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: without monetary incentives (no unit-pricing), 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 8.5-14% 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., 2014; Fullerton and Kinnaman, 1996; Jenkins et al., 2003; Kinnaman, 2006; Kinnaman and Fullerton, 2000; Palmer and Walls, 1997). As discussed in Bucciol et al. (2014), curbside collection and "Pay-As-You-Throw" programs are associated with recycling rates on average 30 percentage points 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 notwithstanding, being the result of costly policies, high recycling rates 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,

[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%).

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 percentage points 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 determining 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.[2] 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 actual amount of (total and recycled) waste, we provide an estimate of the average marginal impact of recycling on urban waste reduction. Second, we show that curbside collection programs not only positively affect recycling rates (see

[2] 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)

Bucciol et al., 2014; 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.[3] Second, in Italy urban waste management is highly decentralized and the provincial capitals exhibit large differences in terms of waste generation, disposal and recycling across units and periods.[4]

Finally, it is worth pointing out that the absence of unit-pricing programs in place[5] in the municipalities and the periods we consider allows us to rule out illegal dumping and burning as possible explanations of the decrease in waste generation associated with increased recycling.[6] In fact, unless the introduction

[3]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.

[4]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).

[5]Law No. 22/1997 introduced in Italy a waste management tariff (TIA) based on the principle of full-cost pricing. The part of this tariff aimed at covering fixed costs depended on the size of household living space and on the family size. Another part was connected with variable management costs, which are not a punctual definition of the costs per single household, but are variously determined in general on the basis of past trends of waste generation in the place where the household live. The latter is reduced by 10% to 20% if domestic composting and/or join garden waste door-to-door collection programs are implemented. The previous tax (TARSU) was calculated by considering the size of household living spaces. In 2012 – the most recent year in our data – the TARSU tax was still adopted in many Italian municipalities (only around 17% of municipalities having adopted the TIA tariff – see ISPRA, 2013). This is because Law 22/1997 provided for a gradual transition phase (see also Mazzanti et al., 2008).

[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.

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 of 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; 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[8] and recycling rates for 116 provincial capitals in Italy from 2000 to 2012 come from the Italian National Institute of Statistics (ISTAT).[9]

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 at no significant intra-distribution dynamics.[10]

Figure 2 reports the same info with respect to the recycling rate of municipal waste.[11] Average recycling rates (mean and median) exhibit a linear increasing trend: the mean (median) recycling rate increased by 26.4 (28.2) percentage points (p.p.) from 13.7% (12.3%) in 2000 to 40.1% (40.5%) in 2012. The

[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.

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

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

[10]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.

[11]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).

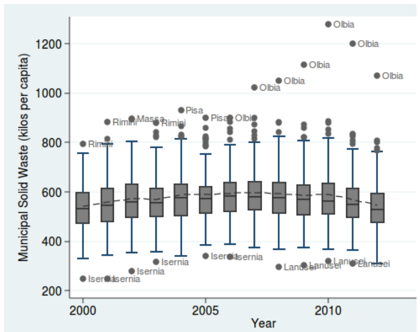

Figure 1: Box plots with means (dashed line) of municipal waste

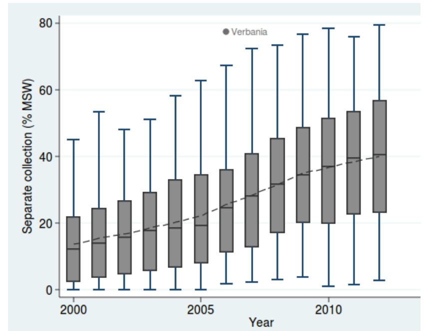

Figure 2: Box plots (dashed line) of recycling rates of municipal waste

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

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 (Table 1 summarizes the information on the 10-year mobility). In particular, 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, 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 the cold one.[12]

[12]Using the Queen-contiguity weights matrix based on the province of the municipality, Moran's I for recycling rates is as high as 0.72, while the Getis-Ord standardized G statistic is

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

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

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).[13] In fact, this 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.[14] 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 per capita urban waste generation.[15] These changes 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), where eight out of the ten largest municipalities in Italy (Rome, Milan, Naples, Palermo, Genoa, Bologna, Bari and Catania) show recycling rates below the average (Figure 6).

