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The Intended and Unintended Consequences of Taxing Waste*

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Abstract

This paper investigates the economic and environmental effects of pay-as-you-throw (PAYT) waste programs. Using a newly constructed longitudinal dataset of Italian municipalities and a staked-by-event design, we obtain three main findings: (i) PAYT programs significantly reduce total waste production; (ii) they further decrease waste management costs and leave municipal finances unaffected; (iii) they generate positive spillover effects on pro-environmental behaviors not directly targeted by the program. Survey evidence suggests that PAYT increases environmental awareness and concerns of the population in treated municipalities.

JEL Codes: C21, H23, Q53

Keywords: Waste Management, Taxation, Difference-in-Differences, Variation in Treatment Timing

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1 Introduction

Municipal solid waste (MSW) represents the forth largest supplier to global emissions of greenhouse gases (Kaza et al., 2018).[1] In the United States, roughly 290 million tons of waste are produced each year, corresponding to 2.2 kg per person daily; although only 30% of the total waste production is recycled, its sustainable management and disposal saves each year over 193 million metric tons of carbon dioxide equivalent ($MMTCO_2E$), which is comparable to the emissions that could be reduced from taking almost 42 million cars off the road in a year (EPA, 2020).[2] Limiting the environmental impact of waste production thus represents a key policy challenge; over the last decade, several countries have promoted guidelines and policies that stimulate recycling, limit the use of land-filling, and incentivize responsible consumer behavior.[3] A potentially effective policy tool to achieve these goals is represented by "pay-as-you-throw" (PAYT) schemes, which apply the polluter pays principle by charging households on the basis of the amount of unsorted (non-recyclable) waste they produce (Schwartz, 2010). Compared to traditional fixed-fee waste taxation, this new approach creates a direct economic incentive to generate less waste.[4]

This paper estimates the economic and environmental consequences of the adoption of PAYT taxation schemes. For this empirical investigation, we use a newly-constructed longitudinal dataset of Italian municipalities over the 2010-2019 period; these data provide information on the year in which the program was introduced, the type and quantity of waste generated, municipality characteristics, municipal balance sheets indicators, and a set of outcomes not directly targeted by waste taxes, such as the distribution of high polluting vehicles and the use of renewable energy.

To establish causality, we exploit the staggered adoption of PAYT across municipalities over time. In 2010, this program was already operational in about 4% of Italian municipalities, while the rest of them had a traditional flat fee scheme that taxes households on the number of their members and the surface of their house. By the end of

[1] Municipal solid waste generally refers to trash and garbage generated by households.

[2] Europe presents relatively more sustainable figures, as the average European produces about 1.45 kg of waste per day; while the share of municipal waste recycled (i.e. material recycling and composting) is about 48% (Eurostat, 2021).

[3] Examples are the EU Waste Framework Directive 2008/98/EC and the National Framework for Advancing the U.S. Recycling System.

[4] According to the last estimates available, the share of population covered by PAYT schemes in the U.S. is about 25% (Skumatz and Freeman, 2006).

our observation period, the share of treated municipalities more than doubled (8.3%), accounting for almost 10.4% of the Italian population. Following the recent advances on two-way-fixed-effects models with variation in treatment timing and heterogeneous treatment effects (De Chaisemartin and D'Haultfœuille, 2021), we employ a stacked-by-event design. Our empirical strategy compares the outcomes of municipalities treated earlier – treated units – with those of municipalities treated later – or not-yet treated, our comparison units – before and after PAYT introduction (Cengiz et al., 2019; Vannutelli, 2021).

We obtain three key findings. First, PAYT introduction has a strong effect on waste avoidance, i.e. households' efforts to reduce total waste production: the adoption of PAYT significantly reduces the total amount of municipal waste by about 8% in the year of policy adoption and 9% over the following three years. As this program imposes a premium only on the non-recyclable component of waste, the estimated effect is almost entirely driven by a reduction in the production of unsorted waste, which decreases by 43%. We also find increases in specific recyclable materials, such as plastics and electronic items, although, the overall effect on sorted waste is not statistically significant.[5] Further, we show that the largest reduction in total and unsorted waste occurs in municipalities with larger shares of low-educated and low-income individuals, who may be more sensitive to the economic incentives created by the policy; at the same time, this last effect might suggest that acquiring specific environmental knowledge, e.g. how to better recycle or re-use items, can improve environmental outcomes among less educated households.

Second, PAYT introduction induces a sizeable reduction in waste management costs. While a decrease in total costs can be attributed to the lower generation of waste, we further find that the cost per kilogram of waste decreases by about 10% two years after the program is introduced. These results are consistent with insights from public economic theory: making households pay for the amount of public good they consume reduces free-riding and leads households to an efficient pattern of public good consumption (Oates, 1999). The reduction in unsorted waste may ultimately change treated municipalities' waste management production function (e.g. by reducing landfilling), leading

[5]Our results are robust to alternative estimators (Callaway and Sant'Anna, 2021), the inclusion of municipality characteristics (such as income, education, and support for the Green party) measured at baseline, and Conley standard errors, which capture potential dependence based on spacial proximity. We also test for pre-treatment differences in trends by applying the methods developed by Rambachan and Roth (2020).

to efficiency gains. Under the new tax scheme, the decrease in waste generation reduces municipalities' tax revenues, this loss is however fully compensated by the decrease in per capita expenditures (in particular those related to waste management), thus leaving municipal finances unaffected. This finding is particularly important since the financial uncertainty generated by the introduction of a PAYT scheme is often credited as one of the main obstacles for its adoption (IFEL, 2019).

Third, we estimate spillover effects of PAYT adoption on outcomes not directly targeted by the program, i.e. the unintended consequences of the program. Specifically, we find that the share of high-polluting cars decreases in treated municipalities by about 2% two years after the new tax is implemented and, in the same period, the share of electric cars increases by 14%. We further show that in PAYT municipalities the use of renewable energy, measured by the number of per capita photovoltaic systems, is about 9% larger than in non-treated ones. Survey evidence helps shedding light on the mechanisms behind the estimated effects: following the adoption of PAYT, respondents in treated municipalities become more concerned about the environment. This result suggests that the introduction of the program increased awareness of the environmental challenges local communities have to face. In line with this interpretation, we do not find any increase in illegal diversion, i.e. (illegal) dumping along roadsides, in bordering towns following the adoption of the policy.

The most common arguments against climate policies, such as carbon pricing, are about their effectiveness, cost, and distributional impact (Dechezleprêtre et al., 2022; Douenne and Fabre, 2022). This work shows that PAYT programs are particularly effective in reducing waste, ultimately generating sizeable environmental gains: using the Waste Reduction Model (WARM) developed by the U.S. Environmental Protection Agency, we calculate that the estimated 9% reduction in total waste production, following the implementation of the policy, is comparable to the emissions that could be reduced from taking almost 92,000 passengers vehicles off the road in a year. PAYT programs also improve the progressivity of the local tax system: switching from a flat-fee scheme to PAYT reduces the incidence of the waste tax on income from 1.5% to 0.95% for households in the bottom decile of the income distribution, while it increases it from 0.6% to 1% for those in the top decile (Messina et al., 2018). Our results further suggest that the largest reduction in waste, and thus in the amount of the tax paid, is among low-income and low-educated households, potentially mitigating concerns about the distributional consequences of the policy.

This paper adds to the debate on the role of economic incentives in promoting individual behaviors that benefit the environment, such as recycling and waste reduction (Kinnaman, 2006; Viscusi et al., 2011). As in previous studies that investigated the effects of PAYT on households' trash generation (Fullerton and Kinnaman, 1996; Kinnaman and Fullerton, 2000), we find that unit-based pricing significantly reduces waste disposal (Wright et al., 2019). The magnitude of the estimated effects is similar to the ones found for the Swiss Canton of Vaud (Carattini et al., 2018) and for a sample of Italian municipalities (Bucciol et al., 2015; Bueno and Valente, 2019; Valente, 2020).[6]

Our contribution to this growing literature in economics is three-fold. First, we add causal evidence on the effectiveness of PAYT in reducing waste outcomes by applying the recent advances on the difference-in-differences literature (De Chaisemartin and D'Haultfœuille, 2021) and by using a new dataset covering all Italian municipalities for a 10-year period. Second, by relying on unique data on municipal balance sheets, we are able to compute the effects of this policy on municipalities' revenues and costs (including waste management), as well as on the amount paid by households in waste taxes. Finally, to the best of our knowledge, this is the first paper that estimates positive spillover effects on environmental attitudes and outcomes not directly targeted by PAYT programs. This set of results is particularly important as they show that the monetary incentives created by PAYT schemes foster both extrinsic and intrinsic motivation of pro-environmental behavior (Benabou and Tirole, 2003, 2006; Dwenger et al., 2016).

Our paper is organized as follows. Section 2 describes the institutional setting and the data, Section 3 presents the empirical strategy, Section 4 presents the main results on the intended consequences of PAYT, while Section 5 on the unintended consequences. Section 6 concludes.

[6] Carattini et al. (2018) find that the introduction of a PAYT scheme in one Swiss Canton (Vaud) reduced unsorted waste by 40%. Bucciol et al. (2015) use municipal data from the Italian province of Treviso and estimate a positive effect of PAYT incentive schemes on the sorted-to-total waste ratio. Bueno and Valente (2019) use synthetic control method to assess the effects of Unit Pricing Systems on municipal solid waste in the Italian municipality of Trento, finding a reduction of 37.5% in unsorted waste. Valente (2020) explores price heterogeneity of PAYT schemes from a sample of Italian municipalities. Using machine learning techniques, this paper estimates a waste reduction of about 50% and positive social welfare effect for municipalities that adopted PAYT.

