Research Article

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Pay as You Throw Threshold Tariff: Evidence on the Incentive to Recycle

https://doi.org/10.1515/bejeap-2022-0448
Received December 30, 2023; accepted January 3, 2024; published online February 12, 2024

Abstract: We study the impact of the introduction of a pay as you throw tariff in Ferrara which presented a low status-quo level of waste recycling. We find that it increased the waste recycling share by 40 % points and decreased the total waste per capita by 30 % points. Our dataset allows the split of the overall effect on waste recycling, finding that 63 % of recycling is due to organic material and 37 % to multimaterial (paper, glass, and plastic). This result suggests that packaging does not constitute the major waste recycling collection. Moreover, we find both an increase in waste recycling and a decrease in total waste, contrary to other case studies with a higher starting level of waste recycling. This leads to the important conclusion that pricing waste is effective in reducing pollution if the waste recycling level is sufficiently low.

Keywords: pay as you throw; municipal waste management; synthetic control method; incentive; waste recycling

JEL: D01; D78; Q53

1 Introduction

The standard approach to waste tariffs envisages a fixed rate that is usually based on the size of the household and\or on the size of the house. Based on a Pigouvian fees approach (Pigou 1920), a growing number of communities has adopted a variable rate pricing model aiming at increasing the share of solid waste recycling.[1] In the 80, this method was firstly introduced in many municipalities in the United

1 For a review of policy incentives to increase household waste recycling, see Halvorsen (2012).

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States[2] (Kinnaman 2006). Afterwards, this variable rate pricing, also known as pay as you throw (PAYT) system was implemented in many European countries, particularly in Switzerland, in the Netherlands, in the northeastern area of Germany, in Denmark, and in Italy (Reichenbach 2008).

1.1 Related Literature

The PAYT system can be of different kinds. The most common one is the bag-based system (Allers and Hoeben 2010; Bucciol, Montinari, and Piovesan 2015; Bueno and Valente 2019; Carattini, Baranzini, and Lalive 2018; Kinnaman and Fullerton 1996, 2000; Van Houtven and Morris 1999), where residents purchase special bags with tags or labels that identify the owner of the bag, and the weight-based pricing system (Allers and Hoeben 2010; Dahlén and Lagerkvist 2010; Dijkgraaf and Gradus 2004; Linderhof et al. 2001; Miranda et al. 1994; Picchio 2023; Sterner and Bartelings 1999; Wright, Halstead, and Huang 2019; Yang and Innes 2007) where the waste collection vehicle weighs the bin and matches this information to the owner's identity. There are also frequency-based or per emptying schemes, where the PAYT tariff is based on the frequency with which waste container is set out for collection, and mixed systems, where usually the frequency-based system is combined with volume and weight-based systems (Morlok et al. 2017).

Almost all the literature finds a decrease in total waste produced, although it may take several years for citizens to adapt their behavior by reducing the amount of waste generated (Cecere, Mancinelli, and Mazzanti 2014). Valente (2023) finds that Italian municipalities reduce the total waste only after three years from the PAYT tariff adoption. Moreover, there can also be the possibility of a rebound effect. Usui (2009), for example, finds a rebound effect in Japan where the total waste reduction effect due the PAYT tariff disappears after 20 years.

The impact on waste recycling is mixed, both in the short and in the long run. This ambiguous results with respect to waste recycling is mostly found in studies using cross-sectional data, which do not allow to perform a proper counterfactual analysis. Other studies (Allers and Hoeben 2010; Bucciol, Montinari, and Piovesan 2015; Carattini, Baranzini, and Lalive 2018; Messina et al. 2023; Picchio 2023) use datasets where they compare municipalities adopting the PAYT tariff with municipalities not adopting it, before and after the adoption. These studies find a decrease in total waste and increase in waste recycling. Nonetheless, Bueno and Valente (2019) by using the synthetic control method (SCM) applied to the municipality of

2 The example most known is that of the city of Marietta (US) in 1994 where two kinds of unit price tariffs were introduced. According to the first, citizens paid by buying bags in which to throw their mixed waste, with the other method citizens bought cans to fill with waste.

Trento, having as counterfactual a pool of other similar Italian municipalities without the PAYT tariff, find no evidence for waste recycling and a decrease in total waste. The different result of Bueno and Valente (2019) can be due to the fact that the treated municipality is Trento which already had a very a high level of waste recycling before the introduction of the new tariff.

1.2 The Contribution of the Paper

We study the impact of the introduction in July 2017 of the PAYT tariff in the Municipality of Ferrara. This is a town with 132,278 inhabitants in 2017, located in the Emilia Romagna region, in the north-east of Italy. The case study of Ferrara is interesting for three reasons: before the introduction of the PAYT tariff the level of waste recycling was very low differently from other cases (Bueno and Valente 2019; Gellynck and Verhelst 2007); the use of a unit price attached to the unsorted waste, produced beyond a given threshold, very close to other comparable cases (Bueno and Valente 2019; Valente 2023); available information for different types of waste recycling collection.

By using a SCM approach, we find that after one year from the implementation of the new tariff, Ferrara strongly increases waste recycling share by 40 % points (p.p.) and decreased the total waste per capita by 30 p.p. The result relative to waste recycling is due to the peculiarity of Ferrara which, differently from other cases, generally using a similar unit price[3] for the unsorted waste beyond a given level, have a low starting level of waste recycling[4] (Bueno and Valente 2019; Gellynck and Verhelst 2007). This result, as also that of Valente (2023), is in line with Kinnaman (2006) who suggests that the PAYT tariff generally fails to produce a relevant change in disposal behavior if households' waste recycling level on a voluntary basis was already satisfactory before the fee implementation. However, the introduction of the PAYT tariff implies a drop of total waste per capita in every context independently from the initial level of waste recycling. This last result determines a cost saving for Ferrara of 3.6 million euros.

Moreover, thanks to the detail of information on waste recycling, we also find that the share of organic waste recycling increases by 30 p.p., while the share of multimaterial waste (plastic, glass, and paper) recycling increase on average by 15

3 In Ferrara the price per liter of unsorted waste was fixed with the introduction of the PAYT tariff at 0.075, not very different from Trento (0.09) as reported in Bueno and Valente (2019), and from other Italian municipalities that have adopted PAYT tariff over time (in a range from 0.073 to 0.088) as said in Valente (2023).

4 In Ferrara the waste recycling share, before the introduction of the PAYT tariff, was 40 %, while it was 67 % in Trento (Bueno and Valente 2019), and 70 % in Flemish region municipalities (Gellynck and Verhelst 2007).

p.p. There are some reasonable motivations for this last finding. The first one is that packaging (which is the great part of multimaterial waste) can decrease because of the change in consumer behavior (people prefer to buy unpacked food because of the recent larger sensibility on this issue). On the contrary it extremely difficult, passing through consumer decision, to decrease the level of organic waste. Secondly, when we evaluate the impact on waste recycling of the PAYT tariff we should also take into account that waste recycling is measured in kilos (kg) and plastics, paper, and glass normally weight much less than organic material.

1.3 Policy Implications

The PAYT tariff seems to be an appropriate policy to reach the European targets of separate collection (i.e. 55 % waste recycling share by 2025, 60 % by 2030, and 65 % by 2035) for municipalities starting with low levels of waste recycling. Moreover, if we simulate the adoption of the PAYT tariff for all Italian municipalities with more of 50,000 inhabitants, now not adopting the PAYT tariff, we would have a decrease in total waste cost of 723 million euros.

The paper is organized as follows: Section 2 describes the institutional settings of waste management and the PAYT tariff adopted in Ferrara, Section 3 contains the description of data, the empirical methodology, and the empirical analysis, Section 4 contains the results of the main specifications, Section 5 reports the analysis on waste substreams, in Section 6 we carry out the placebo tests for the main specification, Section 7 checks for possible spillover, Section 8 discusses the results, and Section 9 concludes.

2 Institutional Setting

In Italy regions are responsible for programming, adopting, and updating regional waste plans and waste management regulatory activities (art. 196 D.Lgs. 152/2006). Provinces, municipalities, and optimal territorial areas, the so called Ambiti Territoriali Ottimali (ATO), also participate to the definition of these plans. Municipal authorities have the legal obligation to provide collection systems and the corresponding right to impose a local fee for cost recovery. The operators entrusted by municipalities with the collection service become legally responsible for the waste they collect and must dispose of it according to the prescriptions of regional plans. In Ferrara, waste collection is managed by HERA.[5] Since 2004, and, before the

5 Agreement stipulated between the Optimal Territorial Area Authority of Ferrara and HERA (2004). HERA is one of the largest utilities in Italy and operates mainly in the environment sector

introduction of the PAYT tariff, waste collection was financed through the TARES, which is a tariff fully covering the costs of collection and disposal services. The tariff was mainly based on the square meters of the house and the family composition.

With the City Council Resolution n.6/2014, Ferrara decided to introduce the PAYT tariff. This was a political decision following the electoral commitment on environmental policy interventions to improve the low level of waste recycling in Ferrara (Tagliani 2014). Starting from July 2017, traditional bins for unsorted waste were replaced by bins with an electronic lock and citizens were provided with an electronic card.[6] This card allows to open the cover of the bin where the unsorted waste can be thrown. Each access to the electronic cover corresponds to 30 L of unsorted waste. It is therefore possible to calculate the total amount of unsorted waste produced by each household in a year.

The PAYT tariff is as follows:

$$Waste\ tariff = ff + bvf + avf - A$$

where *ff* is a fixed fee, *bvf* is a basic variable fee. Both fees cover fixed costs based on the number of family members and the square meters of the house. *avf* is a variable fee computed using the PAYT system. Finally, *A* corresponds to allowances linked to the socio-economic conditions of the household.[7] The part of the tariff linked to the PAYT (*avf*) is applied to the unsorted waste exceeding a given threshold (i.e. for a family with three members the threshold is 1560 L per year) times the unit cost of the service (in 2019 it was 0.055 €/L). Notice that in the first year during which the PAYT tariff was in place, only 10 % of households produced an amount of unsorted waste above the threshold. This means that the introduction of the PAYT tariff was effective in creating the incentive not to produce excessive unsorted waste and that the threshold was realistically computed.

