specification:

$$\ln w_{ijt} = \beta_{0i} + \gamma_i t + \tau_{jt} + \beta_1 r_{ijt} + \epsilon_{ijt} \tag{2}$$

This correlated random trend (CRT) model can be consistently estimated by first differencing Equation (2) to obtain:

$$\Delta \ln w_{ijt} = \gamma_i + \Delta\tau_{jt} + \beta_1 \Delta r_{ijt} + \Delta\epsilon_{ijt} \tag{3}$$

and estimating Equation (3) using a FE estimator with time-dummies (see Wooldridge, 2009, 2010). This specification leads to results in line with the previous estimates, with a point estimate of β_1 equal to -0.18 (column 3).

To sum up, the results summarized in Table 2 point out that a 10% increase in recycling rate tends to produce a reduction of solid urban waste per capita of about 1.7-2%.[23]

Even though our data do not allow us to clarify the motivations behind this result, it seems to support the complementarity between recycling and waste reduction pointed out by D'Amato et al. (2016). In fact, as pointed out by these authors, two opposite forces may shape the relation between recycling and waste reduction: on the one hand, by increasing environmental concerns, recycling policies reduce waste generation; on the other hand, "they may have negative effects due to a sort of multi-tasking effect (à la Holmström and Milgrom, 1991), so that the individual devotes less effort to waste reduction in response to incentives aimed at increasing recycling efforts." (D'Amato et al., 2016, p.84).

As a matter of fact, if such multi-tasking effect was actually at work, the implementation of curbside collection programs, i.e., more demanding and particularly effective recycling policies, should weaken, or at least not strengthen, the effect of recycling on waste generation. In order to investigate this issue, in what follows we shall consider these programs.

3.2. Curbside collection and recycling

To estimate the expected impact of curbside collection on recycling, we estimate the following specification:

$$r_{ijt} = \alpha_{0i} + \tau_{jt} + \alpha_1 D_{ijt} + \boldsymbol{\alpha}_2 \mathbf{Z}_{ijt} + \nu_{ijt} \tag{4}$$

where r_{ijt} is the recycling rate of municipality i in region j and year t (expressed in percentage terms), α_{0i} are municipality-specific dummies, τ_{jt} are (possibly region-specific) time dummies, D_{ijt} is a dummy which takes value 1 if most of the municipality i is served by a curbside collection program over the period t,[24]

[23] We also considered the evidence of systematic differences in the source reduction effect of recycling between the North of Italy and the rest of the country by including an interaction term in Equation (1) between the recycling rate and a dummy for the regions in the North. Since the interaction term was never significant and all the other results remain the same, we decided not to report the regressions to save on space. Results are available upon request.

[24] This variable has been collected directly by the authors through direct contacts, via email or phone, with the administrative staff of the municipalities included in the dataset. Data are available at request.

Table 2: Recycling and waste generation

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Model	FE	FE	CRT	FE	FE	FE	FE
Recycling rate (0-1)	-.182***	-.193***	-.179***	-.198***	-.209***	-.168**	-.176**
	(.046)	(.066)	(.060)	(.066)	(.069)	(.071)	(.071)
TIA dummy				.0091	.0075	.0048	.0027
				(.0109)	(.0113)	(.0116)	(.0119)
ln Income per capita					.329**	.437***	.447***
					(.140)	(.140)	(.141)
ln Tourists						.016	.019
						(.012)	(.013)
Time dummies	Yes						
Region-specific time dummies		Yes	Yes	Yes	Yes	Yes	Yes
Δ tourist district $\times$ ln Tourists							Yes
Observations	1,504	1,504	1,388	1,504	1,388	1,333	1,333
Cross-sectional units	116	116	116	116	116	116	116
R^2	.267	.416	.361	.417	.394	.405	.435

Dependent variable: ln Urban waste per capita. FE = Fixed-Effects; CRT = Correlated Random Trend.
HAC-robust standard errors in parentheses. Significance levels: * 10%, ** 5%, *** 1%.