2 Institutional Background and Data Description

2.1 Waste Management in Italy

Solid waste management in Italy is financed through a municipal tax, which is a flat fee proportional to households' members and house surface (in m^2).[7] This source of revenue plays a fundamental role in local budgets, accounting for almost one fifth of municipal revenues (Messina et al., 2018). However, this tax scheme provides no incentives to sort or reduce waste production since households incur no direct costs for waste management services: the marginal cost for each additional unit of trash disposed is zero.

Over the last decade, Italy has witnessed an increase in the number of municipalities that adopt usage-pricing models, i.e. pay-as-you-throw taxation schemes (PAYT) for disposing unsorted waste, the *Tarip (Tari Puntuale)*.[8] These programs establish a direct link between costs and users' behaviors towards waste by internalizing the costs of waste disposal to their generators. Under PAYT, the costs of waste management are covered by a flat and a variable fee. The flat part, which can be identical for all users or determined according to specific parameters, such as households' members and house surface, covers the fixed costs of the service. The variable part, instead, is computed according to the amount of unsorted waste presented for collection by the household. The production of unsorted waste is generally measured in terms of frequency (number of emptying) or mass (Kg of waste).[9]

PAYT schemes are a policy tool highly supported by Environmental Agencies;[10] from

[7]The "modern history" of Italian waste taxation can be traced back to 1993, with the introduction of the "Tassa per lo smaltimento dei rifiuti solidi urbani" (TARSU). The TARSU was replaced in 1997 by the "Tariffa per l'igiene ambientale" (TIA). This was the first waste tax in Italy to use coefficients proportional to households' members and house surface to determine the amount of the tax. In 2013, the TIA was substituted by the "Tassa sui rifiuti comunali" (TARES), which was replaced one year later by the TARI (IFEL, 2019; Messina et al., 2018). In 2021 the average amount paid by Italian households in waste tax was 312 euros (ISPRA, 2021).

[8]The official introduction of the Tarip by the Italian legislation dates back to the law 147/2013 (IFEL, 2019), but different municipalities implemented PAYT schemes well before taking advantage of the CEE directive n. 442/1991.

[9]Waste is typically measured by weight or size. Households can be identified ex-ante, via prepaid bags, or ex-post, using electronic keys, tag on bags or bins with chip.

[10]For example, in the EU Directive 2018/851, PAYT schemes are explicitly cited among the economic instruments that member states should use in order to promote the application of the waste hierarchy. Also the US Environmental Protection Agency supports this approach to solid waste management (see https://archive.epa.gov/wastes/conserve/tools/payt/web/html/index.html).

a technical point of view, PAYT systems can be implemented in any municipality.[11] However, local authorities face four main challenges in the process of PAYT adoption. First, the unambiguous identification of individual users, which also requires the adoption of appropriate measures to deal with data privacy and confidentiality. Second, the measurement of waste streams at the individual user level (e.g. from door-to-door collection, street containers or at civic amenity sites), which may require adaptation of pre-existing infrastructures. Third, the definition of unit pricing that can effectively drive behavioral changes (Valente, 2020).[12] Forth, the engagement of citizens to ensure a correct understanding of the features of the scheme and their commitment. A strong public education and outreach plan is crucial to successfully implement a PAYT program. Residents need to be informed about the underlying rationale behind the PAYT and the structure of the new system. Specific information often provided by communities include: a discussion of their waste management goals and how PAYT will help meet them; the types and costs of all services offered; the means by which fees will be collected; the municipality's plans for enforcement of penalties for illegal diversion (e.g. no leakage into the municipal solid waste of adjacent authorities with no PAYT or into litter bins on the streets) and other forms of noncompliance.

2.2 Data

Waste Outcomes. The Italian National Environmental Protection Agency (Ispra) provides longitudinal data on waste production and management costs at the municipal level. These data cover the 2010-2019 period and offer extremely detailed information on waste generation by type (unsorted, sorted, and type of recycled item), waste costs per capita and per Kg of waste.[13]

This dataset, unfortunately, does not contain the information on whether and when a municipality adopted PAYT programs. We retrieved this information from IFEL (2019), a technical report drafted by the national association of Italian municipalities (ANCI), that provides the number of municipalities by region that had PAYT schemes as of the

[11] The technical requirements a municipality must follow in order to implement a PAYT taxation scheme in Italy are regulated by a national law, the Decreto Ministeriale 20/04/2017.

[12] As a rule of thumb of a number of investigations of the costs structure of waste management, it has been shown that the fixed-costs account for 60-80% of total costs, whereas the variable costs account for 20-40% (Bilitewski, 2008).

[13] Note that the information about costs is available from 2011 onwards. The datasets can be downloaded for free at the following website: `https://www.catasto-rifiuti.isprambiente.it/`.

31st of December, 2018. We then contacted each Regional Environmental Protection Agency (ARPA) asking the list and year of adoption of all PAYT municipalities in their region.[14]

Municipal Characteristics and Balance Sheets. Overall, our final sample is a fully balanced panel of $7,690$ municipalities observed for 10 years, 2010-2019.[15] We merged this dataset with municipality characteristics data from the 2001 Census of Italian Population, tax declarations from the Ministry of Economy and Finance, electoral results from the Ministry of the Interior, as well as shape-files of administrative boundaries of Italian municipalities. The restricted database *AIDA PA*, provided by Bureau van Dijk, gathers detailed and harmonized information on municipal governments' spending and revenues. In particular, these data include information on current revenues (tributary revenues, revenues from contributions and transfers, non-tributary revenues), current expenditures (mainly ordinary costs, such as personnel and purchase of goods and services), capital accounts expenditures (investments in public works, furniture, equipment, capital transfers, investments and conferments). They further provide specific information on waste expenditures, such as costs for the administration, inspection, collection, sorting, treatment and disposal of waste. The costs of transportation to treatment sites or landfills are also included.

Environmental Outcomes and Attitudes. This paper aims at uncovering potential spillovers from PAYT adoption on environmental outcomes other than waste. To this end, we employ data on the number and type of vehicles in each municipality. This dataset comes from the Automobile Club of Italy (ACI) and provides information on the number of cars classified by European emission standards over the 2011-2020 period.[16]

[14]We thank each ARPA office for their incredible support in this project. The response rate to our enquiries was 100%; however, some municipalities did not report the year of adoption. These are mainly municipalities of the autonomous region of Friuli-Venezia Giulia and of the province of Padua, representing about 14% of all PAYT municipalities that we observe in our data as of the end of 2019.

[15]As explained above, we drop from the sample all municipalities with missing year of adoption (115). We also dropped from the sample municipalities that, over the observed period, experienced a change in their administrative boundaries, i.e. they split in two different ones or they merge into a new municipality (these are 400, of which 24 that adopted PAYT between 2010 and 2019).

[16]The European emission standards are vehicle emission standards for exhaust emissions of new vehicles sold in the EU, EEA member states and the UK. The standards are defined in a series of European Union directives staging the progressive introduction of increasingly stringent standards. Automobile Club of Italy (ACI) data are available at this link:

Following EU standards, we classify as high-polluting vehicles those registered as Euro 0 (produced before 1992), Euro 1 (produced since 1992), and Euro 2 (produced between 1996 and 1999). The data also include information on the number of electric cars. As an additional environmental outcome, we collected data on the geographical distribution of solar panels across municipalities as of July 2022. These data contain information on each of the 891,937 photovoltaic systems installed in Italy, including their location and power capacity (in Kw); official reports (GSE, 2022) estimate that approximately 80% of them are for residential use.[17]

We finally employ survey data in order to test if PAYT adoption changes opinions regarding the environment and climate. In particular, we use IPSOS Polimetro that, among other things, interviewed respondents about the most important issues in their municipalities.[18] Among possible answers, there is "Environment and pollution", that we take as a proxy for environmental concerns. The data cover the period 2010-2014, for a total of about 1,800 respondents living in 126 PAYT municipalities.

2.3 Descriptive Statistics

Over the observation period, the share of municipalities that introduced PAYT more than doubled (from 4% to 8.3%). Figure 1 shows that in 2010 most of PAYT municipalities were located in Northern-East areas of the country, but they gradually spread in central and Northern-West areas. We observe 637 PAYT municipalities, which account for 8.3% of municipalities in our sample.

Table 1 compares summary statistics of waste outcomes - sorted (recycled), unsorted (mixed), and total municipal waste measured in Kg per capita - and key characteristics of non-PAYT and PAYT municipalities measured at baseline. Waste outcomes of PAYT municipalities significantly differ from those of non-PAYT municipalities. Differences between PAYT and non-PAYT municipalities largely capture regional differences and the North-South divide: treated areas are slightly richer and bigger than non-treated.