To avoid illegal dumping, such as mixing unsorted waste with recycling waste or putting the garbage outside the bins, during the initial period of the PAYT tariff controls were intensified by local authorities in the most touristic areas of the municipality. Local police cars were equipped with a camera which can automatically read vehicle license plates to identify those who leave waste outside the bins. In addition, to control for waste discharging outside the bins away from the center of the town, the number of hours of monitoring by ecological guard associations were doubled.[8]

(waste management), in the water sector (aqueducts, sewers, and purification) and in the energy sector (especially gas, distribution, and sale of electricity).

6 Each card is matched only with one user.

7 For a complete description of the waste tariff see Appendix A.

8 See https://www.comune.fe.it/6125/attach/presidente_cons/docs/5145_2018_ferri.pdf.

3 Empirical Analysis

3.1 Preliminary Analysis

If we look at the mean of total waste per capita and waste recycling share, we find that after the introduction of the PAYT tariff in Ferrara, total waste and waste recycling are respectively lower and higher than before the introduction of it. The mean of total waste per capita decreases from 41 to 23.8 kg after the introduction of the PAYT tariff in July 2017, and the share of waste recycling increases from 38.2 to 58.9 %. On the other hand, all the other 36 municipalities served by the same utility (HERA) in Emilia Romagna, not adopting the PAYT tariff, show a smaller average decrease in total waste after July 2017 (−7 kg per capita), and as well a smaller average decrease in the waste recycling share (−10.4 %).

We do a first test of the impact of the introduction of the new tariff by estimating the following equation:

$$y_{cm} = \beta\, treated_c + \gamma\, post_m + \delta\, treated_c \times post_{cm} + \vartheta_c + \pi_m + \varepsilon_{cm}$$

where y_{cm} is, according to the estimate we deal with, waste recycling share, total waste per capita, organic waste recycling share or multimaterial waste recycling share in municipality c and month m; *treated* is a dummy equal to 1 for the Municipality of Ferrara, and *post* is a dummy equal to 1 for the months after July 2017; ϑ_c and π_m are respectively municipality and monthly fixed effects (FE).

The coefficient of interest is δ which accounts for the differential impact on y_{cm} due to the introduction of the PAYT tariff in Ferrara with respect to the traditional tariff applied by any other included municipality of the dataset. Namely, we estimate a difference in differences model where the only treated municipality is Ferrara and all the other 36 municipalities are not treated. The coefficient (δ) of the interaction between the treatment dummy and the dummy indicating the period after the introduction of PAYT tariff is negative (−10.161) and statistically significant at 1 % for the total waste per capita and positive (0.311) and statistically significant at 1 % for the waste recycling share (Table 1). Moreover, δ is positive and statistically at 1 % significant when the dependent variable is the organic waste recycling share and the multimaterial waste recycling share. The former (0.210) increases more than the latter (0.101).

These results are confirmed by applying the Synthetic Difference in Differences (SDD) analysis, proposed by Arkhangelsky et al. (2021). The SDD adds to a difference in differences model various weights for each single unit of the control group and for each temporal unit under analysis. Unit weights are designed so that the average outcome for the treated units is approximately parallel to the weighted average

Table 1: Difference in differences estimation results.

	(1) Waste recycling share	(2) Total waste per capita	(3) Organic waste recycling share	(4) Multimaterial waste recycling share
Treated × post	0.311[a] (0.016)	−10.161[a] (0.880)	0.210[a] (0.006)	0.101[a] (0.017)
Observations	1776	1776	1776	1776
R-squared	0.57	0.41	0.51	0.65
Number of municipalities	37	37	37	37
Municipal FE	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes

Notes: Robust standard errors clustered at municipal level are reported in parentheses [a]$p < 0.01$.

outcome for control units in the pretreatment period.[9] The coefficient of the interaction between the treated dummy and the dummy indicating the period after the introduction of PAYT tariff is positive (0.336) and statistically significant at 1 % for waste recycling share, while the same interaction is negative (−8.272) and statistically significant at 1 % for total waste per capita (Table 2). Moreover, also in this case, the coefficient of the interaction between *treated* and *post* is positive and statistically significant at 1 % when the dependent variable is the organic waste recycling share and the multimaterial waste recycling share. The former (0.204) increases more than the latter (0.125).

Notice that with only one treated unit a difference in differences approach can lead to biased results. Conley and Taber (2011) show that in a two-way fixed effect difference in differences setting with a very small number of treated units, the estimated coefficient is not consistent, in fact, as the size of the sample increases, the estimator does not converge to the true value of the coefficient. The use of an inconsistent estimator provides biased results, even with an infinite amount of sample information (Wooldridge 2015).

3.2 The Synthetic Control Method

To overcome this potential bias, we use the SCM which was originally proposed by Abadie and Gardeazabal (2003) and Abadie, Diamond, and Hainmueller (2010) with

9 In our case the weights are built using these pretreatment variables: personal income per capita, quota of population over 65, population density, quota of population with a high school diploma, quota of volunteers, hotels per capita, quota of firms in the service sector, firms per capita, turnout (referendum 2011).

Table 2: Synthetic difference in differences estimation results.

	(1) Waste recycling share	(2) Total waste per capita	(3) Organic waste recycling share	(4) Multimaterial waste recycling share
Treated × post	0.336[a] (0.025)	−8.272[a] (2.732)	0.204[a] (0.018)	0.125[a] (0.012)
Observations	1776	1776	1776	1776
Number of municipalities	37	37	37	37
Municipal FE	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes

Notes: Standard errors are calculated with the placebo procedures, as suggested in Arkhangelsky et al. (2021) with single treated unit. [a]$p < 0.01$.

the purpose of estimating the effect of any policy intervention when a small number of treated units is available. In a framework, where only one unit is treated, the SCM is shown to be the most suitable method to be used (Abadie 2021).

The SCM implies the construction of an "artificial counterfactual" (called *synthetic control*), which is then used as a reference for comparison with the *treated unit*, in our case the Municipality of Ferrara (Abadie, Diamond and Hainmueller 2015; and for a recent review, see Abadie 2021). The selection of the comparison units is done through a data driven procedure. Operatively, the *synthetic control* is built as a weighted average of the units in the so-called donor group. This group in our case is composed by all other municipalities served by the same utility, used by Ferrara, and in the same region of Ferrara. The weights are chosen so that the derived synthetic control matches as closely as possible the treated unit in the period before the treatment, for both the outcome variable and some predictors that are unaffected by the outcome.

The trajectory of the outcome in the synthetic control must mimic what it would have been the path of the outcome in the affected unit if the policy had never occurred. Therefore, the causal effect of the intervention is estimated as the difference between the observed outcome of the treated municipality and the outcome of the synthetic municipality in the posttreatment period. The main key assumptions of the SCM listed by Abadie (2021) are big difference between the posttreatment and the pretreatment outcome differences between the treated unit and the donor group in the descriptive statistics, low volatility of the outcome variable, availability of a donor group necessary to pick up comparable units to build up the synthetic counterfactual, no anticipation effect and, availability of units to be used for the synthetic control which must not be affected by the policy to be tested. This last assumption is called "no spillovers effect" or Stable Unit Treatment Value Assumption (SUTVA).

More formally, in line with Abadie, Diamond, and Hainmueller (2015), we take a sample of $K+1$ units, indexed by k, where $k=1$ is the treated unit, and $k=2\ldots K+1$ are the units belonging to the donor pool. The units are observed at the same time periods, $t=1\ldots T_0\ldots T$, with the pretreatment period T_b when $t<T_0$ and the posttreatment period T_a when $t\geq T_0$, where T_0 is the time when the treatment starts. We define $X_1=(s\ x\ 1)$ as the vector of the s variables (predictor variables) accounting for the pretreatment characteristics of the treated unit, and $X_0=(s\ x\ K)$ as the matrix collecting the values of the same s variables for all the other units in the donor pool. When more than one time-unit in the pretreatment period is available, the mean value of the s variable along the pretreatment time-units is taken. A vector of weights W is chosen to minimize the weighted mean square error $(X_1 - X_0W)' V (X_1 - X_0W)$, where V is a diagonal of predictor weights, which reflects the relative importance assigned to the predictor variables when the discrepancy between X_1 and X_0W is measured. We choose the predictor weights V, in line with Abadie, Diamond, and Hainmueller (2010), by minimizing $(Z_1 - Z_0W(V))' (Z_1 - Z_0W(V))$, where Z_1 is a vector and Z_0 is a matrix of the outcome variable before the treatment for the treated and for the donor group, respectively. We then let $Y_1=(T_a\times 1)$ be the vector of the posttreatment outcome for the treated unit and $Y_0=(T_a\times K)$ be the matrix posttreatment outcome for all the units in the donor pool. The synthetic control estimator of the effect of the treatment is given by $(Y_1 - Y_0W)$. A discrepancy in the outcome variable in the posttreatment period is interpreted as the causal effect of the treatment.

3.3 Data Used to Implement the Synthetic Control Method

To apply the SCM, we use all 36 municipalities served by HERA, which were not affected by the introduction of any PAYT tariff.[10] We use a panel dataset spanning from January 2015 to December 2018. Bueno and Valente (2019) use municipal monthly data, which allows us to precisely define the effect of the policy that started in July 2017.[11]

10 The list of the municipalities is reported in Appendix B. Using a sample only of municipalities belonging to the same region guarantees more homogeneity in unobserved time-varying heterogeneity like opportunistic behavior in waste collection, reactions to sanctions, and environmental preferences. The SCM estimates are in this case more reliable than in case we had used municipalities belonging to different regions.

11 With yearly data we would have missed the clear-cut impact of the policy, since, in year 2017 the waste recycling and total waste data include both the untreated and the treated period. Moreover, in absence of monthly data, we would end up with a panel with only three years before the introduction of the policy, not enough to implement the SCM (Abadie, Diamond, and Hainmueller 2015).

