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# Pay as you throw: evidence on the incentive to recycle

Leonzio Rizzo[1] and Riccardo Secomandi[2]

**Abstract**

The Pay as you throw (PAYT) system implies that people pay according to the unsorted waste they produce. Its impact has been studied with mixed results on waste recycling. We study a PAYT system with a threshold: users pay a fee up to a given number of bags produced, after this number they are charged for every additional bag. We test with a monthly panel dataset the impact of the introduction of this system by using the Synthetic Control Method (SCM) approach where the treated municipality is Ferrara and the synthetic counterfactual is a weighted combination of municipalities of the same region served by the same waste collection company. We find that the introduction of the new tariff strongly increased waste recycling and strongly decreased Ferrara's total waste with respect to its synthetic counterfactual. In fact, after one year of the implementation of the new tariff, Ferrara has increased waste recycling percentage of total waste by 40 percentage points and decreased the total per capita waste by 30 percentage points with respect to the synthetic counterfactual.

**Keywords**: Pay As You Throw, Municipal Waste Management, threshold, Synthetic control, incentive, recycling.

**JEL**: D01; D78; Q53.

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## 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 tax approach (Pigou, 1920), an increasing number of communities has adopted a variable rate pricing model aiming at reaching an efficient level of Municipal solid waste.[3] There were many cases in the 80s in US where this method was introduced[4] (Kinnaman, 2006). Afterwards, the pay as you throw (PAYT) system was implemented in many European countries, particularly in Switzerland, in Netherlands, in the northeastern area of Germany, in Denmark and in Italy (Reichenbach, 2008). The reason underpinning the use of the PAYT system is that citizens must feel the marginal cost of a unit more of produced mixed waste and so of a unit less of waste recycling to the extent that the two phenomena are linked. The method to do so is to use a unit price tariff for the unsorted waste: citizens pay according to the quantity of unsorted waste they produce. Testing the impact of the introduction of the tariff is extremely relevant to understand if it can increase the rate of circularity of the economy by converting waste into new products (recycling) and/or decrease the amount of total waste produced. As regards total waste per capita, there is in fact a need for reduction, given that in OECD countries it has remained stable at around 500 kg per capita over the last 20 years (Figure 1). Nevertheless, recycling has doubled over the last 20 years in OECD countries, passing from 80 kg to 139 kg per capita (Figure 1). How much of this last effect is due to the introduction of the PAYT system? Could the PAYT system also work in reducing total waste per capita, which does not seem to have been reduced in aggregate? Answering these questions is important if we want to understand how the PAYT system can contribute to reaching the EU target regarding waste recycling, which should be 60% of total waste by 2030.

[INSERT FIGURE 1 AROUND HERE]

The literature provides strong evidence that the PAYT has a negative impact on total waste, however there is no consensual evidence on the impact on waste recycling. It is our objective to quantify the effect of the PAYT in the municipality of Ferrara on total

[3] For a review of policy incentives to increase household recycling, see Halvorsen (2012).

[4] 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.

waste per capita and also on waste recycling. It is important checking for both effects. In fact, if the introduction of the tariff causes an increase in recycling, it implies an increase in the quota of resources devoted to the circular economy. Moreover, if it causes a decrease in total waste, it means that before the introduction of the tariff, total waste was excessive with respect to the case when citizens can feel the marginal cost of producing it and so it was inefficiently produced.

The PAYT system can be of two different kinds: the bag-based system, where residents purchase special bags with tags or labels that can identify the owner of the bag, and the weight-based pricing system, where the waste collection vehicle weighs the bin and matches this information to the owner's identity. Kinnaman and Fuellerton (1996, 2000), Van Houtven and Morris (1999), Allers and Hoeben (2010), Bucciol et al (2015), Carattini et al. (2018), and Bueno and Valente (2019) analyse the impact of the adoption of the PAYT bag-based system. They all find a decrease in total waste, but only two of them (Kinnaman and Fuellerton,1996; Bucciol et al 2015) find an increase in waste recycling. The impact of the weight-based pricing system is analysed by Miranda et al. (1994), Sterner and Bartelings (1999), Dijkgraaf and Gradus (2004), Yang and Innes (2007), Dahlén and Lagerkvist (2010), Allers and Hoeben (2010), Linderhof (2011), and Wright et al. (2019). All these works find a negative effect on total waste and a positive effect on recycling, except Dahlén and Lagerkvist (2010) who find a null effect on recycling. Finally, Gellynck and Verhelst (2007) find no effect on both total waste and recycling, analysing the impact of the introduction of weight-based pricing system in Belgium where, however, the level total waste was already very low and the level of waste recycling very high before the introduction of the tariff.

The impact of PAYT system has been studied using dataset of different granularity. In particular, Kinnaman and Fuellerton (1996), Van Houtven and Morris (1999), Sterner and Bartelings (1999), and Linderhof (2011) using micro-data at households' level. These works are generally related to one municipality and so with a missing counterfactual group of comparison. These papers find a decrease in total waste and an increase in waste recycling. The exception is Carattini et al. (2018) who find only an effect on total waste but using a panel dataset at households' level with 261 Switzerland municipalities, including treated and control municipalities. Then Miranda et al. (1994), Kinnaman and Fullerton (2000), Dijkgraaf and Gradus (2004), Gellynck and Verhelst (2007), Huang et al. (2011), and Wright et al. (2019) use municipal cross-section data finding a decreases in total waste, except Gellynck and Verhelst (2007), and mixed evidence about recycling. In fact, Miranda et al. (1994) and Dijkgraaf and Gradus (2004) find an increase in recycling while Kinnaman and Fullerton (2000) find a no effect on recycling. Finally, Yang and Innes (2007), Dahlén and Lagerkvist (2009), Allers and Hoeben (2010), Bucciol et al. (2015), Carattini et al. (2018), and Bueno and Valente (2019) use panel datasets - where the time dimension is along years - which allows to implement counterfactual analyses. All these works find a negative effect on total waste and a positive effect on recycling, except Bueno and Valente (2019). The different result of Bueno and Valente (2019) can be due to the fact that their treated municipality is Trento which has already a very a high level of recycling before the introduction of the PAYT.

In particular, Bueno and Valente (2019), using SCM, study the effects of the introduction of a unit pricing system on the waste, consisting in a fee per given amount of unsorted waste, in the municipality of Trento, having as counterfactual a pool of other similar Italian cities without the PAYT system belonging to different regions and served by different firms. In our work, we also use the SCM with a more homogenous sample since all the municipalities belong to the Emilia Romagna region and are served by the same multi-utility. This is very important because all municipalities analyzed have the same regional rules on waste management and, given that they are served by the same multi-utility, it is possible to compare treated and control municipalities to which the same technology of waste collection is applied. Moreover, the PAYT tariff of Ferrara differs from that of Trento. In fact, in Ferrara citizens can throw unsorted waste without paying an additional fee up to a given amount per month; after that any additional amount of waste is charged with a per unit fee. Contrary to Bueno and Valente (2019) and consistent with Bucciol *et al.* (2015) and Yang and Innes (2007), we find that the introduction of the new tariff increased waste recycling in Ferrara with respect to its synthetic model. We also find that the total waste decreased but at a lower rate. In fact, after one year of the implementation of the new tariff Ferrara increased its waste recycling percentage of total waste with respect to its synthetic counterfactual by 40 p.p. (percentage points). The total waste decreased with respect to its synthetic counterfactual by 30 p.p. The different result for recycling with respect to Bueno and Valente (2019) could be driven, among other factors, by the fact that Ferrara, before the introduction of the tariff, had a lower level of waste recycling (40% of total waste), than Trento[5] (67% of total waste): this means that there could be a technological threshold of recycling beyond which it is difficult to go.

The novelties of our work related to the previous literature are threefold. First, we estimate the impact in terms of recycling and total waste of a particular form of PAYT that involves a threshold below which the tariff related to the production of waste is not holding. This is a very peculiar and unique feature of the PAYT system applied to Ferrara which implies that the cost of a reasonable quota of unsorted waste is shared among all members of the community and the cost beyond this quota is beard by the single household. The rationale of the threshold is that there is a physiological amount of unsorted waste which cannot be avoided with the available recycling technologies. To the best of our knowledge, it is the first time that a PAYT tariff with a threshold is used to test the effect on total waste and recycling. Notice that, this mechanism, used in setting the carbon tax in Australia and Northern European countries (Pezzey and Jotzo, 2013), helped making the tax more acceptable, reducing the emitted CO2. Second, we adopt the Synthetic Control Method (SCM) that in our fits better than a classical Difference-in-Difference. In fact, Abadie (2021) shows, in a context with few treated unites, that a weighted combination of not treated units (which is the control used in the SCM) provides a more appropriate comparison than any single not effected unit alone. To the best of our knowledge only Bueno and Valente (2019) have adopted the SCM to evaluate the impact of the introduction of a PAYT, but with respect to their contribution we use a sample of municipalities more homogeneous. In fact, our analysis includes only municipalities belonging to the same Region, therefore with the same objectives of waste management defined in the regional plan, and all municipalities have the same technology for waste collection because they are all served by the same multiutility. Finally, we use municipal monthly data, which allows us to define in a correctly way the effect of the policy which starting in July 2017. If we want to compare the recycling and the total waste before and after the policy, we need a month granularity. With yearly data we could have not detected in a clear-cut way the impact of the policy since in year 2017 the recycling and total waste are due both to the absence and the introduction of the tariff. Moreover, the monthly dataset can let us measure behavioural effects of very short, short, and long time.