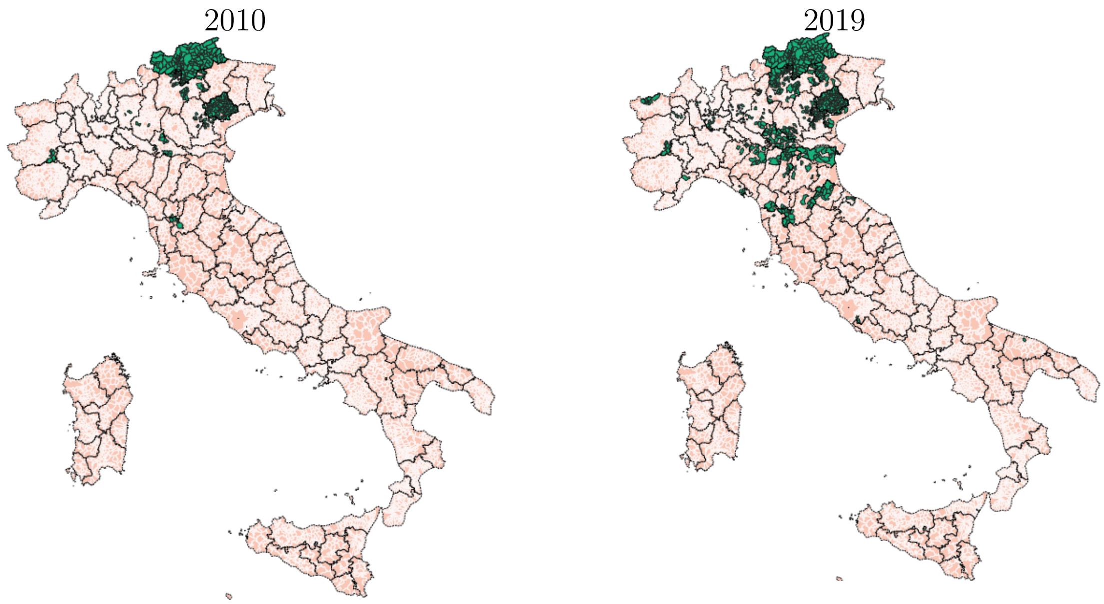
The decision to introduce PAYT schemes is not random, as it primarily depends on

https://www.aci.it/laci/studi-e-ricerche/dati-e-statistiche/open-data.html.

[17]These data are provided by the Gestore Servizi Energetici (GSE) and can be downloaded at the following website https://www.gse.it/dati-e-scenari/open-data.

[18]IPSOS is one of the largest public opinion polling companies in Italy http://www.ipsos.it/. The IPSOS Polimetro is a series of repeated cross-sections spanning from January 2010 to December 2014 that capture individual voters' political preferences and overall assessment of the economic, social, and political situation in Italy.

Figure 1: PAYT Municipalities in 2010 and 2019



Notes: The Figure plots Italian municipalities' administrative borders. Green shaded areas are PAYT municipalities in 2010 (left) and 2019 (right).

municipalities' recycling rates. This is not surprising as adopting PAYT municipalities are those where households are more used to recycle helps preventing policy adverse effects (Valente, 2020). Because of the non random introduction of PAYT, we focus on the *ever treated*, i.e. on PAYT municipalities only. In particular, we develop the analysis on the sub-sample of municipalities that introduced PAYT from 2010 onward, the first year in which we have information on waste outcomes. We thus exclude those who were never treated, i.e. most of municipalities in Southern Italy, and those who were treated before 2010. We end up with a balanced panel of 333 PAYT municipalities, covering a population of around 3.7 million people. Figure A.I in the Online Appendix shows that about half of PAYT adopters in our final sample are small municipalities, with less than 5,000 citizens.

Table 1: Descriptive Statistics, Non-PAYT vs PAYT Municipalities

	Non-PAYT (7053)		PAYT (637)	
	Mean	SD	Mean	SD
	(1)	(2)	(3)	(4)
Waste Outcomes 2010				
Total waste	477.800	524.591	476.958	374.910
Unsorted	303.545	333.810	192.195	191.922
Sorted	174.600	239.765	284.762	210.157
% Sorted	36.598	22.356	59.798	14.989
Population Census 2001				
Population	7213.978	41890.618	7686.724	14732.364
Population Density	284.473	648.858	275.219	429.457
Household Size	2.521	0.318	2.660	0.275
% School Dropouts	22.584	8.494	22.224	7.692
% Secondary and Tertiary Educated	36.061	8.631	35.393	8.316
Labor Force Participation	46.615	6.762	54.541	4.419
Unemployment	10.956	9.049	3.665	2.249
European Elections 2009				
Turnout	0.688	0.150	0.700	0.100
Green party (%)	0.029	0.030	0.033	0.040
Income p.c. (euro) 2010	19951.850	3103.649	21856.499	2700.826

Notes: The Table reports descriptive statistics for municipal waste outcomes (upper panel) and key municipal characteristics (lower panels). Waste outcomes - total municipal waste, unsorted waste (mixed waste) and sorted waste (recyclable waste) - are measured in Kg per capita. The share of sorted waste is measured as the ratio between sorted and total waste.

3 Empirical Strategy

Our identification strategy relies on the staggered adoption of PAYT across treated municipalities. In a standard set-up, we would estimate the following two-way fixed effect (TWFE) specification

$$Y_{mt} = \alpha_m + \nu_t + \delta Treated_{mt} + \varepsilon_{mt} \tag{1}$$

Where Y_{mt} is an outcome of interest measured at the municipality level, $Treated_{mt}$ is an indicator for whether municipality m has PAYT in place at time t, α_m are municipality fixed effects, ν_t are year fixed effects. δ is the coefficient of interest, capturing the average PAYT effect on PAYT municipalities (ATT).

However, recent advances in econometric theory cast doubt on the validity and robustness of the traditional TWFE estimator in settings with variation in treatment timing and heterogeneous effects across units or over time (Borusyak et al., 2021; Callaway and Sant'Anna, 2021; De Chaisemartin and d'Haultfoeuille, 2020; De Chaisemartin and D'Haultfœuille, 2021). Generally speaking, the TWFE estimator pools comparisons of units initially treated at different times, including comparisons of *late-treated* units with *early-treated* units, i.e. with units that already received treatment. These types of comparisons are referred to as the "forbidden ones", as the δ estimated from Equation 1 can only be interpreted as a weighted average of causal effects and some of these weights can be negative (Goodman-Bacon, 2021). In the Online Appendix B we provide evidence that, in our setting, these concerns are mitigated. We perform the Goodman-Bacon decomposition and show that the weight of the "forbidden comparisons" - late-treated *vs* early-treated - is relatively small and, more importantly, not negative (Table B.I and Figure B.I). However, in our main strategy we address these concerns and build a staked-by-event design, which compares municipalities that are treated earlier to municipalities that are treated later - treated *vs* not-yet-treated.

Following the most recent empirical literature (Cengiz et al., 2019; Vannutelli, 2021), we build a "rolling control group" by constructing our estimation dataset as follows.[19] First, we create a separate dataset for each of the years of PAYT introduction. In each of these datasets, municipalities that introduce PAYT in that year are considered treated, while municipalities that will experience the treatment in later years serve as comparison units. Second, in every dataset we create event-time indicators relative to the year of PAYT introduction. Municipalities that experience treatment in the last year, 2019, serve only as comparison units.

Our main estimation equation is:

$$Y_{mt} = \alpha_m + \nu_{pt} + \beta Treated_{mc} + \delta Treated_{mc} \cdot Post_{mt} + \sum_{s \neq -1} \gamma_s \cdot D^s + \varepsilon_{mt} \qquad (2)$$

where $Treated_{mc}$ is a dummy that takes value 1 if the municipality m is a treated municipality in the cohort c. This variable is not collinear with α_m, the municipality

[19] We replicated our main results using the Stata package *csdid* by Callaway and Sant'Anna (2021) All our findings are consistent with those estimated using this package. We show these results in Section 4.3.

fixed-effects, since the same municipality can appear both as treated and comparison unit. $Post_{mt}$ is a dummy equal to 1 for the years in which PAYT is in place. The D^s are a set of relative event-time indicators that take value 1 if year t is s periods before (if negative) or after (if positive) PAYT introduction. The inclusion of the relative event-time dummies allows to control for event-time trends that are not captured by the province-by-year fixed-effects ν_{pt}. Standard errors are clustered at the municipality level. This level of clustering also accounts for the repeated appearance of municipalities as treated and controls.[20] The parameter of interest in this static specification is δ, which measures the average PAYT effect on treated municipalities, using municipalities that have not introduced PAYT yet as controls.

To further investigate pre-trends and the dynamic evolution of the PAYT effect, we also estimate a non parametric event-study specification:

$$Y_{mt} = \alpha_m + \nu_{pt} + \beta Treated_{mc} + \sum_{k \neq -1} \delta_k \cdot D^k \cdot Treated_{mc} + \sum_{s \neq -1} \gamma_s \cdot D^s + \varepsilon_{mt} \quad (3)$$

In this specification, the coefficients of interest are the δ_k, measuring the change in the outcomes of treated municipalities k years before/after PAYT introduction, relative to pre-treatment year, compared to the change in outcomes of comparison municipalities, that have yet-to-be treated. We estimate treatment effects up to three periods from PAYT adoption.

Our main identification assumption is that treatment timing is randomly assigned.[21] Following Deshpande and Li (2019), we provide evidence that the timing of PAYT introduction is not predicted by a wide array of pre-treatment characteristics of the municipality.[22] Column (1) of Table A.I in the Online Appendix A shows that, once controlling

[20]Our results are robust to spatial HAC correction of standard errors (Conley, 1999; Hsiang et al., 2011), which allows for both cross-sectional spatial correlation and location-specific serial correlation.

[21]Figure A.II in the Online Appendix shows the evolution of PAYT adoption over time.