Table 3: Curbside collection and recycling

	(1)	(2)	(3)	(4)	(5)	(6)
Model	FE	FE	CRT	FE	FE	FE
Curbside collection dummy	14.29***	9.42***	4.91***	9.29***	8.14***	8.18***
	(2.53)	(1.92)	(1.74)	(1.91)	(1.90)	(1.93)
TIA dummy	1.25	3.18**	2.01*	3.10**	3.43**	3.27**
	(1.71)	(1.49)	(1.18)	(1.45)	(1.48)	(1.49)
ln Income per capita				8.58	-.76	-2.62
				(14.7)	(15.8)	(16.2)
ln Tourists					-.62	-2.05
					(1.02)	(1.49)
Time dummies	Yes					
Region-specific time dummies		Yes	Yes	Yes	Yes	Yes
Δ tourist district $\times$ ln Tourists						Yes
Observations	1,504	1,504	1,388	1,388	1,333	1,333
Cross-sectional units	116	116	116	116	116	116
R^2	.639	.821	.289	.810	.791	.794

Dependent variable: Recycling rate (0-100%). FE = Fixed-Effects; CRT = Correlated Random Trend.
HAC-robust standard errors in parentheses. Significance levels: * 10%, ** 5%, *** 1%.

and $\mathbf{Z}_{ijt}$ is the vector of controls, i.e. the TIA dummy, income per capita in the municipality and total nights spent in tourist accommodations in the tourist district the municipality belongs to.

Equation (4) is estimated by means of a FE estimator with HAC-robust standard errors. The results, summarized in columns (1)-(2) and (4)-(7) of Table 3, show that curbside collection positively affects recycling. According to the point estimates of α_1 in the different specifications, curbside collection programs increase the expected recycling rate by 8-14 p.p. Moreover, the same results show that the recycling rate has been also positively affected by the new waste management tariff (TIA), although the effect is lower and less statistically significant: the expected recycling rate is 2-3 p.p. larger with the new tariff.

For completeness, we also estimate a CRT model that includes municipality-specific time trends along with region-specific time dummies (column (3) of Table 3). In this model, the expected impact of curbside collection programs on recycling rates is still positive and statistically significant, but actually lower: the 95% confidence interval of α_1 is 1.5-8.3. However, as it is estimated in first differences and there are possible lagged effects of collection programs on recycling, this model likely underestimates the impact of curbside collection on recycling.

3.3. Curbside collection and source reduction

Finally, we analyze the impact of curbside collection programs on waste generation. To quantify such impact, we estimate the following specification:

$$\ln w_{ijt} = \lambda_{0i} + \tau_{jt} + \lambda_1 D_{ijt} + \boldsymbol{\lambda}_2 \mathbf{Z}_{ijt} + \epsilon_{ijt} \tag{5}$$

where the log of the urban waste per capita ($\ln w_{ijt}$) is regressed on the curbside collection dummy (D_{ijt}), (region-specific) time-dummies (τ_{jt}) and a number of controls. The results are summarized in Table 4.

These results show that the source reduction effect of curbside collection programs is rather large. The lower (yet positive and statistically significant at the 10% level) estimate is returned by the CRT model; but, as argued above, the model underestimates the source reduction effect of curbside collection as this effect takes time to fully develop. In the FE model with controls for the tariff regime, income per capita and tourism (column 7), the point estimates of λ_1 entails that curbside collection decreases expected solid urban waste per capita by 4.7%.

The estimated expected impacts of both curbside collection and recycling on waste generation is shown in columns (1)-(6) of Table 5, which summarize the results of the estimations of the following specification:

$$\ln w_{ijt} = \beta_{0i} + \tau_{jt} + \beta_1 r_{ijt} + \beta_2 D_{ijt} + \boldsymbol{\beta}_4 \mathbf{Z}_{ijt} + \epsilon_{ijt} \tag{6}$$

Curbside collection affects waste generation both directly (the conditional expected level of waste p.c. is about 4 p.p. lower in municipalities that adopted curbside collection programs) and indirectly, via an increase in the expected level of recycling rate (which in turn has got a source reduction effect).