The application of the PAYT tariff starts on July 2017, so our dataset consists of 48 months in total, 18 months after the introduction of the PAYT tariff and 30 months before it. We run four iterations of the SCM, using as outcome variables (Table 3) the share of waste recycling, the total waste per capita, the share of organic waste recycling (such as vegetable, food, and garden waste), and the share of multimaterial waste recycling (including paper, paperboard, plastic, metal, wood, and glass). The share of waste recycling is the ratio between kilos of waste recycling and kilos of total waste. The share of organic waste recycling is the ratio between kilos of organic waste recycling and kilos of total waste. The share of multimaterial waste recycling is the ratio between kilos of multimaterial waste recycling and kilos of total waste. Data on the quantities of waste produced are provided by HERA through the management platform of the supra-municipal waste disposal plants.

We use nine socio-economic variables as predictors of Ferrara's pretreatment characteristics, which are yearly variables (collected from ISTAT and Ministry of Economy) coinciding with the years of the pretreatment, which, according to the monthly waste data provided by HERA, are 2015 and 2016 (Table 3). When we use data from the last Census or the last referendum regarding urban waste collection before 2017, they refer to 2011. As Johnstone and Labonne (2004), we include as predictors different economic and demographic determinants of household municipal solid waste, measured in the period 2015–2016, like the quota of population over 65 (ISTAT), quota of firms in the service sector (ISTAT), personal income per capita (Ministry of Economy), number of firms per capita (ISTAT), and population density (ISTAT). Kinnaman and Fullerton (2000) show that educated citizens have greater preference for a clean environment, so we add as predictors the quota of population with a high school diploma, coming from the 2011 Census (ISTAT). Tsai (2008) shows higher social capital increases household waste recycling. For this reason, we include in the predictors the quota of volunteers from the 2011 Census (ISTAT) and the turnout in the 2011 referendum (Ministry of Interior),[12] as a proxy of the municipal social capital (Fiorino, Galli, and Pontarollo 2021). Finally, the tourist population has lower propensity to separate waste collection (Mateu-Sbert et al. 2013), so we include in the predictors for 2015–2016 the number of per-capita hotels (ISTAT), as a proxy for the municipal tourism level.

In addition, and in line with Abadie, Diamond and Hainmueller (2010), to obtain a more accurate estimate of the synthetic Ferrara before treatment, we also include four lags of the outcome variable, 6, 12, 18, and 24 months before the introduction of the PAYT tariff. Once the synthetic control weights are obtained, they are then applied to the outcome variables for the whole period of analysis to obtain

12 The 2011 referendum referred to local public services, such as urban waste collection.

Table 3: Summary statistics of the outcome variables (panel A) and predictors in the per-treatment period (panel B).

PANEL A						
	Source	**(1) n**	**(2) Mean**	**(3) SD**	**(4) Min**	**(5) Max**
Organic waste recycling share	HERA	1776	0.077	0.072	0	0.442
Multimaterial waste recycling share	HERA	1776	0.180	0.138	0.011	0.606
Total waste per capita	HERA	1776	39.619	13.413	16.835	161.13
Waste recycling share	HERA	1776	0.257	0.156	0.028	0.709
PANEL B						
	Source	**(1) n**	**(2) Mean**	**(3) SD**	**(4) Min**	**(5) Max**
Firms per capita	ISTAT	74	0.077	0.017	0.050	0.124
Hotels per capita	ISTAT	74	0.005	0.006	0	0.034
Personal income per capita	Ministry of Economy	74	13,088	1409	9350	16,992
Population density	ISTAT	74	267.4	262.8	8.076	1375
Quota of firms in the service sector	ISTAT	74	0.729	0.069	0.559	0.854
Quota of population over 65	ISTAT	74	0.241	0.036	0.168	0.352
Quota of population with a high school diploma	Census (ISTAT)	37	0.385	0.046	0.314	0.499
Quota of volunteers	Census (ISTAT)	37	0.107	0.057	0.033	0.360
Turnout (referendum 2011)	Ministry of Interior	37	0.644	0.055	0.424	0.740

Notes: Waste data are 1776 because they relate to 48 months and 37 municipalities served by HERA: $48 \times 37 = 1776$. The predictors relate only to the pretreatment period. Quota of population with a high school diploma, quota of volunteers, turnout (referendum 2011) refer only to one year for 37 municipalities. The rest of the predictors refer all to two years (2015 and 2016) for 37 municipalities and therefore they sum up to 74 (37×2) observations.

the synthetic Ferrara. Finally, the synthetic Ferrara outcome variable is compared with the corresponding variable of Ferrara to correctly test the relevance of the treatment.

4 Baseline Results

We first analyze the impact of the introduction of the PAYT tariff on the waste recycling share and the total waste per capita.

4.1 Waste Recycling Share

When focusing on the waste recycling share, synthetic Ferrara emerges as a combination of the municipalities of Faenza (weight = 64.7 %), Cesena (17.7 %), Lugo (15 %), and Cervia (2.6 %). The predictors (socio-economics characteristics of the pretreatment period) of Ferrara and the synthetic Ferrara are very similar, in fact the differences between the mean values of each variable between the treated unit and the synthetic control are very low (Table 4).

Graphically, before the introduction of the PAYT tariff, the waste recycling share of the synthetic Ferrara and of Ferrara do not differ, while, after the introduction of the tariff, the waste recycling share of Ferrara is much higher than that of synthetic Ferrara (Figure 1). The shaded area (Born et al. 2019) is built by adding and

Table 4: Predictors (Ferrara and synthetic Ferrara) for waste recycling share.

	Ferrara	Synthetic Ferrara	Ferrara-synthetic Ferrara
Firms per capita	0.088	0.090	−0.002
Hotels per capita	0.001	0.002	−0.001
Personal income per capita	16,408	14,575	1833
Population density	328	295	33
Quota of firms in the service sector	0.847	0.806	0.041
Quota of population over 65	0.278	0.249	0.029
Quota of population with a high school diploma	0.499	0.451	0.048
Quota of volunteers	0.117	0.130	−0.013
Turnout (referendum 2011)	0.634	0.646	−0.012
Waste recycling share (July 2015)	0.428	0.409	0.019
Waste recycling share (January 2016)	0.384	0.421	−0.037
Waste recycling share (July 2016)	0.375	0.383	−0.008
Waste recycling share (January 2017)	0.242	0.219	0.023

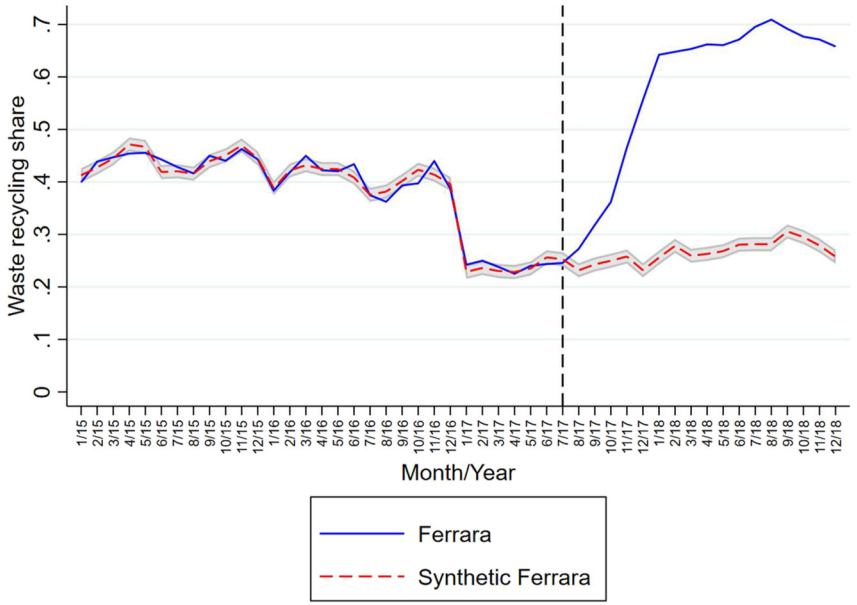

Figure 1: Ferrara versus synthetic Ferrara, waste recycling share. Notes: The blue line represents the waste recycling share of Ferrara, while the red line the waste recycling share of the syntethic Ferrara. The shaded area (Born et al. 2019) is built by adding and subtracting to the waste recycling share of the synthetic Ferrara one standard deviation of the difference between the waste recycling share of Ferrara and synthetic Ferrara before the introduction of the PAYT tariff.

subtracting to the outcome of the synthetic Ferrara one standard deviation of the difference between the outcome of Ferrara and synthetic Ferrara before the introduction of the PAYT tariff. As such, this area gives an upper and a lower limit of an interval within which Ferrara would fall on average in the pretreatment period. From January 2015 to December 2016, the waste recycling share was around 45 % for both Ferrara and the synthetic Ferrara. In January 2017, we observe a decrease in waste recycling for Ferrara and the synthetic Ferrara, which is due to a change in national legislation removing from the reporting duties the neutral fraction, a particular type of waste. The waste recycling share was 25 % for Ferrara and the synthetic Ferrara in 2017 before July, and, from July 2017, the month of the introduction of the new tariff, the synthetic Ferrara stayed around 26–27 % while Ferrara arrived at 70 % in one year. Moreover, notice that after July 2017 the waste recycling share for Ferrara lies outside the shaded area, before defined.

The quantitative results are shown in Table 5. Eighteen months before the introduction of the PAYT tariff, the waste recycling share of Ferrara lies within the upper/lower bound interval for the synthetic Ferrara, with some few exceptions. In

Table 5: Waste recycling share: Ferrara versus synthetic Ferrara.