[5] https://www.comune.trento.it/Aree-tematiche/Ambiente-e-territorio/Rifiuti-urbani/Gestione-integrata-rifiuti/Raccolta-differenziata/Risultati-raggiunti

The paper is organized as follows: Section 1 describes the institutional settings of waste management and the PAYT tariff adopted in Ferrara, Section 2 contains the description of data, the empirical methodology used and empirical analysis, Section 3 contains the results of the main specifications, Section 4 reports the heterogeneity analysis, in Section 5 we carry out the placebo tests for the main specification, Section 6 discusses the results and Section 7 concludes.

## 1. Institutional setting

The Environmental Code[6] in Italy is the main national law on waste management. It deals with different authorities regarding waste management, assigning specific responsibilities to different institutional levels. Regions have consolidated the role of directions determining the general limits and objectives. Indeed, Regions are responsible for the preparation, adoption and updating of the regional waste plan and waste management regulatory activities (art. 196 D.Lgs. 152/2006). Provinces and municipalities also participate in the definition of these plans. However, art. 23 of D.Lgs. 22/1997 defines that the optimal territorial areas (so called Ambito Territoriale Ottimale - ATO) for the management of urban waste are in intermediate level between Regions and Municipalities. ATO usually corresponding to areas of Italian provinces. The optimal territorial areas ensure territorial unitary management of urban waste and prepare specific waste management plans, coordinating with municipalities and regions. Municipalities apply policies determined at ATO level through the municipal waste plans. Local authorities have the legal obligation to provide collection systems and the corresponding right to impose a local tax aimed at cost recovery. The operators to which municipalities entrust the collection service become legally responsible for the waste they collect and have to dispose of it according to the prescriptions of regional and ATO plans. The Waste Framework Directive 98/2008 moved municipal waste management in Europe up the waste management hierarchy (Cerqueti *et al.*, 2021). Then municipalities are the authorities that concretely choose the management system and all policies in order to address targets fixed by the highest-level authorities (Bonelli *et al.*, 2016).Waste collection in Ferrara, managed since 2004 by Hera S.p.A.[7], was financed until 2018

[6] Legislative Decree n. 152/2006.

[7] Agreement stipulated between the Optimal Territorial Area Authority of Ferrara (AATO6) and Hera S.p.A (2004). Hera is one of the largest multi-utilities in Italy and operates mainly in the environment sector (waste management), in the water sector (aqueducts, sewers and purification) and in the energy sector (especially gas, distribution and sale of electricity).

through the TARES[8], which is a tariff that fully covers the costs of the collection and disposal service: the total amount of this tariff mainly depends only on the surface area of properties and the composition of the family.

With the City Council Resolution n.6/2014, Ferrara decided to introduce the PAYT system with a radical change in the municipal waste-collection law. Starting from July 2017, bins were provided for waste recycling and bins equipped with an electronic cover for unsorted waste. Each user has been provided with an electronic card.[9] This card allows the opening of the cover of the bin where the unsorted waste can be thrown. Each access to the electronic cover corresponds to 30 liters of unsorted waste.

The part of the tariff[10] computed using the PAYT system is given by the product of the liters of unsorted waste minus a minimum threshold and the unit cost of the service (in 2019 it was 0.055 € / liter).

To avoid illegal dumping, such as mixing unsorted waste with recycling waste or putting the garbage outside the bins, during the implementation period of the PAYT system controls were intensified by local authorities, in particular in the most touristic areas of the town.[11] As an indirect measure of illegal dumping in waste collection, we collect data on the so-called bulky waste in the municipality of Ferrara. The bulky waste is a special type of unsorted municipal waste that for its size is not possible putting in the bins. Then the bulky waste is taken in waste collection center, usually without controls on the size of the waste. After the introduction of PAYT in July 2017, the contributions of bulky waste in the waste collection centers of Ferrara would not seem to have a sudden increase (Figure 2).

[INSERT FIGURE 2 AROUND HERE]

There is also the possibility that the citizens of Ferrara could "export" the waste into neighboring jurisdictions (Erhardt, 2019). However, municipalities bordering Ferrara (red line) and municipalities bordering the neighboring municipalities of Ferrara (blue line)

[8] TARES was introduced with the Decree n. 201/2011.
[9] Each card is matched to only one user.
[10] For a complete description of the tariff see appendix A.
[11] In particular, after the introduction of the PAYT, local police cars were equipped with a camera that can automatically read car number of citizens who leave waste outside the bins. In addition, for controlling the discharging waste away from the center of the town, the number of hours of monitoring by ecological guard associations were doubled (see https://www.comune.fe.it/6125/attach/presidente_cons/docs/5145_2018_ferri.pdf ).

show (Figure 3) no significant change in unsorted waste after the introduction of PAYT (2017).

[INSERT FIGURE 3 AROUND HERE]

## 2. Empirical analysis

### *2.1. Identification: Synthetic Control Method*

We use the SCM to test how after July 2017 the PAYT tariff impacted on waste recycling and total waste per capita.

Synthetic control methods were originally proposed in Abadie and Gardeazabal (2003) and Abadie et al. (2010) with the aim to estimate the effects of policy interventions on a small number of units (e.g. cities, school districts, or countries), on some outcome of interest.

The SCM aims to simulate the outcome path of a treated unit if it did not undergo a particular policy or event. The SCM built a reference comparison unit as an "artificial counterfactual" (called *synthetic control*), which is then used as a reference for comparison to the real *treated unit*, in this case the municipality of Ferrara (Abadie, Diamond and Hainmueller, 2015; and for a recent review, see Abadie, 2021).

The SCM attempts to formalize the selection of the comparison units using a data driven procedure. Operatively, the *synthetic control* is built as a weighted average of the units in the control group, in this case other municipalities served by the same multiutility. The weights are chosen so that they match as closely as possible the treated unit, before the treatment, for several unaffected predictors of the outcome and outcome itself. The trajectory of the outcome in the synthetic control mimic what it would have been the path of the outcome in the affected unit, if the policy had never occurred.

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 "case of interest" or "treated unit", and $k$ = 2... $K$+1 are the "potential comparisons" making up the donor pool. The units are observed at the same time $t$ periods, $t$ = 1, .... $T$ with a given pre- and post-intervention period. The synthetic control is the weighted average of the units in the donor pool; so, it is a $(K \times 1)$ vector of weights $W = (w_2, .... W_{K+1})$, with $0 \leq w_k \leq 1$ for $k = 2, .... K$ s.t. $w_2$ + ... + $w_{J+1}$ = 1.

$X_1 = (s \times 1)$ is the vector of the values for the pre-intervention characteristics of the treated unit, and $X_0 = (s \times K)$ is the matrix collecting the values of the same variable for all the other units in the donor pool. These variables are chosen on the understanding they are good predictors of the outcome variable within vector $X_1$ and pre-intervention values of the outcome variable may themselves be included. A vector of weight, $W$, is selected so that the size of the difference between the pre-intervention characteristics of the treated unit and those of the units making up the donor pool is minimized. Specifically, the vector $W$ 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 dependent variable before the treatment for the treated and for the donor group, respectively.

We then let $Y_1 = (T_1 \times 1)$ be the vector of the post-intervention values of the outcome for the treated unit and $Y_0 = (T_1 \times K)$ be the matrix collecting the values of the same variables for all the units in the donor pool. The synthetic control estimator of the effect of the treatment is given by $(Y_1 - Y_0W)$. Since we construct a synthetic control unit with similar behaviors to the treated unit in the pre-intervention period, a discrepancy in the outcome variable after the intervention is interpreted as the true effect of the intervention itself.

## *2.2. Data Sample and Empirical Strategy*

In order to apply a synthetic control method, we use all the municipalities served by the waste collection company Hera in the Emilia Romagna region and not affected by the introduction of a PAYT tariff, which are 36[12]. Given the short timespan since January 2015, we use high-frequency data. In particular, we use a panel dataset spanning the months from January 2015 to December 2018. The application of the PAYT starts on July 2017, so our dataset consists of 48 months in total, 18 after the introduction of the PAYT system. We run four iterations of the SCM, using as outcome variables the share of waste recycling (on total waste), 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) (Table 1). The share of

[12] The list of the municipalities is reported in Appendix B.

organic waste recycling is the ratio between kilos of organic waste and kilos of total waste. The share of multimaterial waste is the ratio between kilos of multimaterial waste 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 9 socio-economic variables as predictors of Ferrara's pre-intervention characteristics, which are annual variables taken before the beginning of the pre-treatment period (Table 2). 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: per capita income, quota of firms in the service industry, number of firms per capita, quota of population over 65, and density. Kinnaman and Fullerton (2000) show that educated citizens have greater preference for a clean environment, so we add as pre-treatment control the quota of population with a high school diploma, as in the last Census. Tsai (2008) shows higher social capital increase household waste recycling. For this reason, we include in the pre-treatment control the quota of volunteers in last Census and the turnout in the 2011 referendum[13], as a proxy of the municipal social capital. Finally, the tourist population have a lower propensity to separate collection (Mateu-Sbert *et al.*, 2013), so we include the variable number of per-capita hotels, as a proxy for the municipal tourism level. These data were collected from Italian National Institute of Statistics (Istat), Ministry of Economy, and Ministry of the Interior.

[INSERT TABLE 1 AROUND HERE]

[INSERT TABLE 2 AROUND HERE]

In addition, and in line with Abadie, Diamond and Hainmueller (2010), to obtain a more accurate replicate of the "artificial counterfactual" of the treated municipality before treatment, we also include four lags of the dependent variable, 6, 12, 18 and 24 months before the introduction of the tariff. Once the synthetic control weights are obtained, they are then applied to the outcome variables for the whole period of analysis to obtain the counterfactual post-treatment behavior of Ferrara. Finally, the synthetic control dependent variable is compared with the corresponding variable for the real Ferrara to correctly test the relevance of the treatment.

[13] The 2011 referendum also referred to local public services, such as urban waste collection.

## 3. Basic Results

We analyze the impact on the waste recycling share and the total waste per capita. In the heterogeneity section we split waste recycling into the organic recycling share and the multimaterial recycling share.