In the next section, we shall analyze more in depth the relation between

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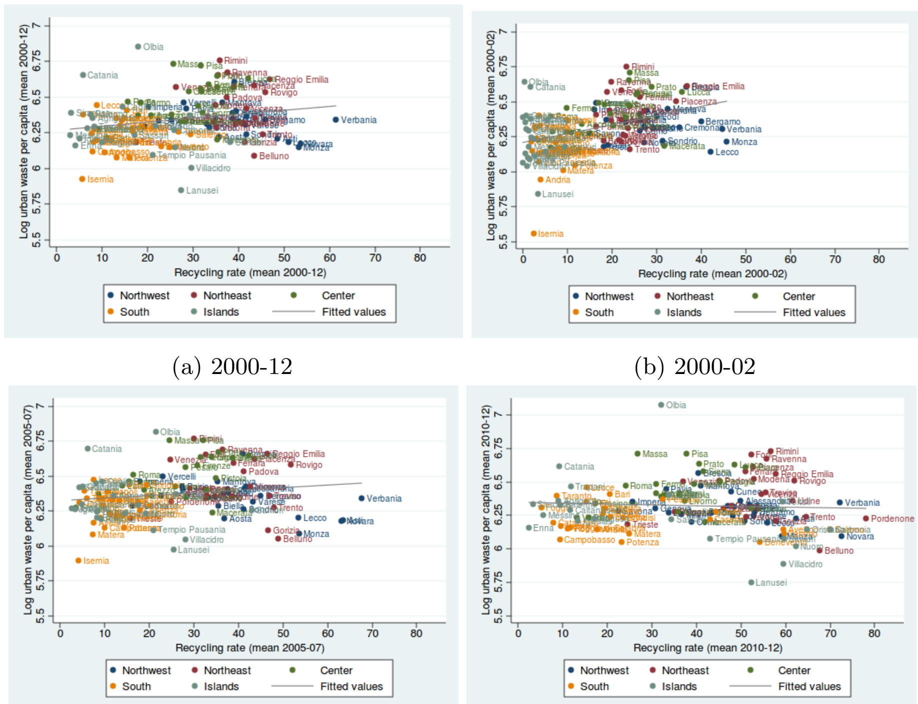
equal to 7.36 (p-value = 0.000), indicating the prevalence of hot spots. As far as per capita municipal waste is concerned, Moran's I is also statistically greater than zero (I = 0.352, p-value = 0.000) and the G greater than what expected under the null (standardized G = 2.5824, p-value = 0.005). As far as Moran's I is concerned, the results are fairly similar using an inverse distance-based weights matrix with a friction coefficient in the range 2-5.

[13] The partial correlation between the two variables including macro-regional dummies is nearly null.

[14] 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.

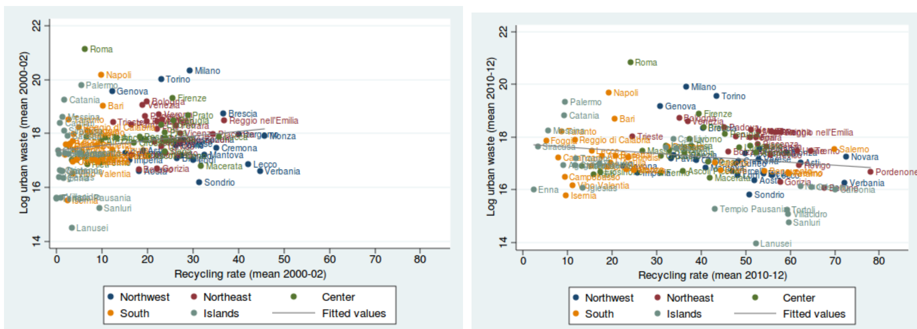
[15] Since 2007, the average yearly rate of decrease of household expenditure has been 1.56% in the islands, 1.21% in the South, 0.31% in the Northeast, 0.22% in the Center and the Northwest (source: Istat).



(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)



(a) 2000-02 (b) 2010-12

Figure 6: Scatter plots of log municipal waste vs. recycling rate (with least squares fit)

recycling and source reduction by estimating the average marginal impact of recycling on source 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 increasing 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, β_{0i} is aimed at capturing unobserved time-invariant municipality-specific factors and ϵ_{ijt} is the (possibly serially correlated) error term.

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 in the regression region and time-specific dummies (a different dummy for each pair of region and year). The point estimate of the coefficient 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 columns (4),(5) and (6), we re-estimate Equation (1) by controlling for income per capita and tourism.[16] We include in the regression the log of income per capita in the municipality (column (4)),[17] along with the log of the total number of nights spent in tourist accommodation establishments in the tourist district (column (5)) (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 issue, in the specification reported in column (6), 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 (5).[18]

[16] These factors are municipality-specific time-variant factors allegedly positively correlated with waste generation per capita and, respectively, positively and negatively correlated with recycling rate. While omitting income per capita will tend to upwardly bias β_1, thus underestimating the marginal effect of recycling on source reduction, not controlling for tourists will tend to downwardly bias the coefficient, therefore overestimating the impact of recycling on source reduction.

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

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

Table 2: Recycling and waste generation

Model	(1) FE	(2) FE	(3) CRT	(4) FE	(5) FE	(6) FE
Recycling rate (0-1)	-.182***	-.193***	-.179***	-.205***	-.165**	-.174**
	(.046)	(.066)	(.060)	(.0690)	(.071)	(.071)
ln Income per capita				.326**	.436***	.447***
				(.140)	(.139)	(.140)
ln Tourists					.016	.0190
					(.012)	(.013)
Time dummies	Yes					
Region-specific time dummies		Yes	Yes	Yes	Yes	Yes
Change tourist district × ln Tourists						Yes
Observations	1,504	1,504	1,388	1,388	1,333	1,333
Number of cross-sectional units	116	116	116	116	116	116
R^2	.267	.416	.361	.393	.404	.434

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%.