Pretreatement period				Posttreatement period			
Month/year	**Lower bound**	**Upper bound**	**Ferrara**	**Month/year**	**Lower bound**	**Upper bound**	**Ferrara**
1/2015	0.390	0.431	0.399	7/2017	0.219	0.260	0.246
2/2015	0.413	0.454	0.439	*8/2017*	*0.200*	*0.241*	*0.273*
3/2015	0.413	0.454	0.447	*9/2017*	*0.219*	*0.261*	*0.318*
4/2015	0.441	0.482	0.454	*10/2017*	*0.224*	*0.265*	*0.362*
5/2015	0.425	0.466	0.455	*11/2017*	*0.217*	*0.259*	*0.465*
6/2015	0.391	0.432	0.443	*12/2017*	*0.209*	*0.250*	*0.556*
7/2015	0.389	0.430	0.428	*1/2018*	*0.219*	*0.260*	*0.642*
8/2015	0.366	0.408	0.416	*2/2018*	*0.224*	*0.265*	*0.648*
9/2015	0.410	0.451	0.450	*3/2018*	*0.233*	*0.274*	*0.653*
10/2015	0.397	0.438	0.440	*4/2018*	*0.236*	*0.277*	*0.662*
11/2015	0.443	0.484	0.463	*5/2018*	*0.232*	*0.274*	*0.661*
12/2015	0.410	0.451	0.443	*6/2018*	*0.242*	*0.284*	*0.671*
1/2016	0.401	0.442	0.384	*7/2018*	*0.234*	*0.275*	*0.696*
2/2016	0.402	0.444	0.418	*8/2018*	*0.238*	*0.280*	*0.709*
3/2016	0.404	0.446	0.450	*9/2018*	*0.254*	*0.295*	*0.692*
4/2016	0.419	0.460	0.422	*10/2018*	*0.248*	*0.289*	*0.677*
5/2016	0.413	0.455	0.420	*11/2018*	*0.243*	*0.284*	*0.671*
6/2016	0.402	0.444	0.434	*12/2018*	*0.235*	*0.277*	*0.658*
7/2016	0.362	0.404	0.375				
8/2016	0.365	0.407	0.362				
9/2016	0.393	0.434	0.393				
10/2016	0.406	0.448	0.397				
11/2016	0.412	0.453	0.440				
12/2016	0.415	0.457	0.387				
1/2017	0.198	0.240	0.242				
2/2017	0.202	0.243	0.250				
3/2017	0.204	0.246	0.238				
4/2017	0.201	0.242	0.225				
5/2017	0.204	0.245	0.240				
6/2017	0.233	0.274	0.244				

Notes: The table shows for each month in the pretreatment and posttreatment period the waste recycling share of Ferrara, the lower and the upper bound of the interval on which the waste recycling share for Ferrara could fall on average in the pretreatment period. The eighteen months after the introduction of the new tariff are highlighted in italics.

contrast, in the 18 months after the introduction of the new tariff, the waste recycling share lies outside this interval (highlighted in italics in Table 5); specifically, it lies above the upper bound, indicating that there is a meaningful increase in the difference between the waste recycling share of Ferrara and that of the synthetic

Ferrara with respect to the pretreatment difference. This positive impact remains stable across all 2018.

In Table 6, we compare growth rates of waste recycling in Ferrara in each month with respect to July 2017 (the date of the introduction of the PAYT tariff) with the same growth rate of waste recycling of the synthetic Ferrara. The difference in the before computed growth rate of waste recycling between Ferrara and the synthetic Ferrara is 5 p.p. in August 2017, and it reaches 30 p.p. in December 2017. In January 2018 the difference is around 40 p.p., and it remains stable throughout 2018, reaching a peak of 44 p.p. in August 2018.

4.2 Total Waste Per Capita

The introduction of the PAYT tariff could also decrease the absolute level of waste production, as already shown in Bueno and Valente (2019). Using the total waste per capita, the synthetic Ferrara is built up with the municipalities of Imola (weight = 31.1 %), Faenza (23 %), Cesena (17.2 %), Sant'Agata sul Santerno (15.4 %), Premilcuore (6.9 %), Gambettola (3.3 %), Santa Sofia (2.7 %), and Roncofreddo (0.5 %). The differences in the means of each predictor (Table 7) between Ferrara and the synthetic Ferrara is very small, confirming the validity of the SCM procedure.

Table 6: Waste recycling growth rate with respect to July 2017 (date of the introduction of the PAYT tariff).

Year/month	Ferrara	Synthetic Ferrara	Ferrara-synthetic Ferrara
17-Aug	0.027	−0.019	0.046
17-Sep	0.072	0.000	0.072
17-Oct	0.116	0.005	0.111
17-Nov	0.220	−0.002	0.221
17-Dec	0.310	−0.010	0.320
18-Jan	0.397	0.000	0.397
18-Feb	0.402	0.005	0.397
18-Mar	0.408	0.014	0.394
18-Apr	0.416	0.017	0.399
18-May	0.415	0.013	0.402
18-Jun	0.426	0.023	0.403
18-Jul	0.450	0.015	0.435
18-Aug	0.463	0.019	0.444
18-Sep	0.446	0.035	0.411
18-Oct	0.431	0.029	0.402
18-Nov	0.426	0.024	0.402
18-Dec	0.412	0.016	0.396

Table 7: Predictors (Ferrara and synthetic Ferrara) for total waste per capita.

	Ferrara	Synthetic Ferrara	Ferrara-synthetic Ferrara
Firms per capita	0.088	0.083	0.005
Hotels per capita	0.001	0.003	−0.002
Personal income per capita	16,408	14,636	1772
Population density	328	329	−1
Quota of firms in the service sector	0.847	0.780	0.067
Quota of population over 65	0.278	0.247	0.031
Quota of population with a high school diploma	0.499	0.439	0.6
Quota of volunteers	0.117	0.123	−0.006
Turnout (referendum 2011)	0.634	0.640	−0.006
Total waste per capita (July 2015)	44.911	44.594	0.317
Total waste per capita (January 2016)	38.063	39.115	−1.052
Total waste per capita (July 2016)	39.420	40.306	−0.886
Total waste per capita (January 2017)	30.532	29.151	1.381

Before the introduction of the PAYT tariff the trend of total waste production is very similar for Ferrara and the synthetic Ferrara (Figure 2). After the introduction of the new tariff, the total waste per capita in Ferrara starts decreasing, while we do not observe the same trend in the synthetic Ferrara. After the first two months from July 2017, the line of Ferrara lies outside the shaded area, confirming that after the introduction of the PAYT tariff, in Ferrara there is an important decrease in the production of total waste with respect to the synthetic Ferrara.

To quantify the effect on the total waste, as before, we compare growth rates of total waste per capita in Ferrara in each month with respect to July 2017 (the date of the introduction of the PAYT tariff) with the same growth rate of total waste per capita for the synthetic Ferrara (Table 8). We find that the difference in growth rates between Ferrara and the synthetic Ferrara is either very small or equal to zero in the first months after the introduction of the new tariff and it increases from October 2017 to January 2018 when the difference is more than 23 p.p. After this first peak, the difference remains relatively large during the observed period, reaching a peak of 32 p.p. in July 2018.

4.2.1 Evidence of No Illegal Dumping of Unsorted Waste

This result could be biased by the possibility that citizens of Ferrara may tempted to export the unsorted waste into neighboring jurisdictions without the PAYT tariff (Erhardt 2019). However, there seems not to be any significant change in unsorted waste (Figure 3) after the introduction of PAYT in 2017 for municipalities bordering

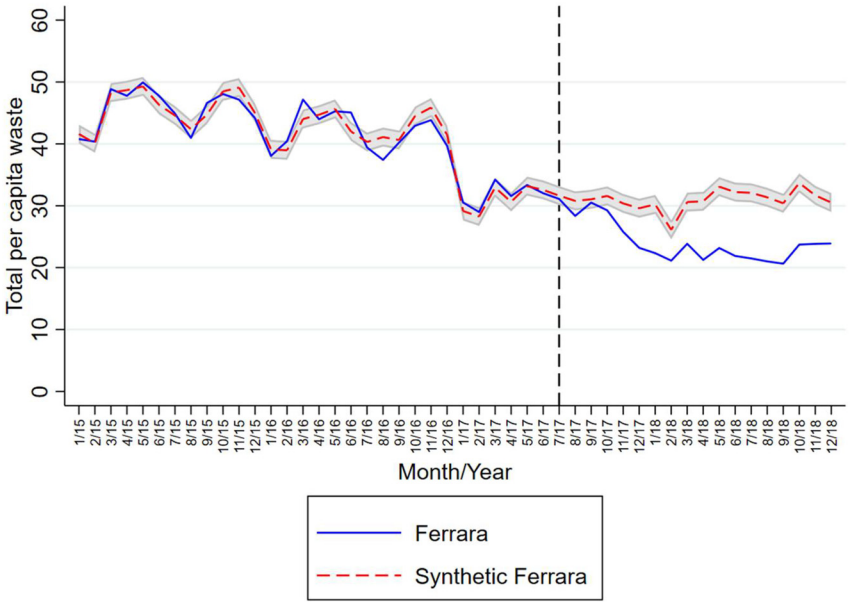

Figure 2: Ferrara versus synthetic Ferrara, total waste per capita. Notes: The blue line is the total per capita waste of Ferrara, while the red line the total per capita waste of the syntethic Ferrara. The shaded area (Born et al. 2019) is built by adding and subtracting to the total waste per capita of the synthetic Ferrara one standard deviation of the difference between the total waste per capita of Ferrara and synthetic Ferrara before the introduction of the PAYT tariff.

Ferrara (blue line) and municipalities bordering the neighboring municipalities of Ferrara (red line).

Another possibility of illegal dumping is to throw unsorted waste by illegally using the bulky waste channel, which would let not pay for the unsorted waste above the allowed threshold. The bulky waste is a special type of unsorted urban waste that is too large to be collected in bins and can be stored in waste collection centers. In the computation of the total waste, bulky waste is not included and so this possible distorting behavior could explain the decrease in total waste per capita. However, after the introduction of the PAYT tariff in July 2017, the level of bulky waste in the waste collection centers of Ferrara did not show any increase in the posttreatment period with respect to the pretreatment (Figure 4).

These two findings confirm that the introduction of the PAYT tariff really induces citizensto a change in their consumption habits reducing total waste production.