### *3.1 Recycling waste share*

If we focus on the recycling waste 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 town of Faenza is the one which most closely resembles the Ferrara waste recycling share over the pre-treatment period. The covariates between the Ferrara and the synthetic Ferrara are very similar, indeed the difference between the mean of each covariate in the treated unit and in the synthetic control are very low (Table 3).

[INSERT TABLE 3 AROUND HERE]

We can conclude that the recycling share of the synthetic Ferrara does not differ from that of real Ferrara before the introduction of the PAYT and that it does differ from that of the real Ferrara after the introduction of the tariff, this being much higher than the previous one (Figure 4). The shaded area (Born *et al.*, 2019) is plus/minus one standard deviation of the difference between synthetic Ferrara and real Ferrara before the introduction of the tariff. As such, this area gives an upper and a lower limit of an interval within which the real Ferrara would fall if it had been included in the pre-treatment period. Waste recycling was around 45% from January 2015 to December 2016 in the real Ferrara and in the synthetic Ferrara. In January 2017 we observe a decrease in the waste recycling in the real Ferrara and also in the synthetic Ferrara due to a change in national legislation that has removed from the reporting a particular type of waste recycling (neutral fraction). Waste recycling was 25% in 2017 before July, and from July the month of the introduction of the tariff the synthetic Ferrara stayed around 26-27% and the real Ferrara arrived at 70% in one year.

After the introduction of the PAYT, the line of the real Ferrara lies outside the shaded area, and before the introduction, it lies inside the shaded area almost all of the time. Hence, this suggests there has been an impact on waste recycling.

[INSERT FIGURE 4 AROUND HERE]

The quantitative results are shown in Table 4: eighteen months before the introduction of the PAYT, the share of waste recycling lies within the upper/lower bound interval for the synthetic Ferrara, with some few exceptions, implying that there is no significant difference between the real and the synthetic Ferrara. In contrast, in the eighteen months after the tariff, the waste recycling share lies outside this interval (highlighted in italics in the table); specifically, it lies above the upper boundary, indicating there is a significant increase in the real Ferrara with respect to its benchmark. This positive impact remains stable during all 2018.

[INSERT TABLE 4 AROUND HERE]

We compute the percentage point (p.p.) difference between the variation in the path taken by synthetic Ferrara with respect to the PAYT (in percentage terms) and the variation in the path taken by real Ferrara with respect to the PAYT (in percentage terms) per month (Table 5). The difference is 5 p. p. after the introduction of the PAYT, rising to 30 p.p. in December 2017. In January 2018 the previous computed difference was around 40 p.p., which remained stable throughout 2018, reaching a peak of 44 p. p. in August.

[INSERT TABLE 5 AROUND HERE]

## *3.2 Total waste per capita*

The introduction of the PAYT 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 control is bult 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%). Analyzing the averages of each control variables (Table 6), we verify that the difference in the covariates between Ferrara and the synthetic Ferrara is very small.

[INSERT TABLE 6 AROUND HERE]

Before the introduction of the PAYT the trend of total waste production is very similar in Ferrara and the synthetic control (Figure 5). After July 2017, the date of the introduction of the PAYT system, the total waste per capita in Ferrara started to decrease, while we do not observe the same trend for the synthetic control. The real Ferrara line lies outside the shaded area after the introduction of the tariff except for the first few months, confirming that after the introduction of the PAYT tariff in the real Ferrara there is a significant decrease in the production of total waste with respect to the synthetic control.

[INSERT FIGURE 5 AROUND HERE]

To quantify the effect for the total waste, we compute the difference in percentage points with respect to the introduction of the tariff between the synthetic Ferrara and the real Ferrara (Table 7). We find that this difference is very small in the first months after the introduction of the PAYT system. Starting from January 2018the difference registered a jump to around 20 p.p., reaching a peak of 32 p. p. in July 2018.

[INSERT TABLE 7 AROUND HERE]

## 4. Heterogeneity

We analyze the results by splitting waste recycling into two kinds: organic and multimaterial.

### *4.1. Organic recycling*

We applicate the SCM using as the outcome variable the share of organic recycling.

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, which most closely resemble Ferrara in share of organic waste over the pre-treatment period. Table 8 shows control variables for Ferrara and the synthetic Ferrara. Also in this case, the difference between the control variables of the treated unit and the synthetic control are very small.

[INSERT TABLE 8 AROUND HERE]

From Figure 6, we conclude that the organic recycling share of the synthetic Ferrara mimics well that of the real Ferrara before the introduction of the tariff and it differs from that of the real Ferrara after the introduction of the tariff, this being much higher than the previous one. Organic waste recycling was around 13% before the introduction of the tariff for both real and synthetic Ferrara and after the introduction the tariff the synthetic Ferrara stayed around 13-15% and the real Ferrara arrived at more than 40% in one year.

[INSERT FIGURE 6 AROUND HERE]

### *4.2. Multimaterial recycling*

Finally, we use as outcome variable in the SCM the share of multimaterial recycling. In this case the synthetic control 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~~,~~ which most closely resemble Ferrara in the share of multimaterial waste over the pre-treatment period. Table 9 also sheds light on the fact that using the synthetic control method allows us to have very similar control variables between the treated and the synthetic municipalities.

[INSERT TABLE 9 AROUND HERE]

From Figure 7, we conclude that also in this case the multimaterial recycling share of the synthetic Ferrara mimics well that of the real Ferrara before the introduction of the tariff and that it differs from that of the real Ferrara after the introduction of the tariff, this being much higher than the previous one. The multimaterial waste recycling was almost 13% in 2017 before the introduction of the tariff for both real and synthetic Ferrara and after the introduction of the tariff Ferrara it jumped to almost 30% during 2018 while the synthetic Ferrara stayed at 13%.

[INSERT FIGURE 7 AROUND HERE]

In Table 10, we compute the difference in percentage points with respect to the introduction of the tariff between the synthetic Ferrara and the real Ferrara, for organic waste and for multimaterial waste. For multimaterial waste, we find a lower effect of the introduction of the PAYT system than for organic waste. In fact, after the trial period (in which people did not pay according to the PAYT tariff even if the system with electronic cards had been implemented) the difference between Ferrara and the control group with respect to the same difference computed in the month when the tariff has been introduced for the multimaterial waste share is between 15 p.p. and 18 p.p. higher, while for the organic waste share it is between 25 p.p. and 30 p.p higher.

[INSERT TABLE 10 AROUND HERE]

## 5. Placebo Experiments

In this section, we run a set of robustness tests to validate our main result. We found some evidence of causality relative to the impact of the PAYT tariff on waste recycling in Ferrara, so we ran municipality and time placebo tests, changing, respectively, the treated municipality and the time of the shock. If we are definitely estimating a causal effect due to the introduction of the PAYT, we expect not to find any effect in the placebo tests.

We first estimate the synthetic control for each of the municipalities in the sample while exposing them to the treatment. If our benchmark estimate is in fact detecting the causal effect of the introduction of the PAYT, the divergence of municipal-specific synthetic controls from the respective data after the treatment date should be considerably smaller than in the case of Ferrara.

Table 11 shows the results of the municipal-placebo experiments for the waste recycling share. In what follows (column 1 Table 11), we use the ratio between the post-and-pre-treatment of the root mean squared prediction error (RMSPE), where the higher the ratio, the greater the difference between treated and synthetic units in the post-treatment case with respect to that of pre-treatment. The RMSPE is equal to the square root of the mean of the square of the difference between the treated and the synthetic control. The second column contains the RMSPE for the pre-treatment period, and the third one the RMSPE for the post-treatment period.

[INSERT TABLE 11 AROUND HERE]

Thus, column 1 of Table 11 quantifies how closely the municipal-specific synthetic controls follow the data post-treatment relative to the pre-treatment fit. Ferrara has a much larger ratio than all the other municipalities (17.696). The robustness of this result can be observed by the fact that if the PAYT 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 coefficient is higher than one: 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.

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 just those municipalities with a ratio below one. Using only this restricted sample, we show that waste recycling share of the "restricted" synthetic Ferrara mimics well that of the real Ferrara before the introduction of the tariff and that it differs from that of the real Ferrara after the introduction of the tariff (Figure 8). The waste recycling was almost 25%

in 2017 before the introduction of the tariff for both real and synthetic Ferrara. After the introduction of the PAYT Ferrara jumped to almost 70% in one year, while the “restricted” synthetic Ferrara stayed stable around 25%. This test confirmed the results obtained in the main analysis.

[INSERT FIGURE 8 AROUND HERE]

We also use the results from the municipal-placebo experiments, to test the presence of a leakage/spill-over effect due to the fact that neighboring municipalities can mimic Ferrara in increasing recycling even if they have not adopted a PAYT system. To do that, for a given municipality we explore a possible relationship between the RMPSE ratio for waste recycling and the distance between the considered municipality and Ferrara (Figure 9). If a leakage/spill-over effect is holding, we should find that the higher the RMPSE ratio[14] in a given municipality is, the lower the distance from Ferrara is. Since we find a no significant correlation index (-0.23) between the RMPSE ratio and the distance of a given municipality from Ferrara, we conclude that differently from Carattini et al. (2018) but, similarly to Sterner and Bartelings (1999) and Dijkgraaf and Gradus (2004), there is no evidence of a serious leakage/spill-over effect after the introduction of the PAYT.

[INSERT FIGURE 9 AROUND HERE]

In Figure 10, we plot the results of the difference between real and 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 lights on the sign of the difference between synthetic and real municipality. The bold line corresponds to the difference for Ferrara. The estimated trend for Ferrara is clearly positive after the treatment, and much higher than the estimated trend for the rest of the municipalities. Before the treatment, the series for Ferrara oscillates around zero and, in any case, does not show a noticeably different trend from the rest of the municipalities. Only in first months of the introduction of the PAYT system (when the tariff was not applied) there are some placebo differences that are higher than Ferrara, but from January 1st 2018 onwards the Ferrara difference is the largest.