[22]Specifically, we estimate the following equation:

$$YearIntro_m = \alpha + X_{mt}^{'} \beta + \varepsilon_m$$

where $YearIntro_m$ is the year in which municipality m introduces PAYT and the vector X includes a wide range of pre-treatment municipality characteristics (population, density, household size, % of school dropouts, % of secondary and tertiary educated, labor force participation, unemployment rate) measured in the 2001 Census, average per capita income in 2010, electoral results from 2009 European Elections (turnout and vote for the Green party), controls for the municipality's electoral cycle and characteristics of the mayor as of December 2009 (education and political affiliation), and accounts indicators of the municipality (administration result and financial autonomy in 2010). Mayors' characteristics and for province fixed effects, no observable characteristics, such as income per capita, education, labor market indicators, and vote for the Green party, consistently predict the timing of PAYT introduction. We further add controls for the municipality's electoral cycle and mayor's characteristics (Column 2), as well as accounts indicators of the municipality (Column 3). These results suggest that the timing of PAYT introduction is random, even if the decision to introduce it or not may not be.[23]

4 The Intended Consequences of PAYT

4.1 Waste Outcomes

Figure 2 displays the effect of PAYT adoption on the production of total, sorted and unsorted waste, as estimated from equation 3. Right after PAYT is introduced, total waste declines by around 8%; this negative effect persists over the following years, while there are no statistically nor economically significant differences before the implementation of the program, thus supporting the common-trend assumption (Figure 2.a).

In Table 2, we quantify the average effect of PAYT over the three years after implementation, as estimated from equation 2.[24] Treated municipalities reduce the generation of total waste by 9% (370 tons, on average). This result is largely driven by a reduction in the production of unsorted waste, which declines by 43%, while we do find a positive, albeit small and not statistically significant, effect on sorted waste. By looking at Figure 2.b, we find that the effect on unsorted waste is significant and negative in the three years following the PAYT introduction; however, we detect small but significant differences in the year before the adoption of the new tax scheme. To mitigate concerns related to these pre-treatment differences, we apply the methodology developed by Rambachan and Roth (2020) and check that our results are robust to mild violations of the parallel trends assumption (see Figure B.II in the Online Appendix B).[25]

accounts indicators are missing for 2 and 12 municipalities, respectively.

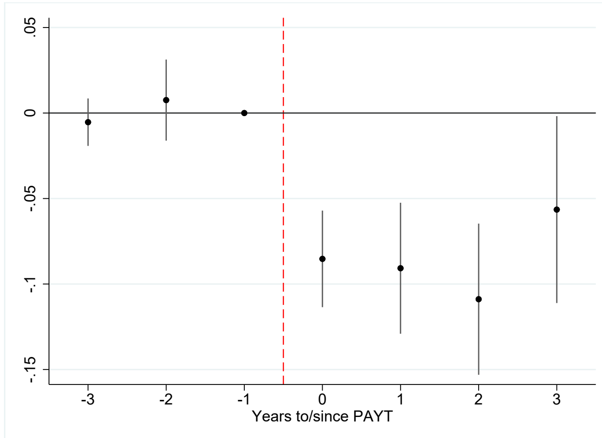
[23]We further test the validity of our identifying assumption by restricting the control group to municipalities that introduced PAYT schemes within 2 years after the treated group, as random timing is more plausible between municipalities that adopted the policy within the same period (Fadlon and Nielsen, 2021). This strategy, however, only allows us to estimate the contemporaneous effect of PAYT, i.e. at year $t+0$ and $t+1$. These results (Table A.III- Panel C) are quantitatively and qualitatively similar as the ones reported in Table 2.

[24]In the online Appendix B we compare our results with a standard TWFE model.

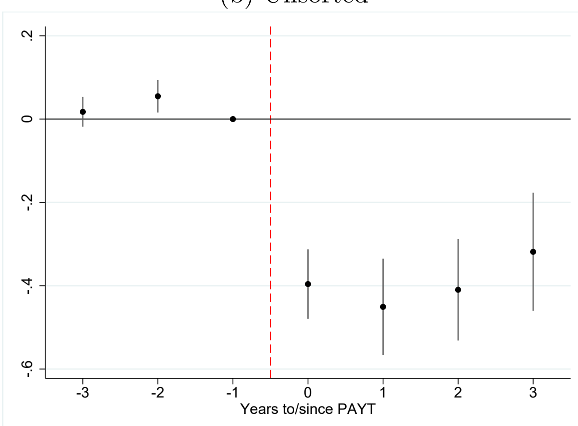
[25]One possible reason for the unsorted component of waste to decline already in period t-1 may be due to the adoption of trial periods before the new tax scheme is implemented.

Figure 2: PAYT and Waste Outcomes

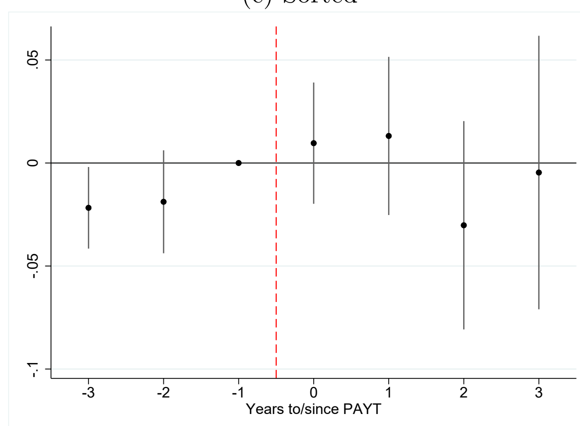
(a) Total



(b) Unsorted



(c) Sorted



Notes: The Figure displays estimates of the changes in waste outcomes - total waste production, unsorted and sorted waste - around the timing of PAYT introduction, as of equation 3. All regressions include municipality and province-by-year fixed effects. Standard errors are clustered at the municipality level. All dependent variables are expressed in log per capita. The vertical line indicates the timing of PAYT introduction.

Sorted waste seems to be largely unaffected by the program; however, when we disaggregate by type of of recycled material, the sign and the significance of the effect become quite heterogeneous. While there are positive effects of PAYT on plastics in the year of policy adoption and the following year, we do not find any significant effect on food-composting waste and glass (Table A.II and Figure A.III in the Online Appendix).[26]

[26]Specifically, we detect no significant changes in the production of food-composting waste, glass, metals, textile and miscellaneous inorganic. There are some positive effects on plastics in the year of policy adoption and the following year. There are also some positive effects on electronic items 3 years

Table 2: PAYT, Waste Production and Costs

	Waste Production			Costs	
	Total	Sorted	Unsorted	per Kg	per Capita
	(1)	(2)	(3)	(4)	(5)
$Treated \cdot Post$	-0.088***	0.014	-0.429***	-0.024	-0.059***
	(0.016)	(0.020)	(0.050)	(0.033)	(0.024)
Observations	10,212	10,212	10,212	4,231	4,231

Notes: The Table reports estimates of the average effect of PAYT introduction in post-treatment period on waste outcomes, as of equation 2. Column (1) reports results on total waste production, column (2) on sorted waste (recycled waste), while column (3) on unsorted waste (mix waste). Columns (4) and (5) use as a dependent variable the cost per Kg of waste and costs per-capita, respectively. All regressions include municipality and province-by-year fixed effects. Standard errors in parenthesis are clustered at the municipality level. Dependent variables in columns (1), (2), (3), and (5) are expressed in log per capita. The dependent variable in column (4) is expressed in log per Kg of waste.

One possible explanation for these effects is that household consumption declines following the introduction of PAYT; unfortunately, we cannot test if this is true as there are not data on consumption patterns at the municipal (or provincial) level. Another likely explanation is that households reduce *wastage*, e.g. food wastage, and increase efforts to reduce total waste through product reuse or sustainable purchases (second-hand, low-package, bulk or biodegradable products). The decline in total waste can also be explained by an improvement in waste disposal practices at the household level induced by educational campaigns that municipalities usually run around the timing of policy adoption.[27] Reassuringly, we find no evidence that households may start disposing their unsorted waste in the street following the new tax scheme. In Figure A.VII in the Online Appendix we show that, if anything, after policy adoption there is a reduction in the collection of street waste.[28]

To give a sense of the environmental impact of PAYT schemes, we rely on the Waste

after PAYT introduction. However, these positive findings are offset by negative impacts on recycled paper and paperboard and wood.

[27]See the information booklet for the correct disposal and recycling of garbage in a large Italian PAYT municipality (i.e. Ferrara): `https://www.gruppohera.it/documents/688182/3759703/Green%20Welcome.pdf/f0d77bbf-1d06-2236-8b8e-ed69a1c6b86c`.

[28]Note that this variable only includes recyclable street waste and is available since 2016. Unsorted street waste is included among the category unsorted waste.

Reduction Model (WARM) developed by the U.S. Environmental Protection Agency.[29] In particular, we are interested in a measure of the savings in terms of greenhouse gas (GHG) emissions that arise from our main finding. According to this model, a 370 ton reduction in total waste implies a decrease in GHG emissions equal to 1297,35 MTC02e; this is equivalent to the yearly emissions from 275 passengers vehicles in a municipality, which corresponds to around 92,000 passengers vehicles considering all PAYT municipalities under study.

4.2 Waste Management and Municipal Finances

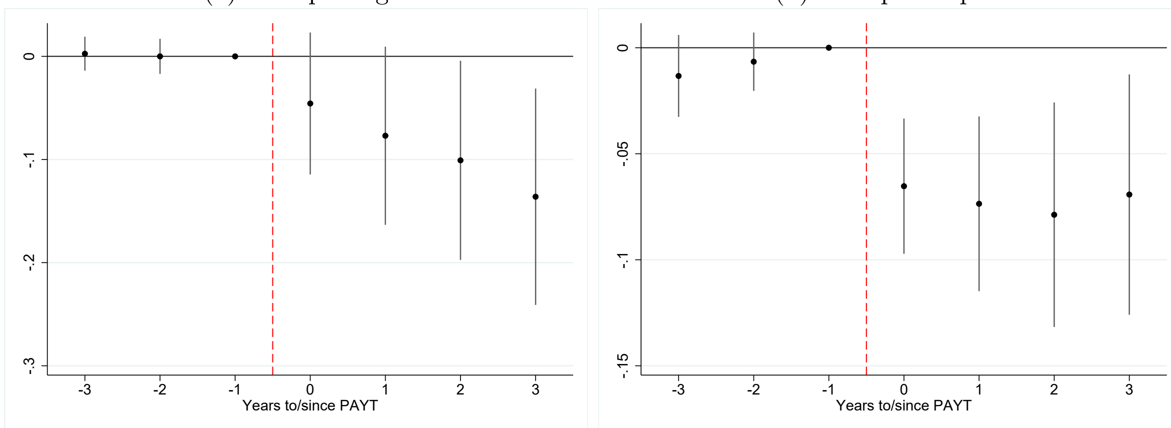
We then turn our analysis to the effects of PAYT on waste managements costs, measured by the Italian National Environmental Protection Agency (Ispra), and different financial indicators of treated municipalities from AIDA PA.