Table 8: Total waste per capita growth rate with respect to July 2017 (date of the introduction of the PAYT tariff).

Year/month	Ferrara	Synthetic Ferrara	Ferrara-synthetic Ferrara
17-Aug	−0.088	−0.027	−0.062
17-Sep	−0.019	−0.019	0.000
17-Oct	−0.059	−0.001	−0.058
17-Nov	−0.171	−0.040	−0.131
17-Dec	−0.254	−0.064	−0.190
18-Jan	−0.282	−0.045	−0.237
18-Feb	−0.321	−0.175	−0.146
18-Mar	−0.233	−0.033	−0.200
18-Apr	−0.317	−0.029	−0.288
18-May	−0.255	0.046	−0.301
18-Jun	−0.296	0.018	−0.314
18-Jul	−0.309	0.014	−0.323
18-Aug	−0.325	−0.008	−0.316
18-Sep	−0.336	−0.039	−0.297
18-Oct	−0.237	0.065	−0.302
18-Nov	−0.233	0.001	−0.235
18-Dec	−0.231	−0.035	−0.196

5 Waste Substreams

It is interesting to see the impact of the introduction of the PAYT tariff on the share of waste recycling split into the share of organic and multimaterial waste recycling.

5.1 Organic Waste Recycling

We apply the SCM using as outcome variable the organic waste recycling share.

The weights computed by the SCM are Lugo (38.5 %), Ravenna (34.8 %), Cesena (12.5 %), Premilcuore (11 %), and Santa Sofia (3.2 %). Hence, the municipalities of Lugo and Ravenna are those resembling more to Ferrara in terms organic waste recycling share over the pretreatment period. Table 9 shows predictors for Ferrara and the synthetic Ferrara. Also in this case, the differences between the means of the predictors of Ferrara and the synthetic Ferrara are very small.

From Figure 5, it can be observed that the organic waste recycling share in the synthetic Ferrara is about 13 % in the pretreatment period and 13–15 % in the posttreatment period, conversely, while in the period before the introduction of the PAYT tariff in Ferrara it was 13 %, then it reached more than 40 % after one year from the introduction of the PAYT tariff.

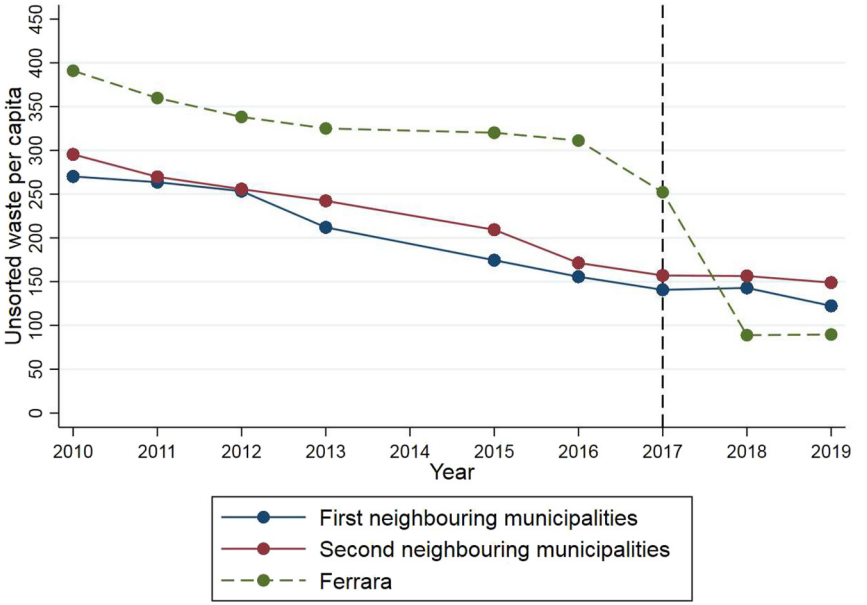

Figure 3: Municipal unsorted waste in Ferrara and in neighboring municipalities, 2010–2019, kg per capita. Notes: The dashed green line represents the unsorted waste per capita of Ferrara that adopted the PAYT in 2017. The blue line describes the average of unsorted waste per capita of municipalities bordering Ferrara (first neighboring municipalities), and the red line the average of unsorted waste per capita of the municipalities bordering the neighboring municipalities of Ferrara (second neighboring municipalities). Data on unsorted waste are from Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA).

5.2 Multimaterial Waste Recycling

Finally, we use as outcome variable in the SCM the multimaterial waste recycling share. In this case the synthetic Ferrara weights are: Sant'Agata sul Santerno (32.7 %), Cesena (28 %), Faenza (13.3 %), Bagno di Romagna (8.7 %), Premilcuore (6.5 %), Gambettola (4.6 %), Ravenna (2.9 %), Lugo (2.1 %), and Imola (1.5 %). Hence the municipalities of Sant'Agata sul Santerno and Cesena are those more like Ferrara in terms of multimaterial waste recycling share over the pretreatment period. Table 10 shows that the means of the predictors are very close between Ferrara and the synthetic Ferrara.

From Figure 6, while in the pretreatment period the multimaterial waste recycling share of the synthetic Ferrara mimics well Ferrara in the posttreatment period it is much higher in Ferrara. In fact, the multimaterial waste recycling share for

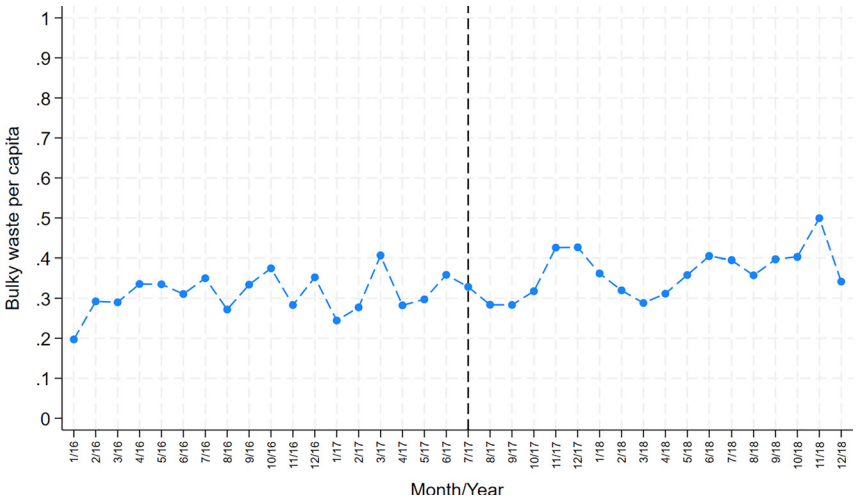

Figure 4: Bulky waste in the Municipality of Ferrara, 2016–2018, kg per capita. Notes: Data on bulky waste are from HERA.

Table 9: Predictors (Ferrara and synthetic Ferrara) for organic waste recycling share.

	Ferrara	Synthetica Ferrara	Ferrara-synthetica Ferrara
Firms per capita	0.088	0.083	0.005
Hotels per capita	0.001	0.004	−0.003
Organic waste recycling share (July 2015)	0.086	0.099	−0.013
Organic waste recycling share (January 2016)	0.090	0.090	0
Organic waste recycling share (July 2016)	0.099	0.100	−0.001
Organic waste recycling share (January 2017)	0.124	0.124	0
Personal income per capita	16,408	14,418	1990
Population density	328	242	86
Quota of firms in the service sector	0.847	0.808	0.039
Quota of population over 65	0.278	0.267	0.011
Quota of population with a high school diploma	0.499	0.428	0.071
Quota of volunteers	0.117	0.140	−0.023
Turnout (referendum 2011)	0.634	0.635	−0.001

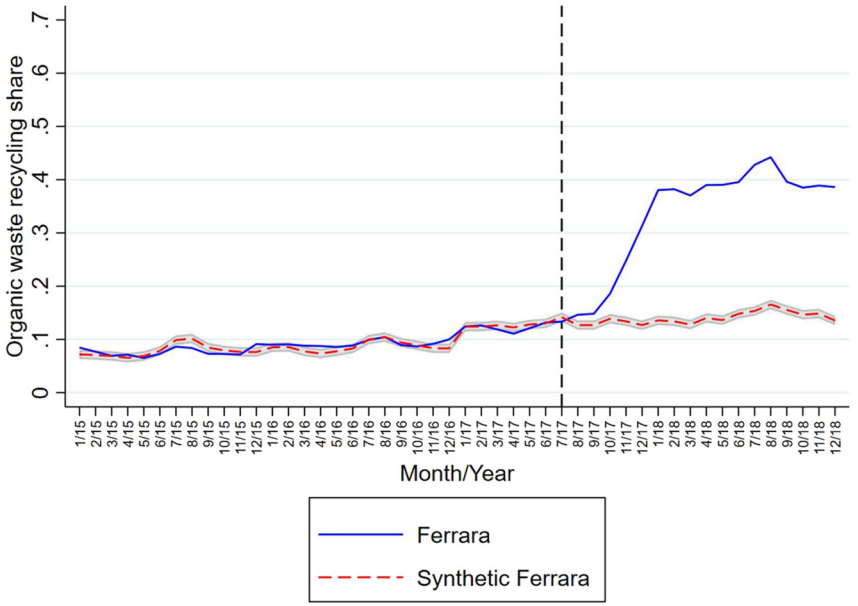

Figure 5: Ferrara versus synthetic Ferrara, organic waste recycling share. Notes: The blue line is the organic waste recycling share of Ferrara, while the red line is the organic waste recycling share of the Syntethic Ferrara. The shaded area (Born et al. 2019) is built by adding and subtracting to the organic waste recycling share of the synthetic Ferrara one standard deviation of the difference between the organic waste recycling share of Ferrara and synthetic Ferrara before the introduction of the PAYT tariff.

the synthetic Ferrara is about 13 % in both the pretreatment and the posttreatment period while for Ferrara it goes from 13 % before the introduction of PAYT tariff to 30 % in September 2018.