[INSERT FIGURE 10 AROUND HERE]

[14] Notice that the higher the RMSPE ratio is, the higher is the difference in recycling between the municipality and the control group after the introduction of the PAYT than the same difference before the introduction of the PAYT.

We also ran another placebo experiment to test for the adequacy of the treatment month. To do so, we changed the treatment month to a period before the tariff had been implemented. In particular, we used 17 months before June 2017.

From Table 12 we can see that for the fake tariff introduction the ratio is always lower than 1, showing that the fake introduction of a tariff does not have any significant impact on the level of waste recycling in Ferrara with respect to its synthetic counterfactual.

[INSERT TABLE 12 AROUND HERE]

We further repeated the SCM estimate by excluding one municipality from the sample one by one. As can be seen from Figure 11, the difference between the real and the synthetic Ferrara remains the same as in the main specification.

[INSERT FIGURE 11 AROUND HERE]

## 6. Discussion

We showed that the introduction of the PAYT tariff has decreased not only the total waste per capita but also increased the recycling waste in Ferrara (treated municipality). The PAYT system seems to be an appropriate policy to reach the European targets of separated collection (i.e. 55% waste recycling by 2025, 60% by 2030, and 65% by 2035), for cities starting with low levels of waste recycling like Ferrara (40%) differently from Trento starting from a high level of recycling (67%) and for which the introduction of the PAYT system did not affect the waste recycling (Bueno and Valente, 2019). Interestingly the case of Ferrara shows that the PAYT system can gradually be introduced by using a mixed tariff with a threshold of unsorted waste after which the PAYT tariff is applied. Below this threshold the previous tariff, based on square meters and number of households, is applied. Interestingly, the so designed tariff has been effective in reducing total waste and increasing recycling despite citizens do not have to pay for each kilo of unsorted waste, but only for kilos after a given threshold.

Moreover, the application of PAYT did not only lead to a reduction in total amount of waste produced but also implied a significant reduction in the costs of waste collection, transport, and disposal. For the municipality of Ferrara, considering the average decrease of total waste in the first year of the application of the PAYT (-18.75%), we compute, using the annual total costs per kg of the waste service[15], that the PAYT system decreases

[15] The annual total costs per kg of the waste service for the year 2019 is 0,2966 €/Kg (source: ISPRA).

the total waste cost of about 5 million euro (37.88 euro per capita). We simulate the introduction of a PAYT in the Italian towns with more of 50.000 inhabitants without a PAYT system. We assumed that the introduction of the PAYT system generates the same waste reduction that we found for Ferrara (-18.75%). In this case we compute a decrease in total waste cost of 723 million euro, which is 39.59 euro per capita.

## 7. Conclusions

Waste recycling is a very hot issue. The way to do it is matter of discussion. The PAYT system is adopted worldwide. The literature does not show unique results on the effectiveness of PAYT in increasing waste recycling. This is because studies refer to different kind of PAYT system (bag-system vs weight-system) and of data (households data vs municipal level data, yearly data vs panel data). We study the effectiveness of the PAYT system introduced in July 2017 in the municipality of Ferrara. The PAYT in Ferrara is a particular system of the bag-based PAYT that involves a threshold below which the tariff related to the production of waste is not holding. We use monthly municipal panel data with all the municipalities of the same region served by the same multi-utility. We adopt the SCM that which allows us to carry out the more efficient counterfactual analysis in the case of a single unit treated (Abadie, 2021). We find that the introduction of the PAYT tariff has increased the recycling waste share of Ferrara 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. Moreover, we find an important decrease of 30 p.p. of the difference between the Ferrara and the synthetic Ferrara in the production of total waste after the introduction of the new tariff. Our results are robust in terms of spatial and time placebo tests. The spatial tests are conducted by replacing the treated town with all the other municipalities in the sample and in the time-placebo test we replace the treatment month with the previous 17 months.

Overall, from our analysis we can conclude that this PAYT system - that is closer to a Pigouvian taxation but with a thresholds mechanism which should make it more acceptable to citizens – is extremely effective in creating an incentive to waste recycling.

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## TABLES AND FIGURES

*Table 1: Summary statistics of the dependent variables, per month.*

| VARIABLES | (1) N | (2) mean | (3) sd | (4) min | (5) max |
|---|---|---|---|---|---|
| Waste recycling share | 1,776 | 0.257 | 0.156 | 0.028 | 0.709 |
| Total waste per capita | 1,776 | 39.619 | 13.413 | 16.835 | 161.13 |
| Organic waste recycling share | 1,776 | 0.077 | 0.072 | 0 | 0.442 |
| Multimaterial waste recycling share | 1,776 | 0.180 | 0.138 | 0.011 | 0.606 |

*Table 2: Summary statistics of predictors in pre-treatment period.*

| VARIABLES | (1) N | (2) mean | (3) sd | (4) min | (5) max |
|---|---|---|---|---|---|
| Quota of population with a high school diploma | 37 | 0.385 | 0.046 | 0.314 | 0.499 |
| Quota of population over 65 | 74 | 0.241 | 0.036 | 0.168 | 0.352 |
| Quota of volunteers | 37 | 0.107 | 0.057 | 0.033 | 0.360 |
| Turnout, Referendum 2011 | 37 | 0.644 | 0.055 | 0.424 | 0.740 |
| Quota of firms in the service industry | 74 | 0.729 | 0.069 | 0.559 | 0.854 |
| Personal income per capita | 74 | 13,088 | 1,409 | 9,350 | 16,992 |
| Hotels per capita | 74 | 0.005 | 0.006 | 0.000 | 0.0335 |
| Firms per capita | 74 | 0.077 | 0.017 | 0.050 | 0.124 |
| Density | 74 | 267.4 | 262.8 | 8.076 | 1,375 |

*Table 3: Control variables treated, synthetic control and donor pool (waste recycling share).*

| | Treated | Synthetic | Difference [Treated-Synthetic] |
|---|---|---|---|
| Personal income per capita | 16,408 | 14,575 | 1,833 |
| Quota of population over 65 | 0.278 | 0.249 | 0.029 |
| Density | 328 | 295 | 33 |
| Quota of population with a high school diploma | 0.499 | 0.451 | 0.048 |
| Quota of volunteers | 0.117 | 0.130 | -0.013 |
| Hotels per capita | 0.001 | 0.002 | -0.001 |
| Quota of firms in the service industry | 0.847 | 0.806 | 0.041 |
| Firms per capita | 0.088 | 0.090 | -0.002 |
| Turnout, Referendum 2011 | 0.634 | 0.646 | -0.012 |
| Waste recycling share (January 2017) | 0.242 | 0.219 | 0.023 |
| Waste recycling share (July 2016) | 0.375 | 0.383 | -0.008 |
| Waste recycling share (January 2016) | 0.384 | 0.421 | -0.037 |
| Waste recycling share (July 2015) | 0.428 | 0.409 | 0.019 |

*Table 4: Waste recycling share: Real vs artificial Ferrara.*

| Month/Year | Lower bound | Upper bound | Treated | Month/Year | Lower bound | Upper bound | Treated |
|---|---|---|---|---|---|---|---|
| Pre-treatement period | | | | Post-treatement period | | | |
| 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 | | | | |

*Table 5: Percentage waste recycling – percentage points differences with respect to the introduction PAYT system (July 2017) between treated and synthetic control.*

| Year/month | Treated | Synthetic | Treated-synthetic |
|---|---|---|---|
| 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 6: Control variables treated, synthetic control and donor pool (total waste per capita).*

| | Treated | Synthetic | Difference [Treated-Synthetic] |
|---|---|---|---|
| Personal income per capita | 16,408 | 14,636 | 1,772 |
| Quota of population over 65 | 0.278 | 0.247 | 0,.31 |
| Density | 328 | 329 | -1 |
| Quota of population with a high school diploma | 0.499 | 0.439 | 0.6 |
| Quota of volunteers | 0.117 | 0.123 | -0.006 |
| Hotels per capita | 0.001 | 0.003 | -0.002 |
| Quota of firms in the service industry | 0.847 | 0.780 | 0.067 |
| Firms per capita | 0.088 | 0.083 | 0.005 |
| Turnout, Referendum 2011 | 0.634 | 0.640 | -0.006 |
| Waste recycling share (January 2017) | 30.532 | 29.151 | 1.381 |
| Waste recycling share (July 2016) | 39.420 | 40.306 | -0.886 |
| Waste recycling share (January 2016) | 38.063 | 39.115 | -1.052 |
| Waste recycling share (July 2015) | 44.911 | 44.594 | 0.317 |

*Table 7: Total per capita waste – percentage points differences with respect to the introduction PAYT system (July 2017) between treated and synthetic control.*

| Year/month | Treated | Synthetic | Treated-synthetic |
|---|---|---|---|
| 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 |

*Table 8: Control variables treated, synthetic control and donor pool (organic waste recycling).*

| | Treated | Synthetic | Difference [Treated-Synthetic] |
|---|---|---|---|
| Personal income per capita | 16,408 | 14,418 | 1,990 |
| Quota of population over 65 | 0.278 | 0.267 | 0.011 |
| Density | 328 | 242 | 86 |
| Quota of population with a high school diploma | 0.499 | 0.428 | 0.071 |
| Organic waste recycling share (January 2017) | 0.124 | 0.124 | 0 |
| Quota of volunteers | 0.117 | 0.140 | -0.023 |
| Organic waste recycling share (January 2016) | 0.090 | 0.090 | 0 |
| Hotels per capita | 0.001 | 0.004 | -0.003 |
| Quota of firms in the service industry | 0.847 | 0.808 | 0.039 |
| Organic waste recycling share (July 2015) | 0.086 | 0.099 | -0.013 |
| Firms per capita | 0.088 | 0.083 | 0.005 |
| Organic waste recycling share (July 2016) | 0.099 | 0.100 | -0.001 |
| Turnout, Referendum 2011 | 0.634 | 0.635 | -0.001 |