Waste Management Costs. Total cost of municipal solid waste management measured by Ispra consists of the costs for the management of sorted and unsorted waste, common costs, and costs of using capital. In particular, it is the sum of: i) costs for street sweeping and washing; ii) costs for waste collection and transport; iii) costs for waste treatment and disposal; iv) other costs inherent to the management of unsorted waste not included in the previous items; v) for sorted waste, costs of separate collection, treatment and recycling, net of proceeds from the sale of recycled materials and recovered energy of different materials; vi) common costs (e.g. administrative costs, general management costs); and vii) capital use costs (e.g. depreciation of mechanical tools for waste collection or street sweeping). Ispra collects information on waste management costs at the municipality level, although, for a small subsample of municipalities, we have information at the level of consortia of municipalities. We exclude these municipalities from our main analysis. This leaves us with 7,854 municipality-year observations, as opposed to the 8,473 observations that would include also municipalities in consortia.

[29] Online Appendix C provides a detailed description of the model.

Figure 3: PAYT and Waste Management Costs

(a) Cost per Kg (b) Cost per Capita

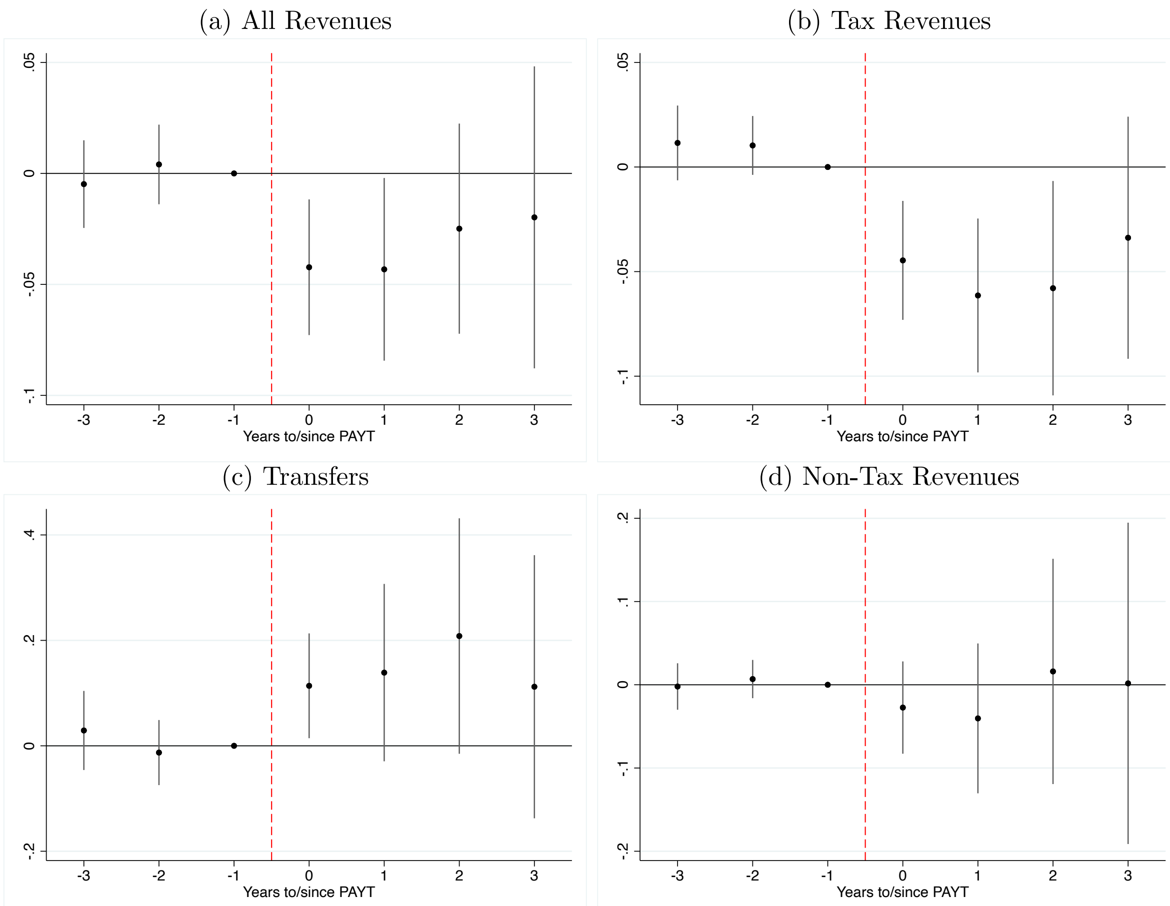


Notes: The Figure displays estimates of the changes in costs per Kg of waste and costs per capita around the timing of PAYT introduction, as of equation 3. All regressions include municipality and province-by-year fixed effects. Standard errors are clustered at the municipality level. All dependent variables are expressed in log. The vertical line indicates the timing of PAYT introduction.

On average, waste managements costs per capita are around 135 Euros, while costs per Kg of waste are around 26 Euros. PAYT introduction leads to a 6% reduction in costs per capita, and a 2.4% reduction, despite being not significant, in costs per Kg of waste, as shown in Table 2. Figure 3 displays the dynamic effects of PAYT introduction on waste costs per capita and per Kg of waste. Costs per capita drop at the time of policy adoption. We interpret this finding as a sharp response to the reduction of total waste production. Costs per Kg of waste, instead, start decreasing only two years after PAYT introduction. A potential explanation for this effect is related to changes in the production function of waste-management by municipalities; as PAYT schemes lead to a change in the composition of waste and improve households' disposal practices, the amount of waste that has to be cleaned and/or landfilled declines, thus reducing municipalities' cost of waste treatment and disposal.

Municipal Balance Sheets. One common argument preventing the adoption of PAYT programs is its cost and its impact on municipal finances. We further explore the impact of PAYT on municipal balance sheets. To this end, we exploit detailed information on municipal revenues and expenditures from balance sheets data covering the 2010-2018 period. In particular, we focus on ordinary revenues and expenditures; the first group includes revenues from taxes, transfers (mainly from central/regional governments), and non-tax revenues (e.g. profits from associated companies, from the provision of public services or from the rental of municipal real estate to third parties). Among total expenditures, there are different categories, such as current expenditures, which refer to municipalities' ordinary expenses (cost of personnel and the provision of municipal services), capital expenditures, and expenses for third-party services.

Figure 4: PAYT and Municipal Revenues



Notes: The Figure displays estimates of the changes in municipal revenues - all, transfers, tax and non-tax revenues - around the timing of PAYT introduction, as of equation 3. All regressions include municipality and province-by-year fixed effects. Standard errors are clustered at the municipality level. All outcomes are expressed in log per capita. The vertical line indicates the timing of PAYT introduction.

Figure 4, Panel (a), shows estimated effects on the log of per capita revenues, as of equation 3. While treated and control units have similar trends before the program was implemented, we observe a drop of about 4% in the two years after the treatment. Revenues then seem to converge to pre-treatment levels in the medium run. Table 3, Panel (a), indicates that the average effect in post treatment years is about 3.9%; to give a sense of the magnitudes, average annual per capita revenues are equal to 1,443 euros, the estimated effect then corresponds to an average reduction of 53 Euros of per capita revenues. Panels (b) to (d) of Figure 4 show that the reduction in municipal revenues mainly occurs from a decline in tax revenues, which combine waste taxes (*TARI*), property tax (*IMU*), and additional income tax (*IRPEF*); as households reduce their waste production, the amount of waste tax paid to the municipality is lower when PAYT is introduced. This decline in tax revenues is only partially compensated by increased transfers from the central or regional governments in the year of policy adoption.[30]