In Table 11, we compare growth rates of organic and multimaterial waste recycling share in Ferrara in each month with respect to July 2017 with the same growth rates of organic and multimaterial waste recycling share for the synthetic Ferrara, respectively (Table 11). When we look at the difference in growth rates between Ferrara and the synthetic Ferrara, we find a lower effect of the introduction of the new tariff for multimaterial waste recycling than for organic waste recycling. In fact, after six months, the difference between Ferrara and the synthetic Ferrara for the multimaterial waste recycling share is between 15 and 18 p.p., while for the organic waste recycling share is between 25 and 30 p.p.

Table 10: Predictors (Ferrara and synthetic Ferrara) for multimaterial waste recycling share.

	Ferraraa	Synthetica Ferrara	Ferrara-synthetica Ferrara
Firms per capita	0.088	0.088	0
Hotels per capita	0.001	0.003	−0.002
Multimaterial waste recycling share (July 2015)	0.342	0.341	0.001
Multimaterial waste recycling share (January 2016)	0.118	0.118	0
Multimaterial waste recycling share (July 2016)	0.276	0.277	−0.001
Multimaterial waste recycling share (January 2017)	0.294	0.296	−0.002
Personal income per capita	16,408	14,060	2348
Population density	328	329	−1
Quota of firms in the service sector	0.847	0.761	0.086
Quota of population over 65	0.278	0.243	0.035
Quota of population with a high school diploma	0.499	0.429	0.07
Quota of volunteers	0.117	0.118	−0.001
Turnout (referendum 2011)	0.634	0.636	−0.002

6 Placebo Tests

In this section, we run a set of robustness tests to validate our main result on the waste recycling share.

6.1 In Space Placebo

We first estimate the synthetic control for each of the municipalities in the sample, exposing each of them to the treatment. The impact of the treatment when we use as treated a fake municipality should be considerably smaller (or even null) than in the case of Ferrara. We evaluate the results by using the ratio between the posttreatment and the pretreatment of the Root Mean Squared Prediction Error (RMSPE), where the higher the ratio, the greater the difference between treated and synthetic units in the posttreatment case with respect to that of the pretreatment.[13]

We estimate how closely the municipal-specific synthetic controls follow the posttreatment data relative to the pretreatment fit. Ferrara has a RMSPE ratio of 17.696 which is much larger than that of all the other municipalities (column 1 of Table 12). The robustness of this result can be observed by the fact that if the PAYT

13 The RMSPE ratio is equal to the square root of the mean of the square of the difference between the treated and the synthetic control.

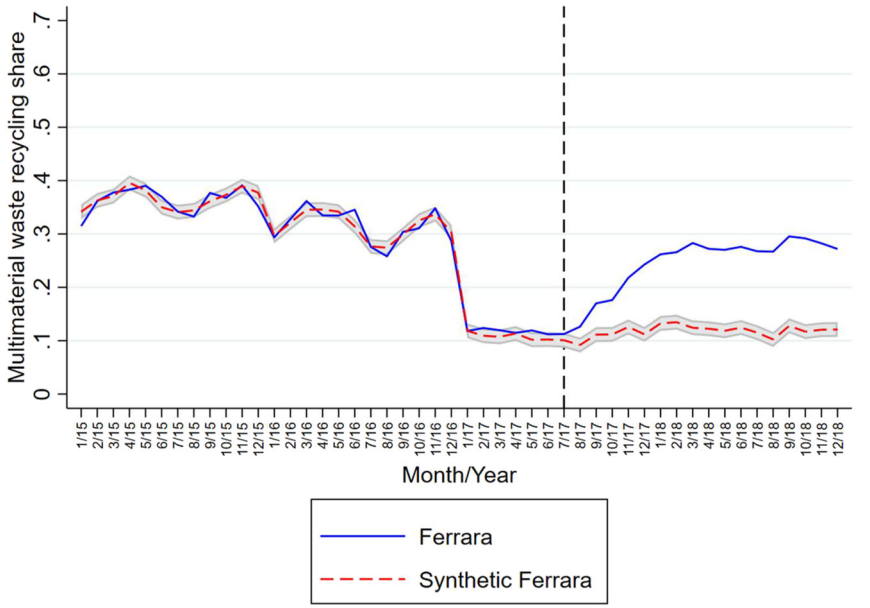

Figure 6: Ferrara versus synthetic Ferrara, multimaterial waste recycling share. Notes: The blue line is the multimaterial waste recycling share of Ferrara, while the red line the multimaterial waste recycling share of the syntethic Ferrara. The shaded area (Born et al. 2019) is built by adding and subtracting to the multimaterial waste recycling share of the synthetic Ferrara one standard deviation of the difference between the multimaterial waste recycling share of Ferrara and synthetic Ferrara before the introduction of the PAYT tariff.

tariff were applied randomly to the municipalities of the dataset, the probability of obtaining a ratio as large as Ferrara's would be $1/36 = 0.027$.

However, there are also 19 municipalities whose RMSPE ratio is higher than one.[14] A priori, this could be evidence of a spill-over effect (Born et al. 2019). Technically the assumption that the donor pool municipalities are unaffected by the treatment is potentially violated. To test the reliability of our results, we therefore restrict the sample to those municipalities with a RMSPE ratio below one. Using only this restricted sample, we show that the waste recycling share of the "restricted" synthetic Ferrara mimics well that of Ferrara before the introduction of the tariff

14 As a rule of thumb, a RMSPE ratio higher than 1 implies that the difference in waste recycling share between the fake municipality and the synthetic control is higher after the treatment than before the treatment. The 19 municipalities whose RMSPE ratio is higher than one are: Faenza, Castel Bolognese, Bagnacavallo, Imola, Gatteo, Conselice, Brisighella, Cesena, Santa Sofia, Cotignola, Bagno di Romagna, Ravenna, Cesenatico, Alfonsine, Russi Savignano del Rubicone, Bagnara di Romagna, Lugo, Verghereto, and Gambettola.

Table 11: Organic and multimaterial waste recycling share growth rate with respect to July 2017 (date of the introduction of the PAYT tariff).

	Organic waste recycling share			Multimaterial waste recycling share		
Year/month	Ferrara	Synthetic Ferrara	Ferrara-synthetic Ferrara	Ferrara	Synthetic Ferrara	Ferrara-synthetic Ferrara
17-Aug	0.013	−0.015	0.028	0.014	−0.009	0.023
17-Sep	0.015	−0.015	0.030	0.058	0.011	0.047
17-Oct	0.052	−0.003	0.055	0.064	0.011	0.053
17-Nov	0.114	−0.008	0.122	0.106	0.025	0.081
17-Dec	0.180	−0.015	0.195	0.130	0.011	0.119
18-Jan	0.247	−0.006	0.253	0.149	0.032	0.118
18-Feb	0.249	−0.008	0.257	0.153	0.034	0.120
18-Mar	0.237	−0.014	0.251	0.171	0.023	0.147
18-Apr	0.257	−0.001	0.258	0.160	0.022	0.138
18-May	0.257	−0.006	0.262	0.158	0.018	0.140
18-Jun	0.262	0.006	0.256	0.164	0.024	0.140
18-Jul	0.295	0.012	0.283	0.155	0.014	0.141
18-Aug	0.309	0.024	0.285	0.155	0.002	0.153
18-Sep	0.263	0.014	0.249	0.183	0.027	0.156
18-Oct	0.252	0.005	0.247	0.179	0.016	0.163
18-Nov	0.256	0.007	0.249	0.170	0.020	0.150
18-Dec	0.253	−0.006	0.259	0.160	0.020	0.139

and it differs from that of Ferrara after the introduction of the tariff (Figure 7). The waste recycling share was almost 25 % in 2017 before the introduction of the tariff for both Ferrara and the "restricted" synthetic Ferrara. After the introduction of the PAYT tariff it was almost 70 % in one year, while for the "restricted" synthetic Ferrara remained stable around 25 %. This test confirms the results obtained in the main analysis.

In Figure 8, we plot the results of the difference between Ferrara and the synthetic Ferrara versus spatial placebos. That is, we consider the possibility that each municipality is a treated municipality and take the difference with its corresponding synthetic. This figure sheds light on the sign of the difference between the real and synthetic municipality. The bold line corresponds to the difference between Ferrara and the synthetic Ferrara. The estimated trend for Ferrara is clearly positive after the treatment, and much higher than the estimated trend for other municipalities. Before the treatment, the line of Ferrara is around zero and, in any case, does not show any relevant different trend from the rest of the other

Table 12: Municipal-placebo tests for waste recycling share.

Municipality	RMSPE ratio	RMSPE pretreatment	RMSPE posttreatment
Ferrara	17.696	0.020	0.362
Faenza	8.152	0.015	0.123
Castel Bolognese	3.317	0.028	0.094
Bagnacavallo	2.743	0.016	0.043
Imola	2.463	0.054	0.133
Gatteo	1.915	0.046	0.088
Conselice	1.913	0.032	0.061
Brisighella	1.757	0.033	0.059
Cesena	1.714	0.048	0.083
Santa Sofia	1.703	0.040	0.068
Cotignola	1.661	0.013	0.021
Bagno di Romagna	1.649	0.028	0.047
Ravenna	1.587	0.032	0.051
Cesenatico	1.514	0.017	0.025
Alfonsine	1.502	0.018	0.027
Russi	1.499	0.036	0.053
Savignano sul Rubicone	1.440	0.024	0.034
Bagnara di Romagna	1.338	0.042	0.056
Lugo	1.335	0.018	0.024
Verghereto	1.283	0.031	0.039
Gambettola	1.134	0.051	0.057
Solarolo	0.991	0.023	0.023
Fusignano	0.981	0.034	0.033
Longiano	0.952	0.030	0.029
Sogliano al Rubicone	0.948	0.031	0.030
Massa Lombarda	0.922	0.032	0.029
San Mauro Pascoli	0.912	0.042	0.038
Sarsina	0.883	0.019	0.017
Roncofreddo	0.824	0.021	0.017
Mercato Saraceno	0.750	0.023	0.017
Sant'Agata sul Santerno	0.670	0.056	0.038
Casola Valsenio	0.639	0.036	0.023
Premilcuore	0.614	0.068	0.042
Riolo Terme	0.537	0.041	0.022
Borghi	0.437	0.036	0.016
Montiano	0.309	0.053	0.016
Cervia	0.252	0.079	0.020