*Table 9: Control variables treated, synthetic control and donor pool (Multimaterial waste recycling).*

| | Treated | Synthetic | Difference [Treated-Synthetic] |
|---|---|---|---|
| Personal income per capita | 16,408 | 14,060 | 2,348 |
| Quota of population over 65 | 0.278 | 0.243 | 0.035 |
| Density | 328 | 329 | -1 |
| Quota of population with a high school diploma | 0.499 | 0.429 | 0.07 |
| Multimaterial waste recycling share (January 2017) | 0.294 | 0.296 | -0.002 |
| Quota of volunteers | 0.117 | 0.118 | -0.001 |
| Multimaterial waste recycling share (January 2016) | 0.118 | 0.118 | 0 |
| Hotels per capita | 0.001 | 0.003 | -0.002 |
| Quota of firms in the service industry | 0.847 | 0.761 | 0.086 |
| Multimaterial waste recycling share (July 2015) | 0.342 | 0.341 | 0.001 |
| Firms per capita | 0.088 | 0.088 | 0 |
| Multimaterial waste recycling share (July 2016) | 0.276 | 0.277 | -0.001 |
| Turnout, Referendum 2011 | 0.634 | 0.636 | -0.002 |

*Table 10: Organic and multimaterial percentage waste recycling – percentage points differences with respect to the introduction of PAYT system (July 2017) between treated and synthetic control.*

| Year/month | Treated | Synthetic | Treated-synthetic | Treated | Synthetic | Treated-synthetic |
|---|---|---|---|---|---|---|
| | Organic waste | | | Multimaterial waste | | |
| 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 |

*Table 11: Municipal-placebo experiments for waste recycling share.*

| Municipality | Ratio | RMSPE pre-treatment | RMSPE post-treatment |
|---|---|---|---|
| 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 |

*Table 12: Fake month/year implementation for waste recycling share.*

| Fake month/year | Ratio | RMSPE pre-treatment | RMSPE post-treatment |
|---|---|---|---|
| 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 |

*Figure 1: Municipal waste in 25 OECD countries, 2000-2017: kg. per capita.*

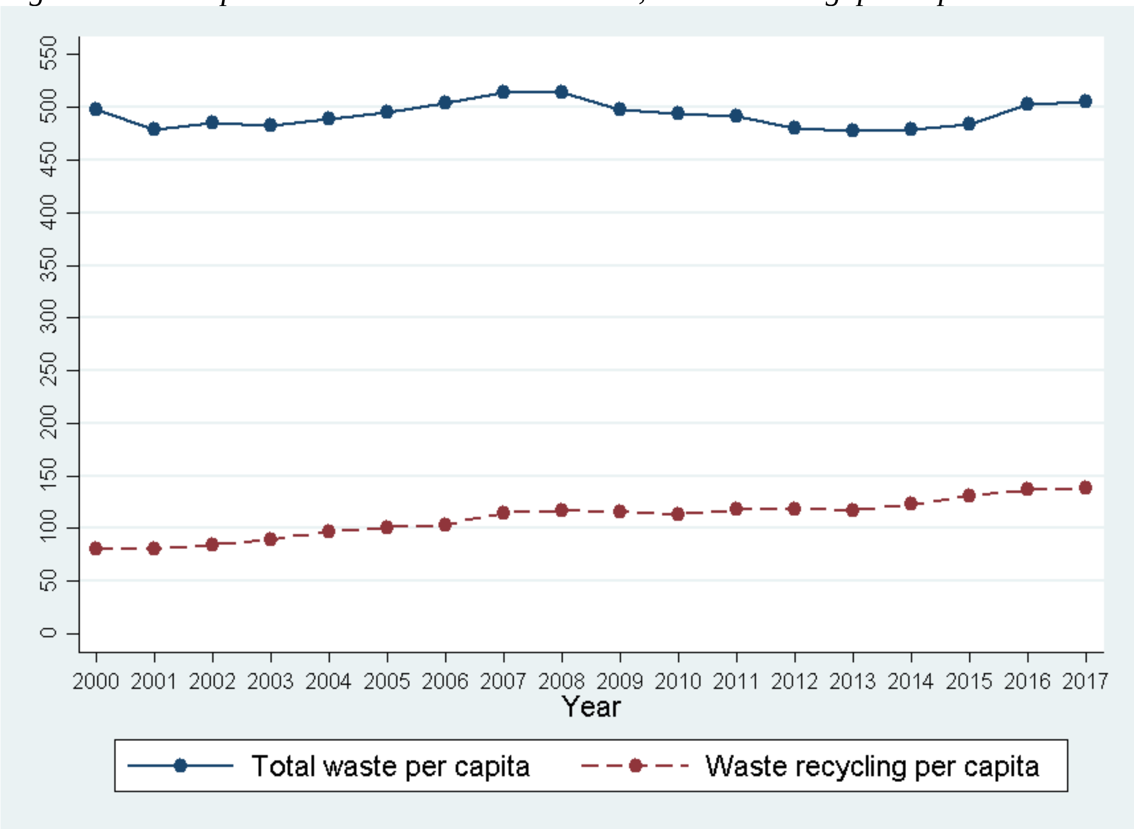


*Figure 2: Bulky waste in the municipality of Ferrara, 2016-2018: kg. per capita.*

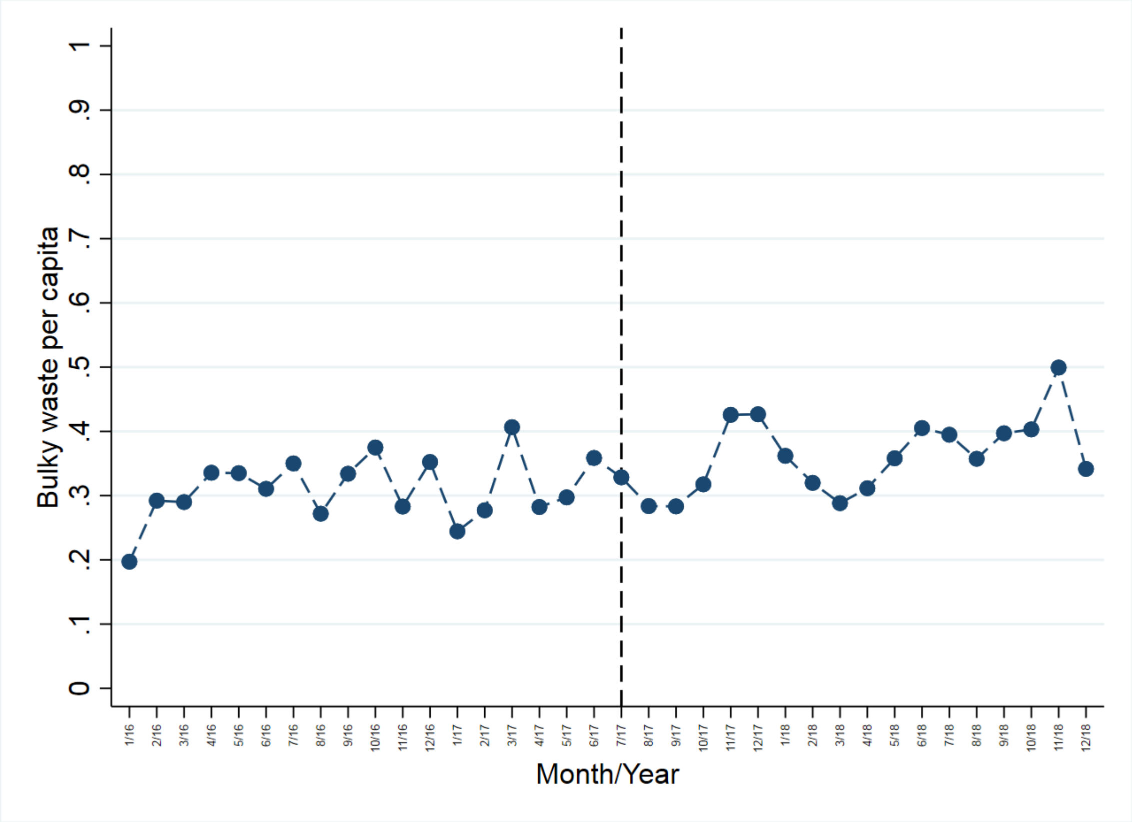
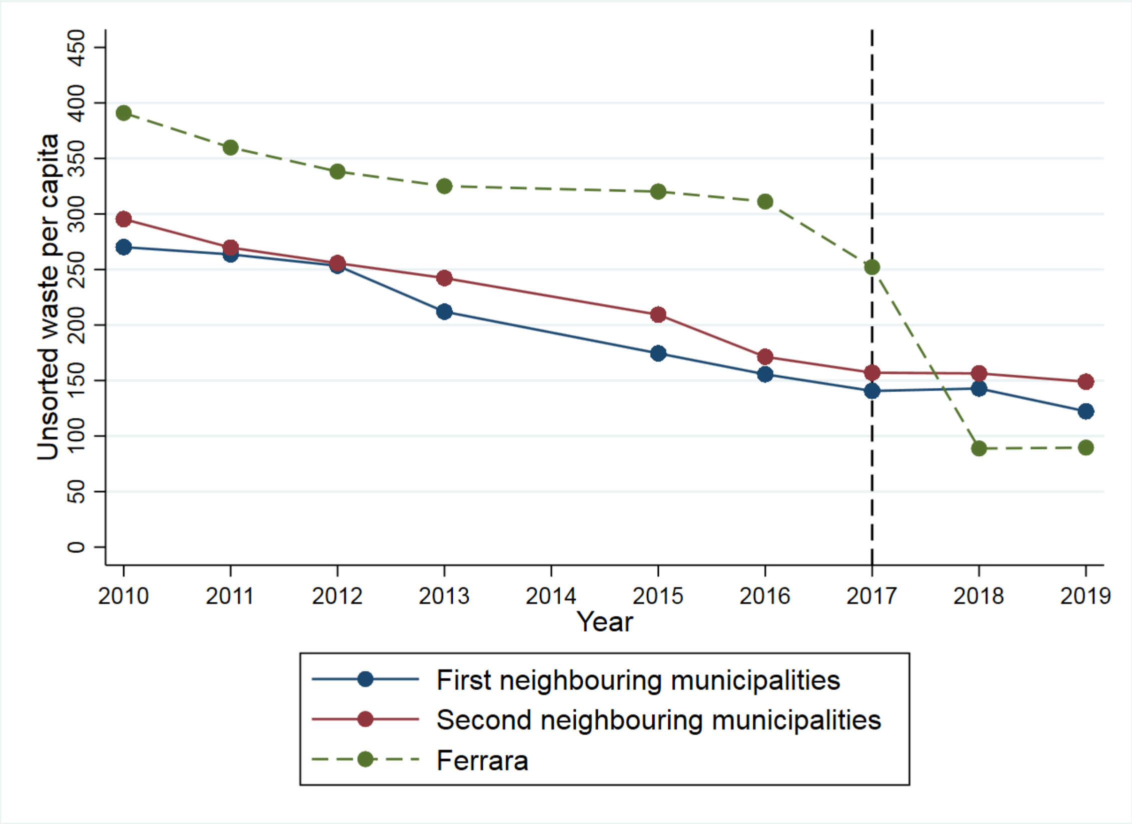