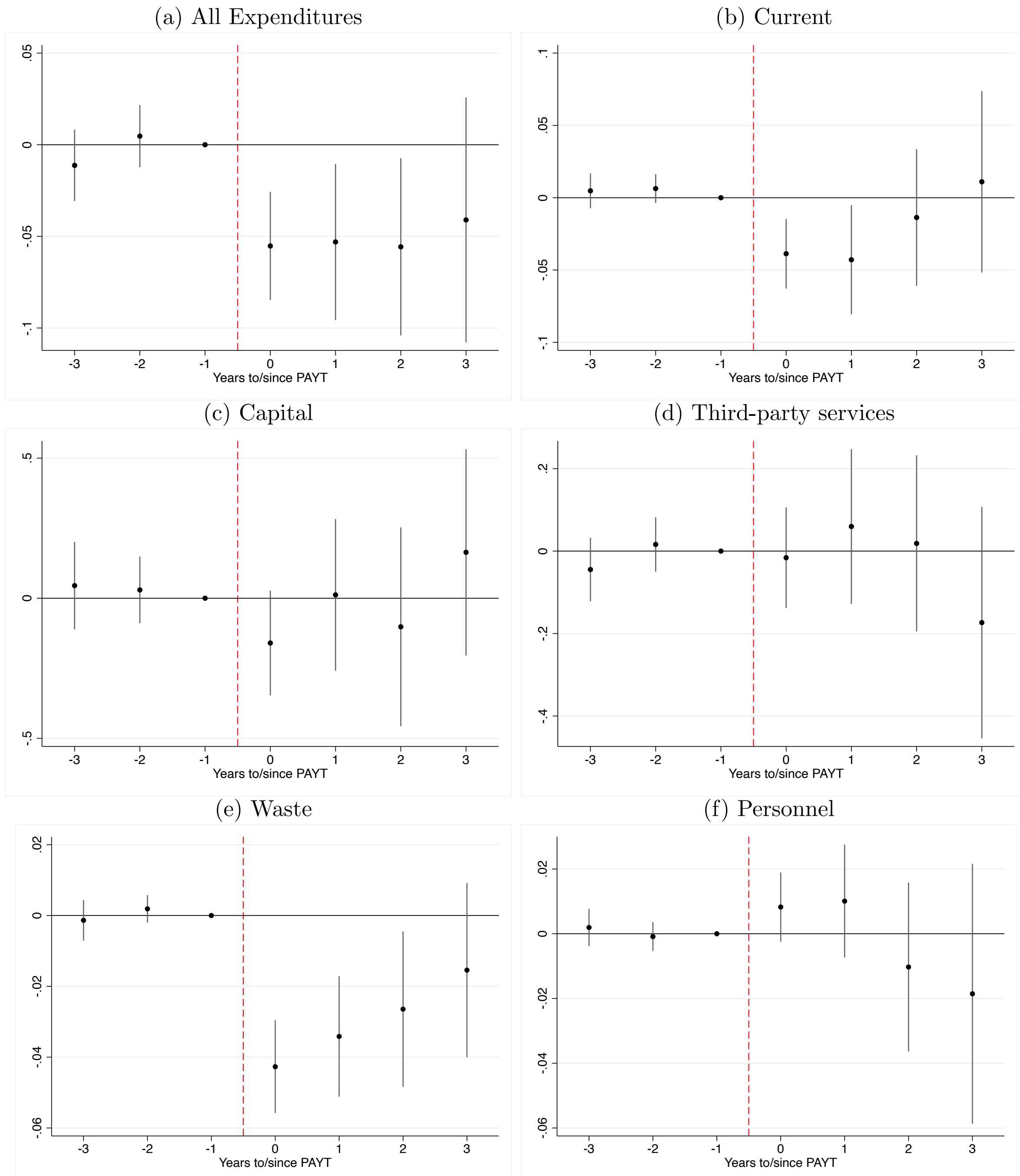
Table 3: PAYT and Municipal Finances

	(1)	(2)	(3)	(4)
Panel A: Revenues	All	Tax	Non-Tax	Transfers
$Treated \cdot Post$	-0.0392**	-0.0579***	-0.0232	0.1260*
	(0.0176)	(0.0173)	(0.0437)	(0.0760)
Observations	10,616	10,616	10,616	10,616
Panel B: Expenditures	All	Current	Capital	Third-party
$Treated \cdot Post$	-0.0534***	-0.0338**	-0.0855	-0.0055
	(0.0174)	(0.0165)	(0.1173)	(0.0749)
Observations	10,616	10,616	10,430	10,496

Notes: The Table reports estimates of the average effect in post-treatment period, as of equation 2. All regressions include municipality and province-by-year fixed effects. Standard errors are clustered at the municipality level. All dependent variables are expressed in log per capita.

[30]This effect is explained by central or regional government transfers that treated municipalities are eligible to receive when implementing PAYT programs.

Figure 5: PAYT and Municipal Expenditures



Notes: The Figure displays estimates of the changes in municipal expenditures around the timing of PAYT introduction, as of equation 3. Outcomes in Panels (a) to (d) are expressed in log per capita; while those in Panels (e) and (f) as share of current expenditures. All regressions include municipality and province-by-year fixed effects. Standard errors are clustered at the municipality level. The vertical line indicates the timing of PAYT introduction.

Similarly, we observe a 5% drop in current expenditures in the two years following

PAYT adoption, Figure 5. Table 3, Panel (b), shows that the average reduction in post treatment periods is about 5.3%. The average annual per capita spending is equal to 1,439 euros, thus PAYT introduction leads to an average reduction of 75 euros of expenditures per capita. By disentangling the different expenditure categories, we find that the only significant reduction is estimated for current expenditures. The data further allow us to look at the share of current expenditures related to waste management, Panel (e) shows an average reduction of about 3.5 percentage points in the post-treatment period (a 34% reduction at the baseline).

This is in line with the results on waste management costs observed in Figure 3 and it is not due to cuts in other types of expenditures, such as current expenditures in personnel, i.e. Panel (f). Overall, the policy does not seem to impose a high cost on municipalities, rather there is a positive revenues-to-expenditure ratio; however, this reverts back to pre-treatment levels after three years since policy implementation.

To summarize, we document four main intended consequences of PAYT introduction. First, a large and persistent drop in the production of total waste (-9%). Our result on waste avoidance can be translated into a reduction of GHG emissions equivalent to the yearly emissions from 92,000 passenger vehicles. Second, a 43% drop in unsorted waste. Third, a significant and persistent reduction in total waste management costs (the sum of the costs for the management of sorted and unsorted waste, common costs, and costs of using capital). In particular, waste management costs per capita decrease by 6%. Fourth, we do not detect significant impact on municipal finances. Both current revenues and expenditures decrease in the first years after PAYT adoption, to catch-up with pre-policy levels thereafter.

4.3 Heterogeneity

Education and Income. We investigate heterogeneous effects by citizens' educational and income level. Intuitively, one would expect largest effects in municipalities with larger shares of low-educated and low-income individuals, since they may be more sensitive to the economic incentive created by the policy. At the same time, better educated municipalities are more likely to produce better waste outcomes. Indeed, it has been shown that education is a good predictor for responsible environmental behaviors (Meyer, 2015).[31] If better educated citizens already had a good knowledge about waste

[31] Individuals with higher education are more likely to recycle, purchase more organic products, and are more engaged in water and energy saving behaviors (Ferrara and Missios, 2005; Poortinga et al.,

prevention and recycling before PAYT implementation, then we should not expect to observe big treatment effects in municipalities with a high share of highly educated citizens. Figure A.IV in the Appendix displays estimates of equation 3 on total waste (panel (a)), unsorted waste (panel (e)), total municipal revenues (panel (i)), and expenditures (panel (m)) in which we interacted the post-treatment indicator with a set of dummies indicating the percentiles of the municipal share of individuals with at least secondary education.[32] Results show that treatment effects are significantly larger in municipalities with a low share of secondary and tertiary educated individuals. The treatment effect for total waste is about 10 percentage point larger for municipalities falling within the 10th percentile of the distribution of education. The patterns are very similar when we estimate heterogeneous effects by municipal income, measured at baseline (panels (b), (f), (j) and (n)). These findings are consistent with two complementary channels; first, as the cost of one additional unit of waste is the same for every household independently of their income, the economic incentive in reducing unsorted waste generated by the policy should be larger for low-income households, which have tighter budget constraints. Second, the acquisition of environment- and waste-specific knowledge at the time of the implementation of the policy may be particularly effective for low-educated households, which eventually improve their waste disposal practices. While the first mechanism may raise concerns about the fairness of the policy, providing citizens with useful information on how to correctly manage waste may further decrease their garbage production and ultimately the amount of waste tax paid to the municipality.

Tax compliance and population. In a second set of regressions, we investigate how the estimated effect on waste production differs depending on the municipality's level of tax compliance and size, measured by its population. As a proxy for tax compliance, we collected information on the municipal share of evasion of Italian television license fee.[33] We expect to find bigger treatment effects in municipalities with higher level of tax compliance. As in the previous exercise, we estimate the interaction between the post-treatment indicator and the percentiles of the distribution of the tax evasion. Panels (c) and (g) of Figure A.IV show that treatment effects are indeed larger in municipalities

2004).

[32] This variable comes from the 2001 Italian Census of the general population.

[33] All owners of television equipment or any other equipment able or adaptable to receive television are required by Italian law to have a television license. The license is partly used to fund the Italian public server broadcaster RAI. The annual cost of the license fee is around 100 Euros. The data are freely available at the following website http://www.twig.pro/canone-rai-la-mappa-dellevasione/.

with lower shares of evasion of the license fee. In particular, the PAYT effect on unsorted waste is almost twice as large in most compliant municipalities, relative to the least compliant.

As a final test, we estimate heterogeneous effects by population size. The management of waste collection and measurement necessary for PAYT adoption should be more easily implemented in smaller municipalities. Panels (d), (h), (l) and (p) of Figure A.IV show that treatment effects are not very different depending on the size of the municipality, although slightly larger in smaller municipalities.

4.4 Robustness checks

Inclusion of Additional Controls. We check the robustness of our main findings to the inclusion of pre-treatment municipal characteristics interacted with year dummies. This allows us to control for differential time trends in the outcome of interest depending on baseline characteristics of the municipalities; these variables are the ones reported in Column (1) of Table A.II: population (in log), density, average household size, the share of school dropouts and individuals with secondary or tertiary education, labor force participation, unemployment, per capita income (in log), voter turnout and vote share of the Green party in 2009. Our main results are essentially unaffected by the inclusion of these control variables (Table A.III in the Online Appendix).

Conley Standard Errors. Another common concern in this type of empirical investigation, which uses both geographical and time variation, is that the error term could be correlated across neighboring municipalities. To account for this type spatial correlation, we use Conley standard errors, which recognize potential dependence based on spatial proximity. Results are highly robust to this standard error correction and are shown in Table A.III in the online Appendix.