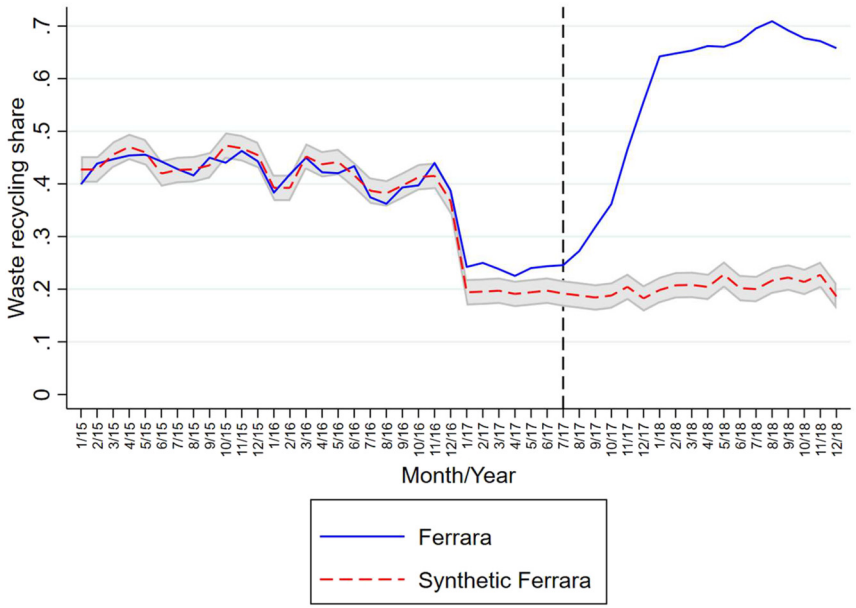

Figure 7: Ferrara versus "restricted" synthetic Ferrara. Notes: The blue line is the waste recycling share of Ferrara, while the red line the waste recycling share of the "restricted" Syntethic Ferrara, that is composed by municipalities with a RMSPE ratio below one. The shaded area (Born et al. 2019) is built by adding and subtracting to the waste recycling share of the "restricted" synthetic Ferrara one standard deviation of the difference between the waste recycling share of Ferrara and the "restricted" synthetic Ferrara before the introduction of the PAYT tariff.

municipalities. Only in the first months of the introduction of the PAYT tariff there are some placebo differences that are higher than Ferrara, but from January, 2018, onwards the difference for the Ferrara case is always the largest.

6.2 In Time Placebo

We investigate the robustness of our result checking that it holds only for the true start of the treatment. To do so, we change the month from which the treatment started to a month before. We redo the SCM procedure only on the pretreatment period, using each of the 17 months before June 2017 as the starting month of the PAYT tariff. From Table 13 we can see that assuming a fake month of the tariff introduction, the ratio between the posttreatment and the pretreatment of the RMSPE is always lower than 1, showing that the using a fake start of the treatment does not have any significant impact on the level of waste recycling share in Ferrara with respect to the synthetic Ferrara.

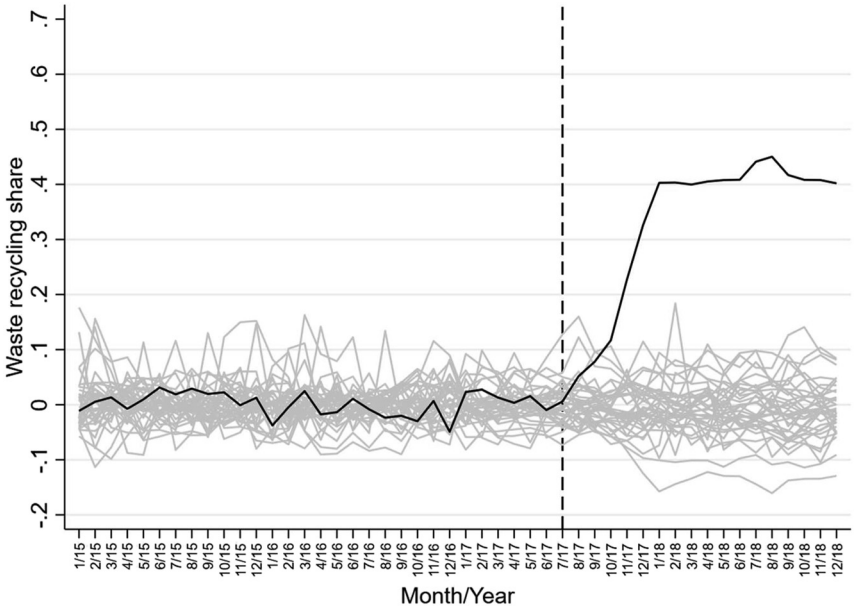

Figure 8: Difference between Ferrara and synthetic Ferrara versus spatial placebos. Waste recycling share.

Table 13: Fake month/year implementation for waste recycling share.

Fake month/year	RMPSE ratio	RMSPE pretreatment	RMSPE posttreatment
1/2016	0.135	0.260	0.035
2/2016	0.144	0.275	0.040
3/2016	0.152	0.259	0.039
4/2016	0.146	0.263	0.038
5/2016	0.159	0.235	0.037
6/2016	0.126	0.266	0.034
7/2016	0.112	0.256	0.029
8/2016	0.120	0.253	0.030
9/2016	0.126	0.259	0.033
10/2016	0.121	0.253	0.031
11/2016	0.131	0.250	0.033
12/2016	0.087	0.232	0.020
1/2017	0.128	0.247	0.032
2/2017	0.083	0.239	0.020
3/2017	0.044	0.218	0.010
4/2017	0.055	0.226	0.012
5/2017	0.032	0.224	0.007
Main specification	17.696	0.020	0.362

6.3 Leave-One-Out Test

Finally, we repeat the SCM estimate by excluding one municipality at a time from the sample and we find that the difference between Ferrara and the synthetic Ferrara remains the same as in the main specification (Figure 9).

7 Spillover Effect

The presence of spillover effects on waste recycling behavior collection in the municipalities of the donor pool could lead to a bias in the SCM results.

First, we use the results from the municipal-placebo tests, to explore the presence of a leakage/spillover effect because neighboring municipalities can mimic Ferrara in increasing waste recycling even if they did not adopt a PAYT tariff. To do so, for a given municipality we explore a possible relationship between the RMPSE ratio for the waste recycling share and the distance (in kilometers) between the considered municipality and Ferrara (Figure 10). If a leakage/spillover effect holds,

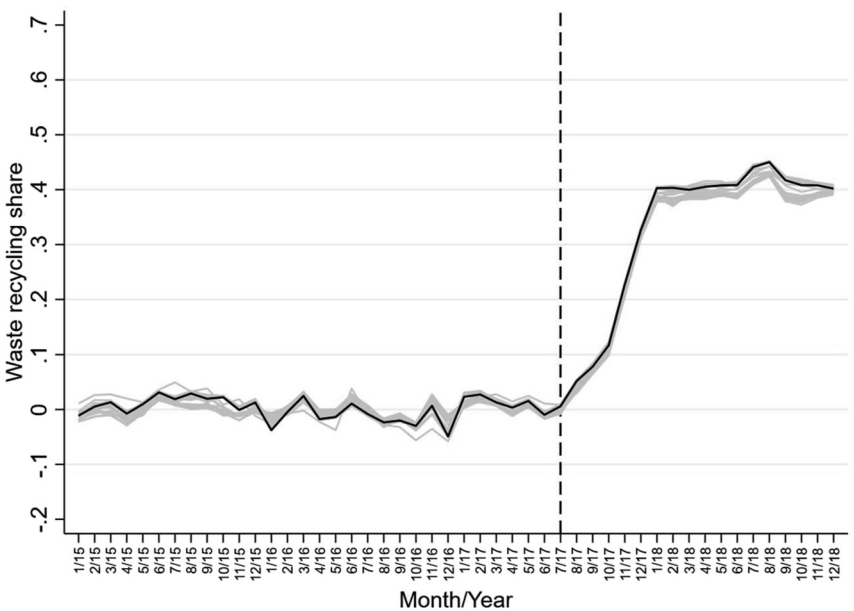

Figure 9: Difference between Ferrara and the synthetic Ferrara, excluding one municipality for each specification.

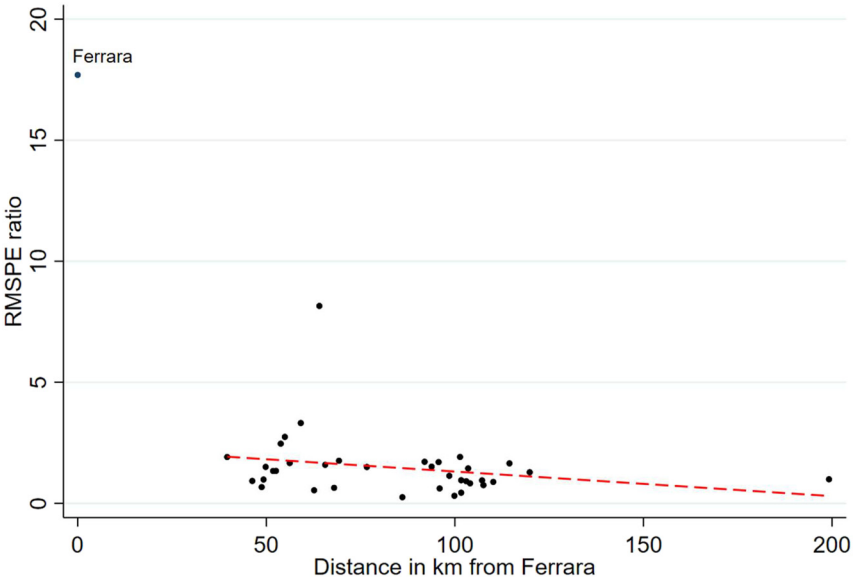

Figure 10: RMPSE ratio and distance from Ferrara.

we should find that the higher the RMPSE ratio[15] in each municipality, the lower the distance from Ferrara. We do not find any significant correlation[16] between the RMPSE ratio and the distance of a given municipality from Ferrara.