*Figure 3: Municipal unsorted waste in Ferrara and in neighbouring municipalities, 2010-2019: kg. per capita.*




*Source: ISPRA.*

*Figure 4: Ferrara vs synthetic control, waste recycling share.*

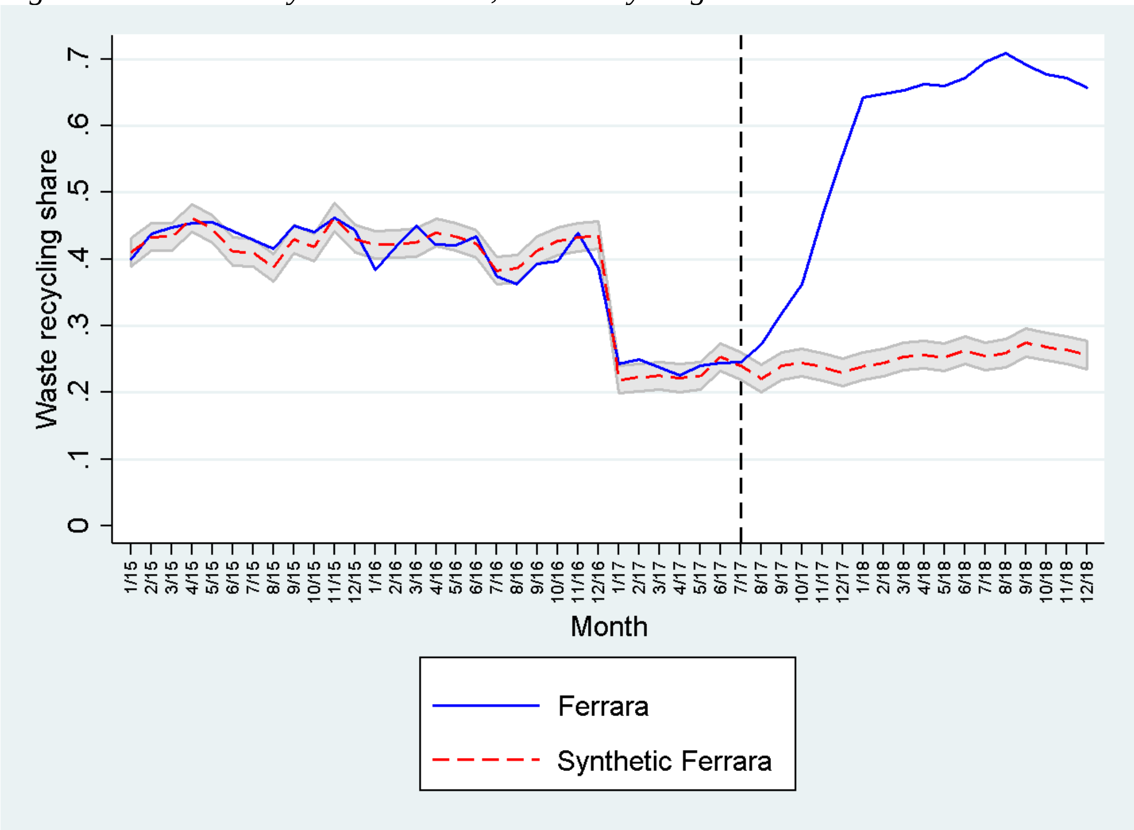



*Figure 5: Ferrara vs synthetic control, total waste per capita.*

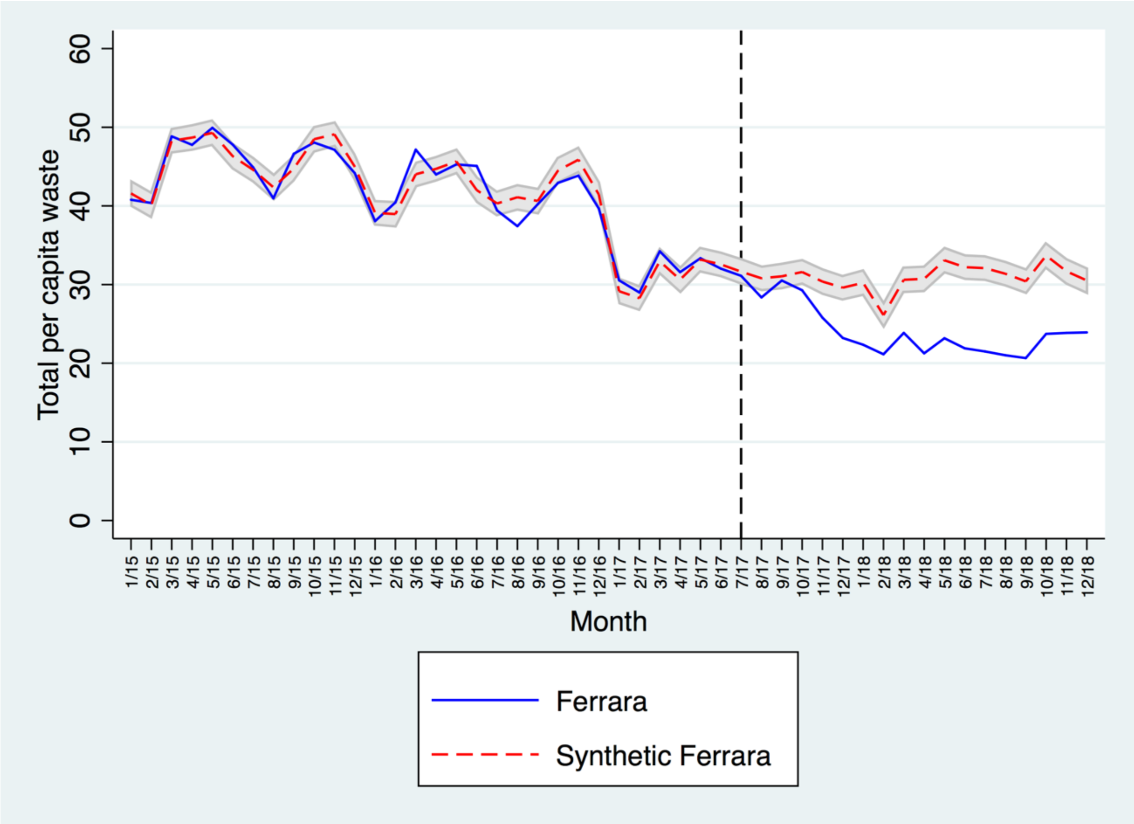


*Figure 6: Ferrara vs synthetic control, percentage of organic waste recycling on total waste.*