As a further robustness check, to control also for municipality-specific trends in waste generation correlated with recycling rate, 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:

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

where $\Delta\tau_{jt}$ is a new set of time effects, and then 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) of Table 2).

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%.

3.2. Curbside collection and recycling

A kind of recycling policies that are deemed particularly effective in increasing recycling rates, although more costly, are curbside (door-to-door) collection programs. To estimate the average impact of these policies 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

Table 3: Curbside collection and recycling

	(1)	(2)	(3)	(4)	(5)	(6)
Model	FE	FE	CRT	FE	FE	FE
Curbside collection (dummy)	14.44***	9.71***	5.02***	9.55***	8.46***	8.52***
	(2.45)	(1.91)	(1.72)	(1.89)	(1.88)	(1.91)
ln Income per capita				7.70	-1.58	-3.29
				(14.58)	(15.75)	(16.15)
ln Tourists					-.699	-2.145
					(1.066)	(1.529)
Time dummies	Yes					
Region-specific time dummies		Yes	Yes	Yes	Yes	Yes
Change tourist district × ln Tourists						Yes
Observations	1,504	1,504	1,388	1,388	1,333	1,333
Number of cross-sectional units	116	116	116	116	116	116
R^2	.638	.818	.285	.807	.787	.790

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

the municipality i is served by a curbside collection program over period t,[19] and $\mathbf{Z}_{ijt}$ is the vector of controls, i.e. income per capita in the municipality and total nights spent in tourist accommodations in the tourist district which the municipality belongs.

Equation (4) is estimated by means of a FE estimator with HAC-robust standard errors. The results, summarized in columns (1)-(2) and (4)-(6) of Table 3, show that the adoption of a curbside collection program positively affect recycling. According to the point estimates of α_1 in the different specifications, curbside collection programs tend to increase expected recycling rates by 8.5-14 percentage points.

For completeness, we also estimate a correlated random trend model that includes municipality-specific time trends along with region-specific time dummies. In this model, summarized in column (3) of Table 3, the 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 1.65-8.39. However, as it is estimated in first differences and there are possible lagged effects of collection programs on recycling, this model likely leads to underestimate 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:

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

[19] 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.

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 columns (1),(2) and (4) of Table 4.[20]

These results show that the source reduction effect of curbside collection programs is rather large. In the FE model with controls for income per capita and tourism (column (4)), the point estimate of the coefficient implies that the adoption of a curbside collection program decreases expected solid urban waste per capita by 4.7%. Moreover, curbside collection programs not only increase recycling rates, as discussed in Section 3.2, but also strengthen the marginal impact of recycling on waste reduction. This is shown in columns (5)-(8) of Table 4, which summarizes the results of the estimations of the following specification:

$$\ln w_{ijt} = \beta_{0i} + \tau_{jt} + \beta_1 r_{ijt} + \beta_2 D_{ijt} + \beta_3 D_{ijt} r_{ijt} + \boldsymbol{\beta}_4 \mathbf{Z}_{ijt} + \epsilon_{ijt} \qquad (6)$$

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 quantified 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 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.

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

[20] As done above, for completeness, we also estimate a correlated random trend model. The results are reported in column (3). However, being estimated in first differences, this model probably underestimate the effect of source reduction produced by curbside collection as long as such effect takes time to fully develop.

Table 4: Curbside collection and waste generation

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Model	FE	FE	CRT	FE	FE	FE	CRT	FE
Curbside collection (dummy)	-.0591***	-.0574***	-.0179*	-.0471***	.0363	.0234	.0497*	.0216
	(.0139)	(.0187)	(.0105)	(.0163)	(.0272)	(.0308)	(.0298)	(.0298)
Recycling rate (0-1)					-.091	-.093	-.138**	-.094
					(.055)	(.066)	(.061)	(.075)
Curbside collection × Recycling rate					-.167**	-.148*	-.141**	-.126
					(.069)	(.082)	(.069)	(.079)
ln Income per capita				.430***				.428**
				(.143)				(.137)
ln Tourists				.023*				.020
				(.013)				(.013)
Time dummies	Yes				Yes			
Region-specific time dummies		Yes	Yes	Yes		Yes	Yes	Yes
Change tourist district × ln Tourists				Yes				Yes
Observations	1,504	1,504	1,388	1,333	1,504	1,504	1,388	1,333
Number of cross-sectional units	116	116	116	116	116	116	116	116
R^2	.264	.420	.345	.436	.291	.435	.367	.449

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%.

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. 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 to investigate this issue.

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