Callaway and Sant'Anna Estimator. We check the robustness of our main findings using the estimator proposed by Callaway and Sant'Anna (2021) (CS thereafter). CS suggest that when treatment effect differs by treatment groups (i.e. different municipalities that introduce PAYT in different years) and over time, there are numerous causal parameter of interest: the ATT is a function of treatment group g, where a group is defined by when units are first treated, and time period t. CS call these causal parameters group-time average treatment effects and propose a two-step estimation strategy with a bootstrap procedure to conduct asymptotically valid inference that adjusts for autocorrelation and clustering. The methodology also allows for the estimation of aggregate treatment effects by relative event time. The main difference between CS approach and our approach is that stacked regression uses OLS to weight treatment effects, while CS does not. Results of estimations using CS methodology are shown in Figure A.V in the Online Appendix. Once again, our main findings are robust to this alternative estimator.

Changes in the Composition of the Treated and Control Group. Another concern is related to changes in the composition of the treated and control group at the time of the treatment. For instance, it could be that high-polluters leave and low-polluter arrive in PAYT municipalities following the new tax scheme. In order to discard this potential issue, we use data on municipalities' demographic balance and migration rates over the 2010-2019 period. Estimates of the PAYT effect on these variables is essentially null, as displayed in Figure A.VI in the Online Appendix.

Parallel Trends Assumption. Figure 2.b displays a small positive pre-trend in unsorted waste two years before policy implementation. The framework proposed in Rambachan and Roth (2020) allows us to test the robustness of our results to possible violation of the parallel trends assumption.[34] Figure B.II in the Online Appendix shows that results for unsorted waste are robust to possible violations of the parallel trend assumption.

5 The Unintended Consequences of PAYT

5.1 Pro-environmental Behavior and Attitudes

Monetary incentives are believed to be particularly effective tools in driving people's behavior; for this reason, most of the environmental policies are designed to target individual economic concerns (Bolderdijk et al., 2013). At the same time, several studies show the importance of non-monetary considerations in influencing individuals' pro-social and pro-environmental behavior (Andreoni, 1989; Benabou and Tirole, 2003, 2006; Taufik et al., 2015).

[34] Results are obtained using the R package "HonestDiD", written by these same authors. Link:https://github.com/asheshrambachan/HonestDiD/. Detailed methodological notes can be found in Online Appendix B.

One major concern related to PAYT policies is that the economic incentives they create may ultimately crowd-out intrinsic motivational basis of pro-environmental behavior. In particular, these programs may generate negative spillovers on environmental behaviors that are not rewarded by the new tax scheme. This may ultimately lead to a "rebound effect", where environmental savings coming from a reduction in total waste are offset by the increase in other actions detrimental for the environment (Berkhout et al., 2000). At the same time, these programs may increase environmental awareness when implemented. There is plenty of anecdotal evidence that environmental campaigns, focusing on climate change challenges, are introduced when PAYT is implemented in order to justify the new taxation scheme.

We thus estimate the extent to which PAYT adoption affects non-targeted environmental outcomes and attitudes of treated municipalities. In particular, we combine our dataset with data on the stock of electric and polluting cars at the municipality level, on the number and power capacity of solar panels in Italian municipalities, and with individual attitudes towards the environment.

PAYT and Electric vs Polluting Vehicles. According to the International Energy Agency, transport has the highest reliance on fossil fuels of any sector and accounts for 37% of CO2 emissions from end-use sectors. The most preferable scenario, which contemplates a net zero emission by 2050, requires transport sector emissions to fall by 20% in less than a decade. Passenger road vehicles are the first contributors to the CO2 emissions of the transport sector. Globally, the emissions of CO2 due to passenger vehicles increased from 2.5 in 2000 to 3.6 in 2018, a 30% raise.[35] Electric vehicles (EV) create a lower carbon footprint over the course of their lifetime than do cars that use traditional, internal combustion engines.[36]

The type of cars individuals own represents a good proxy for their attitudes towards the environment. Specifically, we use information on municipalities' stock of vehicles by the level of emissions they generate and estimate if PAYT adoption affects the share of electric cars and the share of high-polluting cars (Euro 0, 1, and 2) in treated municipalities.[37]

[35] https://www.iea.org/topics/transport.

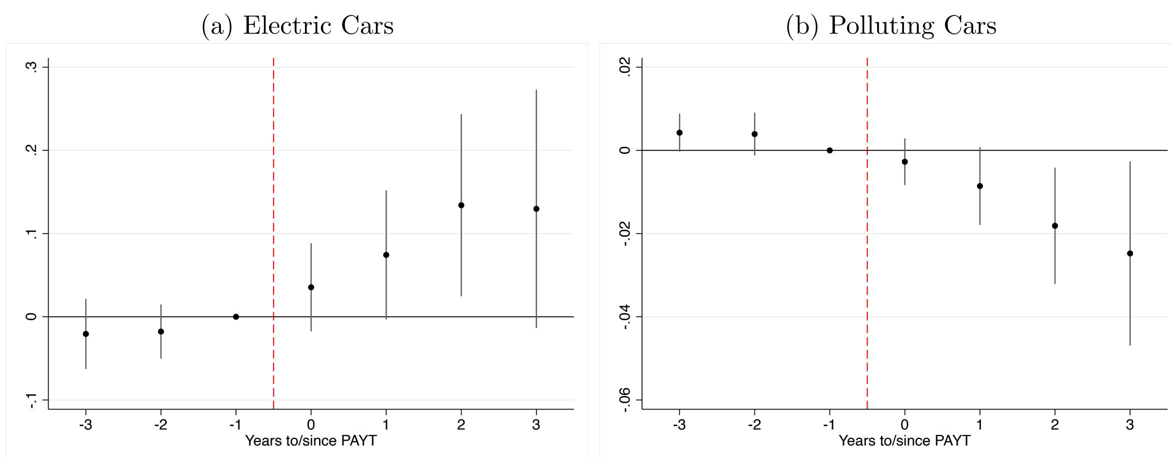
[36] Although the battery and fuel production for an EV generates higher emissions than the manufacturing of comparable cars with internal combustion engines, those higher environmental costs are offset by EV's superior energy efficiency over time (MIT-Energy, 2019).

[37] According to Eurostat, Italy is, after Luxembourg, the European country with the largest numbers of passenger road vehicles, given its population. In 2019, Italy counted 663

Figure 6 plots estimates of equation 3 where the dependent variable is the log share of electric (Panel a) and polluting vehicles (Panel b) around the implementation of the policy. The share of electric cars in Italy is still quite low, around .05% in 2019. We observe an increase of about 10% after the policy is introduced and of about 15% in the following years. We find the opposite pattern for the (log) share of polluting cars, which decreases by about 2% in the post treatment years.

On average, PAYT adoption is associated with a 8% increase in the share of EV, and with a 1% reduction in the share of most polluting cars. Note that these results are unlikely to be due by the various national or regional subsidies for the purchase of less-polluting cars as all our regressions include control for province by time specific shocks.

Figure 6: PAYT and Municipalities' vehicles



Notes: The Figure displays estimates of the changes in the type of cars by level of emissions around the timing of PAYT introduction, as of equation 3. All regressions include municipality and province-by-year fixed effects. Standard errors are clustered at the municipality level. Outcomes are expressed as the log share of total vehicles. The vertical line indicates the timing of PAYT introduction.

Renewable Energy. To corroborate the results presented above, we further investigate the effect of the PAYT on the use of renewable energy in treated municipalities. We thus employ data on the number and power capacity of solar panels across Italian municipalities. Photovoltaic energy became increasingly popular between 2005 and 2015, mainly because of the government incentives that were devised to encourage their use

cars per thousand inhabitants, versus 574 in Germany, 519 in Spain, and 482 in France. https://ec.europa.eu/eurostat/web/products-eurostat-news/-/edn-20210922-1 by Italian households: almost 80% of solar systems in Italy are for residential use (GSE, 2022). The decision to switch to solar energy has both economic and environmental effects: for every household moving to solar energy there would be a reduction of 7.7 tons in toxic greenhouse gases (Wiser et al., 2016); moreover, a fully performing solar-powered system could generate savings of about 1,500 euros per year (Otovo, 2022).

The number of solar systems in a municipality thus represents a good measure of environmentally friendly behavior. Unfortunately, the data only refer to 2022, we thus employ a simple OLS specification in which the dependent variable is the per capita number of photovoltaic systems and the treatment variable is a dummy indicating if the municipality has implemented (at any point in time) PAYT schemes.[38] Regression results are shown in Table 4, the specification in Column (1) only includes province fixed effects: treated municipalities have 9% more solar panels than non-treated.

Table 4: PAYT and Solar Energy

	Number		Power	
	(1)	(2)	(3)	(4)
Treated	0.0901***	0.0899***	0.2427***	0.1464**
	(0.0272)	(0.0258)	(0.0759)	(0.0700)
Province FE	Yes	Yes	Yes	Yes
Controls	No	Yes	No	Yes
Observations	7,386	7,386	7,386	7,386

Notes: The Table reports OLS estimates of the effect of adopting PAYT on the log per capita number and the log per capita power of photovoltaic systems installed across Italian municipalities as of 2022. Controls in columns (2) and (4) include 2001 Census variables (population, density, household size, % of school dropouts, % of secondary and tertiary educated, labor force participation, unemployment rate), average per capita income in 2010, electoral results from 2009 European Elections (turnout and vote for the Green party). Standard errors are clustered at the county level.