Table 4: Curbside collection and waste generation

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Model	FE	FE	CRT	FE	FE	FE	FE
Curbside collection dummy	-.0591***	-.0574***	-.0179*	-.0580***	-.0581***	-.0463***	-.0471***
	(.0139)	(.0187)	(.0105)	(.0187)	(.0182)	(.0160)	(.0161)
TIA dummy				.0063	.0046	.0023	.0005
				(.0110)	(.0118)	(.0120)	(.0123)
ln Income per capita					.307**	.418***	.430***
					(.143)	(.142)	(.143)
ln Tourists						.017	.023*
						(.012)	(.013)
Time dummies	Yes						
Region-specific time dummies		Yes	Yes	Yes	Yes	Yes	Yes
Δ tourist district $\times$ ln Tourists							Yes
Observations	1,504	1,504	1,388	1,504	1,388	1,333	1,333
Cross-sectional units	116	116	116	116	116	116	116
R^2	.264	.420	.345	.420	.396	.407	.436

Dependent variable: ln Urban waste per capita. FE = Fixed-Effects; CRT = Correlated Random Trend.
HAC-robust standard errors in parentheses. Significance levels: * 10%, ** 5%, *** 1%.

In fact, curbside collection programs has got an effect on waste generation mainly by increasing the marginal impact of recycling on waste reduction. This is shown in columns (7)-(12) of Table 5, which sum up the results of the following specification:

$$\ln w_{ijt} = \beta_{0i} + \tau_{jt} + \beta_1 r_{ijt} + \beta_2 D_{ijt} + \beta_3 D_{ijt} r_{ijt} + \boldsymbol{\beta}_4 \mathbf{Z}_{ijt} + \epsilon_{ijt} \tag{7}$$

where the coefficient β_3 captures the differential impact of increased recycling obtained via curbside collection programs on waste per capita.

This coefficient is strongly statistically significant and account for almost $^2/_3$ of the overall marginal effect of recycling on waste generation discussed in Section 3.1. Whereas the marginal impact of increased recycling on waste reduction without curbside collection programs in place is lower and almost never statistically significant, most of the source reduction associated with increased recycling comes from increased recycling obtained via curbside collection.

4. Conclusions

In the paper, we analyzed the empirical evidence in favor of a source reduction effect of policies aimed at increasing recycling and estimated such effect.

Our analysis contributes to the literature on waste management in two main respects. Firstly, we highlight a substantial impact of curbside collection programs on waste reduction. In order not to underestimate the socially optimal rate of recycling, cost-benefit analyses must consider the effect of these programs on waste generation. Secondly, we complement and extend the results of previous studies on the effect of recycling on waste reduction by providing quantitative estimates of such effect. In particular, we find that: i) an increase of 10% in recycling is associated with a decrease of 1.5-2% in total urban waste; ii) curbside