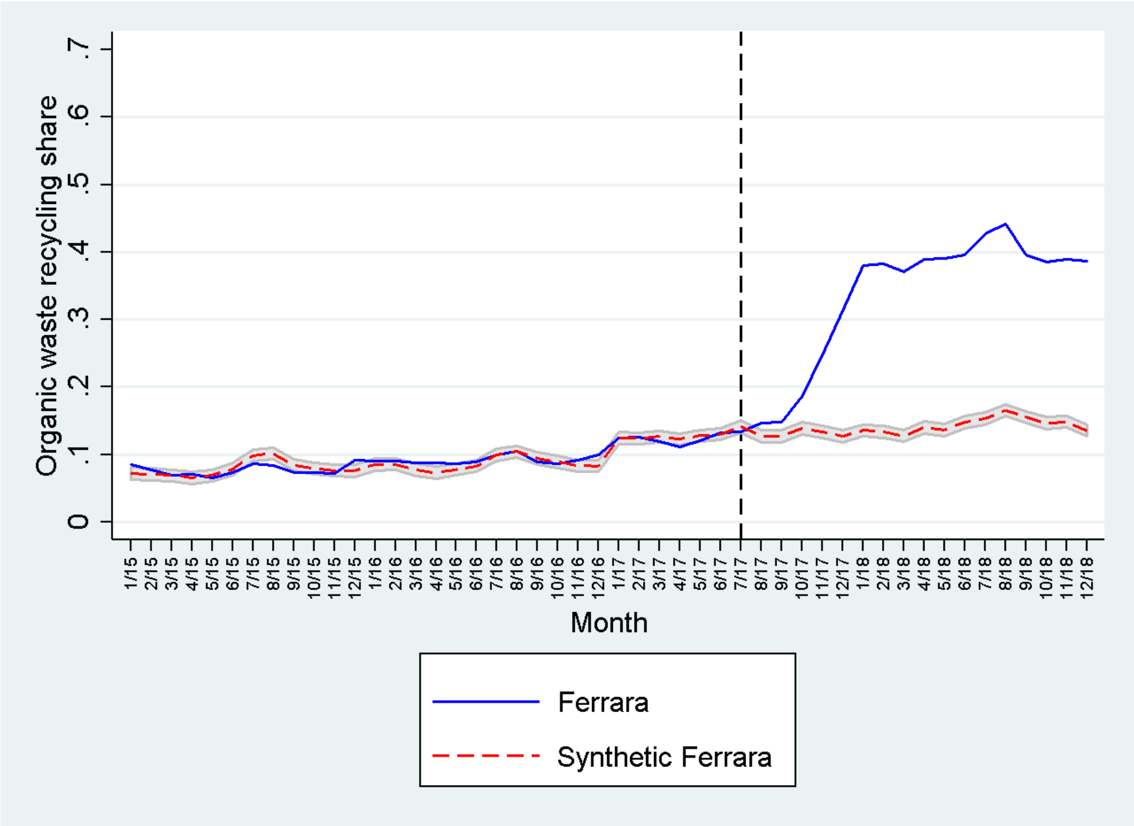



*Figure 7: Multimaterial waste recycling. Ferrara vs synthetic control.*

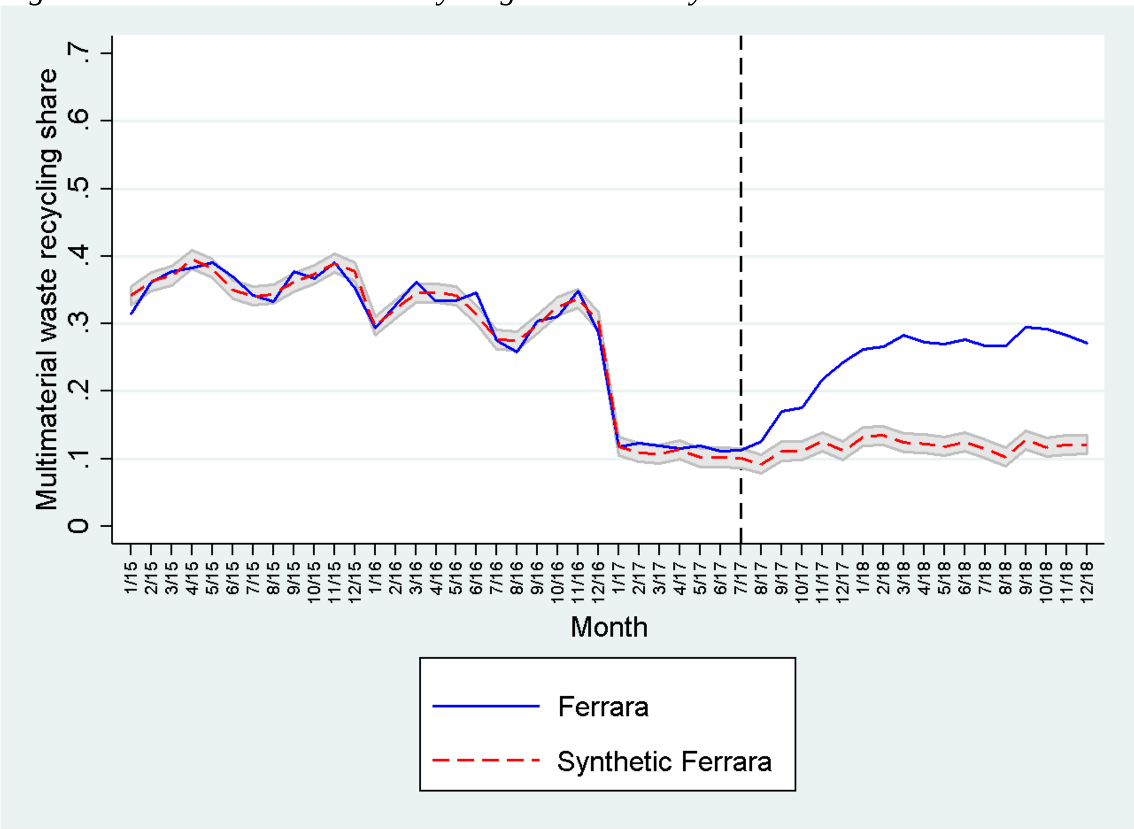


*Figure 8: Ferrara vs "restricted" synthetic control.*

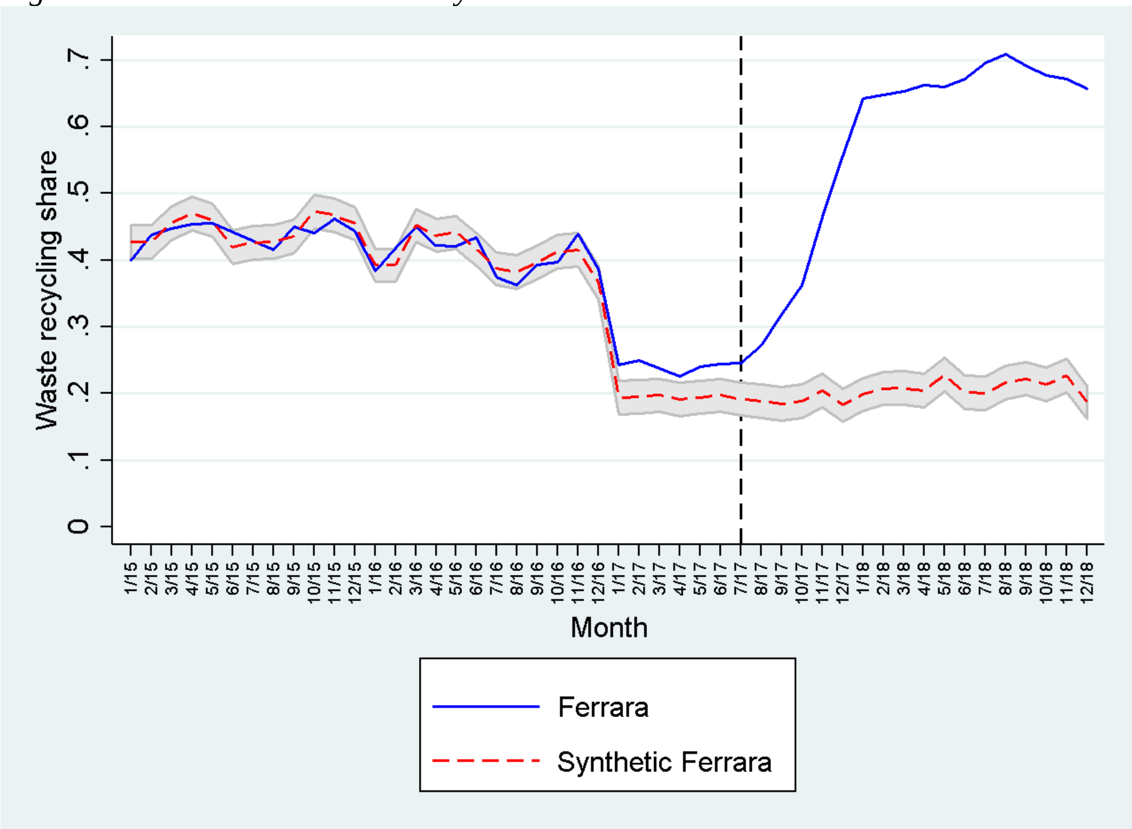



*Figure 9: RMPSE ratio and distance from Ferrara.*

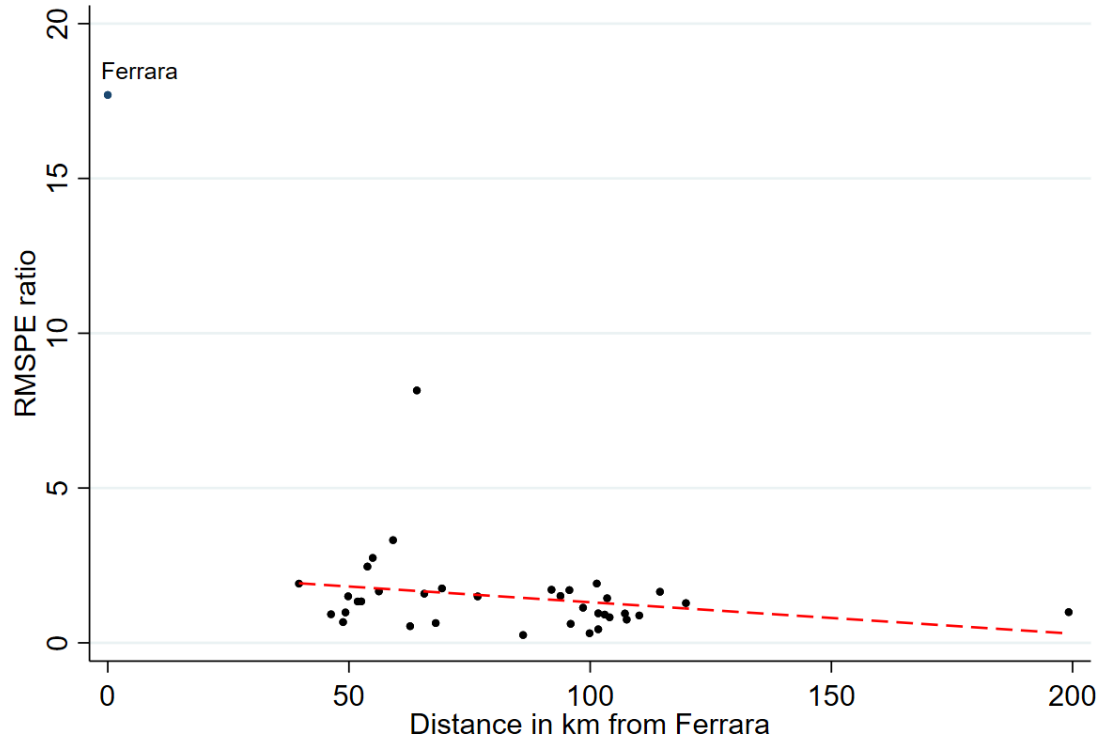


*Figure 10: Difference between real and synthetic Ferrara vs spatial placebos. Waste recycling share.*