Second, we perform the Cao and Dowd (2019) robustness test to check for the presence of spillover effects in the SCM results, as in Bluszcz and Valente (2022).[17] Assuming that the spillover structure is fixed and follow a linear pattern, the SCM procedure proposed in Cao and Dowd (2019) considers spillover effects on the donor pool. We consider as the potentially affected units all municipalities up to 50 km away from Ferrara.

For all the observed months, after the introduction of the PAYT tariff, we see that the gap between Ferrara and the synthetic Ferrara computed with the "traditional" synthetic control method (red dashed line in Figure 11) is not statistically different from the gap between Ferrara and the synthetic Ferrara calculated

15 Notice that the higher the RMSPE ratio is, the higher is the difference in waste recycling share between the municipality and the control group after the introduction of the PAYT tariff than the same difference before the introduction of the new tariff.

16 The pairwise correlation coefficient equal to −0.23 with a p-value of 0.25.

17 We thank an anonymous referee for suggesting this test.

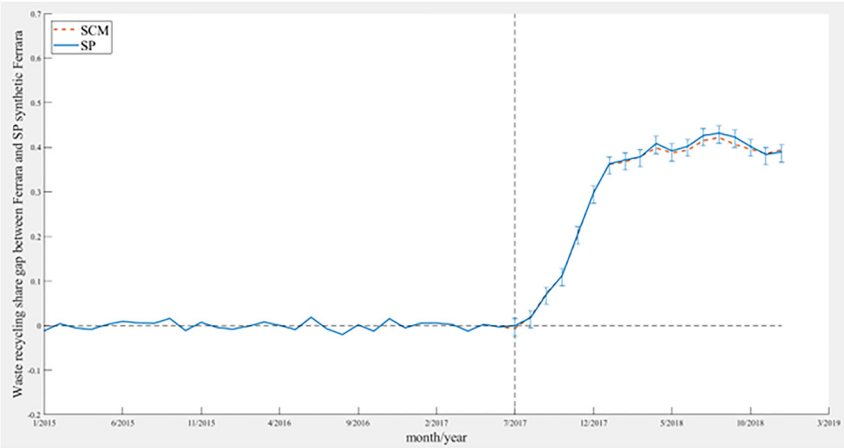

Figure 11: Waste recycling share gap with "traditional" synthetic control method (SCM) and the spillover synthetic control method (SP). Notes: The red dashed line (SCM) is the waste recycling share gap between Ferrara and the synthetic Ferrara not taking into account the spillover effect, while the blue line (SP) is the waste recycling share gap between Ferrara and the synthetic Ferrara taking account spillover effect with the Cao and Dowd (2019) procedure. The error bars are built using the inference procedure of Cao and Dowd (2019).

with the Cao and Dowd (2019) procedure (blue line in Figure 11). This corroborates the absence of spillover effects.

This result confirms Valente (2023) showing that in Italian municipalities it is difficult to observe spillover effects after the introduction of the PAYT tariff because waste tourism in surrounding municipalities is a rare and short-lived phenomenon, and enforcement and monitoring systems are effective to decrease illegal dumping episodes. The same result is also found in similar frameworks in Sterner and Bartelings (1999) and Dijkgraaf and Gradus (2004).

8 Discussion

The PAYT system seems to be an appropriate policy to reach the European targets of separate collection (i.e. 55 % waste recycling share by 2025, 60 % by 2030, and 65 % by 2035), for municipalities starting with low levels of waste recycling like Ferrara (40 %). In fact, in the case of Trento and municipalities of the Flemish region, starting from a high level of waste recycling (respectively 67 % and 70 %), the introduction of the PAYT tariff did not affect waste recycling (Bueno and Valente 2019; Gellynck and Verhelst 2007).

Moreover, it is important to note that the application of the PAYT tariff in Ferrara leading to a reduction in total amount of waste produced, implies a significant reduction in the costs of waste collection, transport, and disposal. The cost saving amounts to 3.6 million euro of savings. This is computed by using the total kilos reduction of unsorted waste after the first year of the introduction of the PAYT tariff (−12,217,527 kg). We obtain this reduction by applying to the annual total waste in the year before the adoption of the PAYT tariff (65,160,143 kg) the average percentage decrease of total waste in the first year of the application of the new tariff (−18.75 %). We then multiply this last result by the unit cost (0.2966 kg/€) in 2017, provided by ISPRA. Hence, we find that the total waste cost reduction is −12,217,527 × 0.2966 = −3,623,719 euros. Finally, we compute the per capita savings (27.39) dividing the total amount (3.6 million euros) by the population of Ferrara in 2017 (132,278).

An interesting exercise is to assume the introduction of a PAYT tariff in Italian municipalities with more of 50,000 inhabitants without a PAYT tariff and follow the procedure we previously described. If the introduction of the PAYT tariff generates the same percentage of waste reduction that we found for Ferrara (−18.75 %) we would have a decrease in the total waste cost of 723 million euros, which is equal to 39.59 euro per capita.

9 Conclusions

Waste recycling is a very hot issue in the political agenda. The PAYT system is a worldwide method used to collect waste and generate incentive to recycle. We study the effectiveness of the bag-based PAYT tariff introduced in July 2017 in the Municipality of Ferrara, in which before the introduction of the PAYT, the level of waste recycling was on average 40 % lower than other case studies previously analyzed as Trento (Bueno and Valente 2019) and the municipalities of the Flemish region (Gellynck and Verhelst 2007). We use a monthly municipal panel data with all municipalities of the same region served by the same utility and adopt the synthetic control method.

We find that the recycling waste share of Ferrara increased with respect to the synthetic Ferrara by 40 p.p. The result is due 25 % to organic waste and 15 % to multimaterial (glass, plastic, and paper) waste. This lower result on multimaterial waste recycling, which mostly includes packaging, can interestingly reflect a change in consumer behavior associated to the fact that people started preferring buying unpacked food. Secondly waste recycling is measured in kilos and plastics, paper and glass normally weight much less than organic waste.

Moreover, we find an important decrease of 30 p.p. of the difference between Ferrara and the synthetic Ferrara in the production of total waste after the introduction of the new tariff.

Indeed, we find both an increase in waste recycling and a decrease in total waste, contrary to other studies (Bueno and Valente 2019; Gellynck and Verhelst 2007) with high starting of waste recycling levels where the introduction of the PAYT tariff had no effect on waste recycling. This drives to the important conclusion that pricing waste is effective in reducing pollution by increasing the waste recycling, if this is initially sufficiently low, confirming Kinnaman (2006) findings.

Acknowledgment: Aacknowledge funding from FIRD 2022, University of Ferrara. We thank Luisa Loiacono who read and commented a previous version of the paper and Filippo Tarsia for helping us in collecting the data kindly provided by HERA. We are grateful to the participants of the XXXIII Annual Conference of the Italian Society of Public Economics (SIEP) in September 2021, and the participants of the 77th Annual International Congress of the Institute of Public Finance (IIPF) in August 2021 for helpful comments.

Appendix

Appendix A: Description of the Tariff Including the PAYT System

The PAYT tariff adopted by the Municipality of Ferrara is the following:

$$Waste\ tariff = ff + bvf + avf - A$$

where the fixed fee (*ff*) is computed according to the area in square meters of the house, valued differently (column 2, Table A1), according to the number of family members (column 1, Table A1). The basic variable fee (*bvf*) is also computed with reference to the number of family members (column 1, Table A1) which is associated to a minimum annual supply of liters of unsorted waste (column 3, Table A1). Namely, the *bvf* is equal to the product of the minimum annual liters times the price per liter (0.055 €/L). The minimum annual liters is also the threshold after which an additional variable fee (*avf*) is added. This fee is computed by multiplying the difference between the actual liters produced minus the minimum annual liters times the price per liter (0.055 €/L).

There are also some allowances (*A*). In particular, there one allowance affecting the incentive to produce waste recycling which is linked to the use of specialized waste collection centers. For each deposit of a specific waste recycling (Table A2) at a collection center, users can deduct from the waste tariff a certain fee based on

Table A1: Components of the waste tariff with the PAYT system in Ferrara, year 2019.

Number household members (1)	Fixed fee (€/square meter) (2)	Minimum annual liters (3)
1	1.021	1080
2	1.357	1380
3	1.555	1560
4	1.647	1740
5	1.906	1920
6 or more	2.058	2100

Source: Municipality of Ferrara (2019).

Table A2: Incentive allowance for deposits to a waste collection center.

Type of waste	Unit deduction (€/kg)
Batteries and accumulators	0.20
Medicines	0.30
Edible oils	0.20
Paper and cardboard, plastic, wood, metal, glass, textile, and mixed packaging	0.05
Electrical and electronic equipment	0.05
Mixed waste from small construction and demolition activities	0.01

Source: Municipality of Ferrara (2019).

the type and weight of the deposited waste. There are also several other allowances for domestic users. For example, if there is a baby in the family unit, or if the family usually uses medical-health devices under medical prescription, the family are allowed to produce unsorted waste for 7680 additional liters per year (Ferrara City Council Resolution n.6/2014).

Appendix B: Municipalities Sample

Alfonsine, Bagnacavallo, Bagnara di Romagna, Bagno di Romagna, Borghi, Brisighella, Casola Valsenio, Castel Bolognese, Cervia, Cesena, Cesenatico, Conselice, Cotignola, Faenza, Fusignano, Gambettola, Gatteo, Imola, Longiano, Lugo, Massa Lombarda, Mercato Saraceno, Montiano, Premilcuore, Ravenna, Riolo Terme, Roncofreddo, Russi, San Mauro Pascoli, Santa Sofia, Sant'Agata sul Santerno, Sarsina, Savignano sul Rubicone, Sogliano al Rubicone, Solarolo, and Verghereto.

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