Table 5: Curbside collection, recycling and waste generation

Model	(1) FE	(2) FE	(3) CRT	(4) FE	(5) FE	(6) FE	(7) FE	(8) FE	(9) CRT	(10) FE	(11) FE	(12) FE
Recycling rate (0-1)	-.129***	-.136**	-.171***	-.141**	-.125*	-.132*	-.091	-.093	-.138**	-.098	-.088	-.097
	(.048)	(.059)	(.059)	(.058)	(.068)	(.068)	(.055)	(.066)	(.061)	(.066)	(.075)	(.075)
Curbside collection dummy	-.0404***	-.0442***	-.0093	-.0447***	-.0361**	-.0363**	.0363	.0234	.0497*	.0260	.0271	.0232
	(.0132)	(.0164)	(.0084)	(.0163)	(.0140)	(.0141)	(.0272)	(.0308)	(.0298)	(.0300)	(.0286)	(.0290)
Curbside dummy × Recycling rate							-.167**	-.148*	-.141**	-.155*	-.138*	-.130*
							(.069)	(.082)	(.069)	(.079)	(.076)	(.078)
TIA dummy				.0108	.0066	.0048				.0128	.0088	.0070
				(.0108)	(.0117)	(.0119)				(.0105)	(.0113)	(.0115)
ln Income per capita					.417***	.427***					.420***	.429***
					(.138)	(.139)					(.137)	(.138)
ln Tourists					.016	.020					.016	.020
					(.012)	(.013)					(.012)	(.013)
Time dummies	Yes						Yes					
Region-specific time dummies		Yes	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes
Δ tourist district × ln Tourists						Yes						Yes
Observations	1,504	1,504	1,388	1,504	1,333	1,333	1,504	1,504	1,388	1,504	1,333	1,333
Cross-sectional units	116	116	116	116	116	116	116	116	116	116	116	116
R^2	.283	.431	.362	.432	.416	.446	.291	.435	.367	.437	.420	.450

Dependent variable: ln Urban waste per capita. FE = Fixed-Effects; CRT = Correlated Random Trend. HAC-robust standard errors in parentheses.
Significance levels: * 10%, ** 5%, *** 1%.

collection programs reduce waste generation by about 4%, increase recycling rate by roughly 10%, and strengthen the marginal effect of recycling on waste minimization, with a 2/3 of the overall effect which arises only if recycling is the consequence of such programs.

Moreover, we also estimate the expected impact of the waste management tariff (TIA) in Italy on solid urban waste generation and recycling. The tariff is based on the principle of full-cost pricing, where a part of the total payment is actually connected with variable management costs and it might have therefore induced some of the effects of unit-pricing programs. We find no evidence of a direct effect of the tariff on total waste production, while we find some evidence of a positive effect of the tariff on the expected recycling rate (and therefore an indirect effect on waste production via the source reduction effect of recycling).

Our data on municipal waste and recycling rates also reveal strong spatial dependence with a very large positive spatial autocorrelation for recycling rates. The dataset used in this study may be further exploited to analyze the spatial and proximity factors that may impact on waste management at the municipal level (for a spatial analysis of waste management, see Mazzanti et al., 2012; Mazzanti and Montini, 2014). In particular, it might be worth investigating if and to what extent the adoption of curbside collection programs is positively affected by spatial proximity, as neighboring municipalities might have incentives to share recovery facilities and recovery schemes (see Mazzanti et al., 2012).

As regards to the motivational drivers behind the observed relations, it is worth pointing out that a significant role in waste reduction behavior seems to be played by intrinsic motivations (Cecere et al., 2014; D'Amato et al., 2016; Gilli et al., 2018), environmental values in particular (D'Amato et al., 2016); and recycling behavior seems to be related to warm-glow (Halvorsen, 2008; Kinnaman, 2006), social norms (Abbott et al., 2013; Brekke et al., 2010; Halvorsen, 2008) and moral norms (Brekke et al., 2003). Our data are not suitable to identify these drivers and quantify their specific impact. This notwithstanding, the key role played by curbside collection programs in generating the previous results disproves the idea of a "multi-tasking effect" triggering substitutability between recycling and source reduction, as already pointed out by D'Amato et al. (2016).

Recycling seems to be motivated by social norms and the desire for social approval (D'Amato et al., 2016): the visibility of recycling efforts favored by curbside programs, that allow for peer judgment, likely fosters recycling and strengthen the complementarity between recycling and waste reduction (on the effect of peer monitoring on recycling see also the recent contribution by Bucciol et al., 2019).

The creation of a dataset including both information on the motivations concerning environmental behaviors, the waste management policies actually adopted, and the amounts of garbage and recycled materials would allow us to investigate the impact of the different motivational drivers on recycling and waste reduction and might be a venue for future research.

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