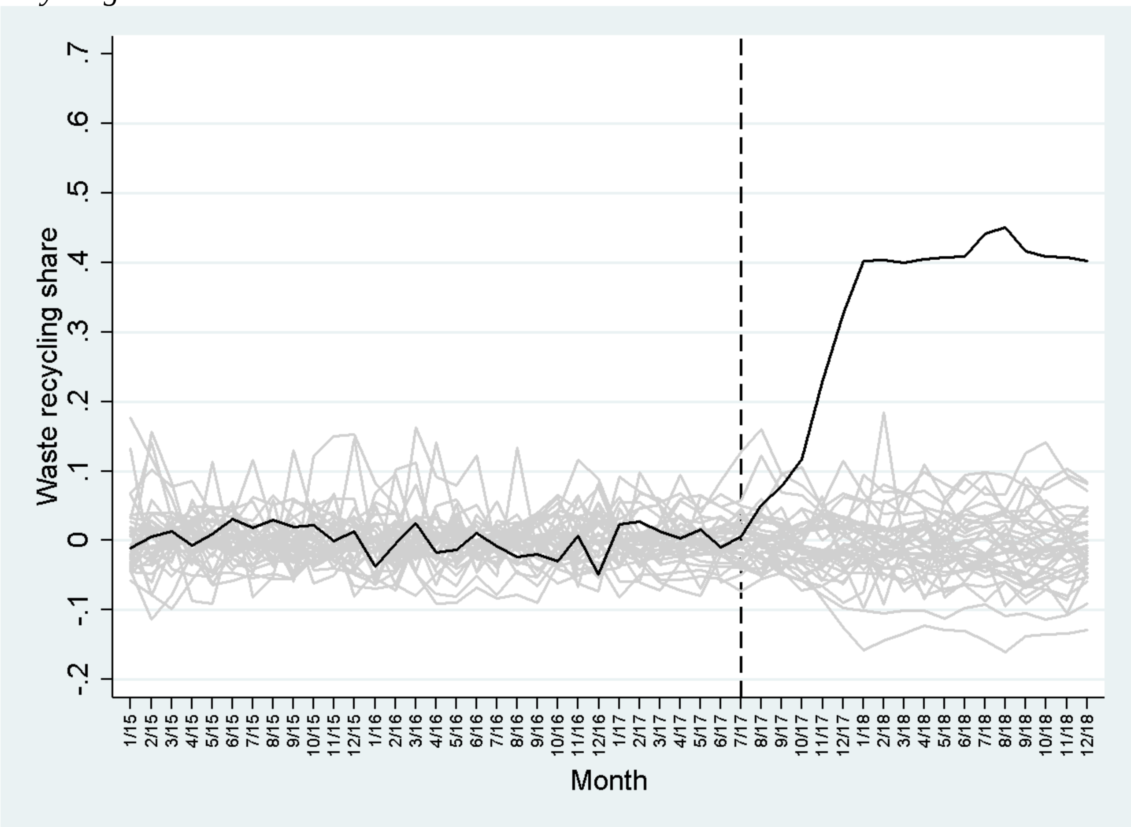
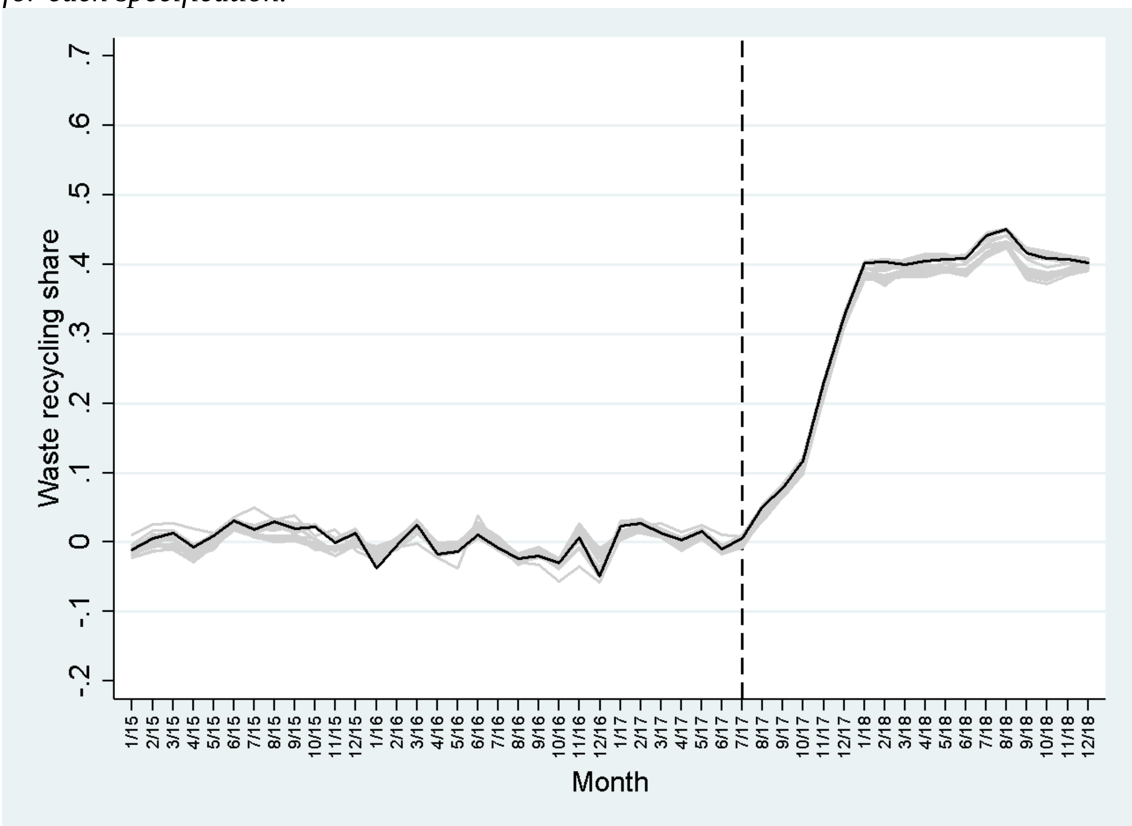



*Figure 11: Difference between real and synthetic Ferrara, excluding one municipality for each specification.*



# Appendix

## A - Description of the tariff including the PAYT system

The computation of the waste tariff with the PAYT is given by the following:

$$Waste\ tariff\ = ff\ +\ bvf\ +\ avf - A \qquad (1)$$

where (*ff*) is a fixed fee, (*bvf*) is a basic variable fee, (*avf*) is an additional variable fee and (*A*) is the allowance linked to socio-economic conditions of the user. The fixed fee (*ff*) covers fixed costs that are independent of the quantities of waste collected. In particular the fixed costs are allocated to each user according to the area in square meters of the house and the number of members in the family (column 2 – Table A1).

The basic variable fee (*bvf*) is also computed with reference to the number of family members and the area in square meters of the house, assuming a minimum supply of liters of waste by the family (column 3 – Table A1). The *bvf* is equal to the product of the minimum in col. 3 Table 1 times the price per liter (0.055 €).

The additional variable fee (*avf*) is the part of the waste tariff linked to the PAYT system. This fee is related to the quantity of unsorted waste, which exceed the threshold after which the fee is activated (column 3 – Table A1). Therefore, the amount for the *avf* is equal to the product between the liters of unsorted waste minus the minimum, and the unit cost of the service (in 2019 it was 0.055 € / liter).

[INSERT TABLE A1 AROUND HERE]

There are some allowances to the waste rate (*A*): there is only one affecting the incentive to produce waste recycling which is linked to the use of specialized waste collection centers. For each deposit of waste for recycling at a collection center, users can deduct from the waste tariff a certain fee based on the type and weight of the waste deposited (Table A2). There are also several other allowances for domestic users.[16]

[INSERT TABLE A2 AROUND HERE]

[16] For example an allowance if there is a baby in the family unit, or if the family usually uses medical-health devices under medical prescription (Ferrara City Council Resolution n.6/2014).

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

| *Number Household members* (1) | *Fixed fee (€/square meter)* (2) | *Minimum annual litres* (3) |
|---|---|---|
| 1 | 1.021 | 1,080 |
| 2 | 1.357 | 1,380 |
| 3 | 1.555 | 1,560 |
| 4 | 1.647 | 1,740 |
| 5 | 1.906 | 1,920 |
| 6 or more | 2.058 | 2,100 |

*Source: Municipality of Ferrara (2019).*

*Table A2: Incentive deduction 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 |
| Bulky waste | 0,05 |
| Mixed waste from small construction and demolition activities | 0,01 |

*Source: Municipality of Ferrara (2019).*

## B – Municipalities sample

| **Municipality** |
|---|
| 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 |
| Verghereto |