We add a full set of municipality characteristics in Column (2): results are only slightly affected both in magnitude and significance. In Columns (3) and (4) we use as dependent variable the per capita (nominal) power capacity: results show that in PAYT municipalities power capacity is 14.6% higher than non-PAYT ones. Although purely descriptive, these results are consistent with previous findings on positive spillovers of

[38] The treatment group is composed by the 333 municipalities that adopted PAYT over the 2010-2019 period; the control group is then represented by non-PAYT municipalities (7,053).

the policy on non-targeted environmental outcomes.

Environmental Attitudes. In order to further analyse if the estimated effects above arise from a change in attitudes towards the environment, we explore Survey data from Ipsos Polimetro over the 2010-2014 period. We focus on the question "What is the (first/second most) important problem today in your municipality?". We classify respondents as environmentally concerned if they choose, among different options, the answer "Environment and Pollution". Overall, we have a sample of 1,193 individuals interviewed between January 2010 and December 2014. Consistently with previous sample selection, we only retained respondents living in municipalities that introduced PAYT between 2010 and 2014.

OLS regression results, which controls for demographic and socio-economic characteristics of respondents, show that, after the treatment, respondents more than double the probability of reporting concerns about the environment. We also explore if individuals worry more about other non-related issues in the post-treatment period. There is no sizeable nor statistically significant effects when looking at concerns such as crime levels, road traffic, political stability or public transports.

Table 5: PAYT and Individual Attitudes

	(1) Environment	(2) Crime	(3) Traffic	(4) Politics	(5) Transports
PAYT	0.0653**	0.0106	-0.0788	-0.0363	-0.0159
	(0.0270)	(0.0425)	(0.0521)	(0.0373)	(0.0232)
Baseline	0.0259***	0.0527***	0.2488***	0.1050***	0.0451***
	(0.0095)	(0.0149)	(0.0183)	(0.0131)	(0.0082)
Observations	1,063	1,063	1,063	1,063	1,063

Notes: The Table reports estimates of a OLS model in which an indicator for PAYT adoption is regressed on different indicators capturing answers to the question "What is the most important problem today in your municipality?". Column (1): Environment and Pollution. Column (2): Crime. Column (3): Traffic. Column (4): Politics. Column (5): Transports. All regressions include controls for age, gender, household composition, education, year, and municipality. Standard errors in parenthesis are clustered at the municipality level.

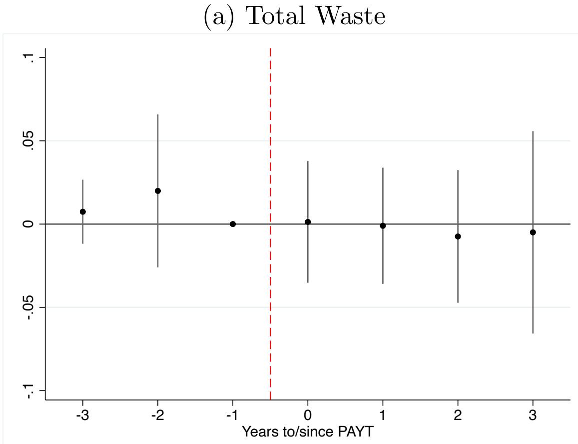
5.2 Spatial Spillover Effects

One of the most relevant drawbacks of the introduction of a PAYT scheme is the so-called "waste tourism", i.e. the illegal discharge of unsorted waste in neighboring municipalities. When a municipality imposes a cost on the production of unsorted waste, citizens of that municipality may dispose their garbage in other neighboring municipalities that are not subject to PAYT. To estimate whether this potential negative spillover effect arises when PAYT is introduced, we first define for each (pivotal) municipality in our sample the set of bordering municipalities. We then run equation 3 where the dependent variable is the average production of street and total waste in bordering towns and the treatment refers to the adoption of PAYT in the pivotal municipality.

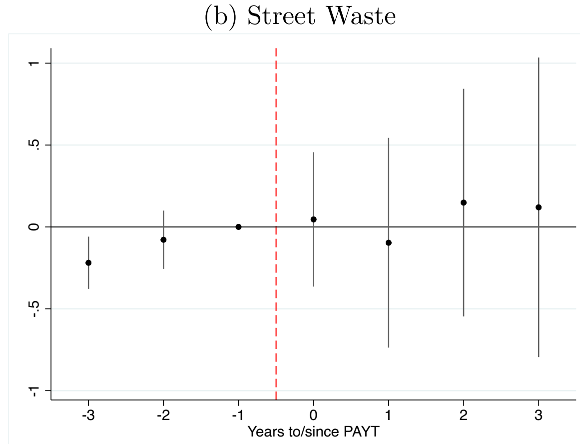
Results are displayed in Figure 7 and confirm what other empirical studies have already shown: PAYT adoption has no significant effect on waste outcomes in neighbor municipalities (Carattini et al., 2018; Valente, 2020). We thus interpret these findings as suggestive evidence of a null effect of the treatment on waste tourism.

Figure 7: Spatial Spillover Effects

(a) Total Waste



(b) Street Waste



Notes: The Figure displays estimates of the changes in the amount of street waste and total waste in municipalities that surround PAYT municipalities around the timing of PAYT introduction, as of equation 3. Outcomes are in log. The vertical line indicates the timing of PAYT introduction.

6 Conclusions

This paper shows that the adoption of pay-as-you-throw (PAYT) taxation schemes generates large environmental gains. Exploiting variation in the timing of the policy introduction and using a stacked-by-event design, we find a large and persistent drop in total waste (-9%), which translates into a reduction of GHG emissions comparable to the one coming from taking 92,000 passengers vehicles off the road in a year. The environmental benefits of PAYT programs become larger when considering their spillover effects on other environmental outcomes: following the implementation of the policy, individuals living in treated municipalities become more concerned about the environment, leading them to increase their use of low-polluting vehicles and of renewable energy.

One of the biggest concerns regarding the existing climate policies is their distributional impact, as they could disproportionately affect low-income households (Colantone et al., 2022; Dechezleprêtre et al., 2022; Douenne and Fabre, 2022). As already shown in (Messina et al., 2018), moving from a flat-fee scheme to PAYT improve the progressivity of the waste tax system; moreover, we find that the largest reduction in waste production is in municipalities where the share of low-educated and low-income households is larger.

While the adoption of PAYT schemes presents some critical issues, such as the definition of an optimal unit pricing and the setting of a waste measurement system, the cost incurred by local governments is fully compensated by the reduction in waste management costs. Using granular data on municipal balance sheets, we estimate that the reduction in tax revenues, after the introduction of the policy, is offset by the reduction in waste management expenditures, ultimately leaving municipal finances unaffected.

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Online Appendix A: Additional Findings

Table A.I: Timing of PAYT Introduction

	(1)	(2)	(3)
Population	-0.0013	-0.0001	-0.0005
	(0.0068)	(0.0067)	(0.0071)
Density	-0.0008	-0.0008	-0.0008
	(0.0006)	(0.0006)	(0.0006)
Household size	-0.8784	-0.9456	-0.7323
	(1.4740)	(1.5523)	(1.3990)
% Dropout	0.0303	0.0304	0.0185
	(0.0236)	(0.0238)	(0.0188)
% II & III educated	0.0341	0.0339	0.0278
	(0.0321)	(0.0354)	(0.0341)
LF participation	-0.0245	-0.0231	-0.0065
	(0.0376)	(0.0434)	(0.0409)
Unemployment	-0.0225	-0.0266	-0.0160
	(0.0521)	(0.0551)	(0.0569)
Income p.c. 2010	0.0029	-0.0053	-0.0013
	(0.0737)	(0.0801)	(0.0824)
Green Party 2009	3.7131	4.0499	0.3725
	(7.7367)	(7.2612)	(7.9812)
Turnout 2009	-1.9105	-2.2041	-2.9843
	(1.5786)	(2.5716)	(2.5955)
Last Local Election - 2005		.	.
- 2006		0.1813	0.1258
		(0.3462)	(0.2923)
- 2007		-0.2523	-0.2544
		(0.2746)	(0.2833)
- 2008		0.3938	0.3782
		(0.5846)	(0.5676)
- 2009		0.1075	0.1592
		(0.2584)	(0.2588)
Mayor Civil List		0.0676	0.0599
		(0.2742)	(0.2703)
Mayor Graduate		-0.0678	-0.0307
		(0.1697)	(0.1209)
Administration Result 2010			-0.3145
			(1.1368)
Financial Autonomy 2010			-1.0863
Observations	342	340	330

Notes: The Table reports OLS regression of equation in footnote 22. All regressions include province fixed effects. Column (1) includes characteristics of the municipalities as of 2001 Census (population, density, household size, % of school dropouts,% of secondary and tertiary educated, labor force participation, unemployment ratee), per capita income in 2010, electoral turnout and vote share for the Green party in 2009 European elections. Column (2) adds mayor's characteristics (education and a dummy for belonging to a civil list) as well as dummies for the last electoral year as of December 2009. Finally, Column (3) adds municipalities' accounts indicators. Standard errors are clustered at the province level.

Table A.II: Total Recycling by Material in PAYT Municipalities Before and Aafter PAYT Adoption

	(1) After PAYT	(2) Before PAYT	(3) Difference
Food-composting	87.92	71.82	16.10***
Plastics	26.13	24.71	1.42
Paper and Paperboard	64.04	65.45	-1.41
Glass	43.88	41.37	2.51*
Electric and electronic items	6.08	5.72	0.36**
Metals	12.69	10.41	2.28***
Textile	3.64	2.80	0.84***
Mis Inorganic	2.22	1.28	0.93***
Wood	19.25	23.19	-3.94***
Observations	4403	1755	

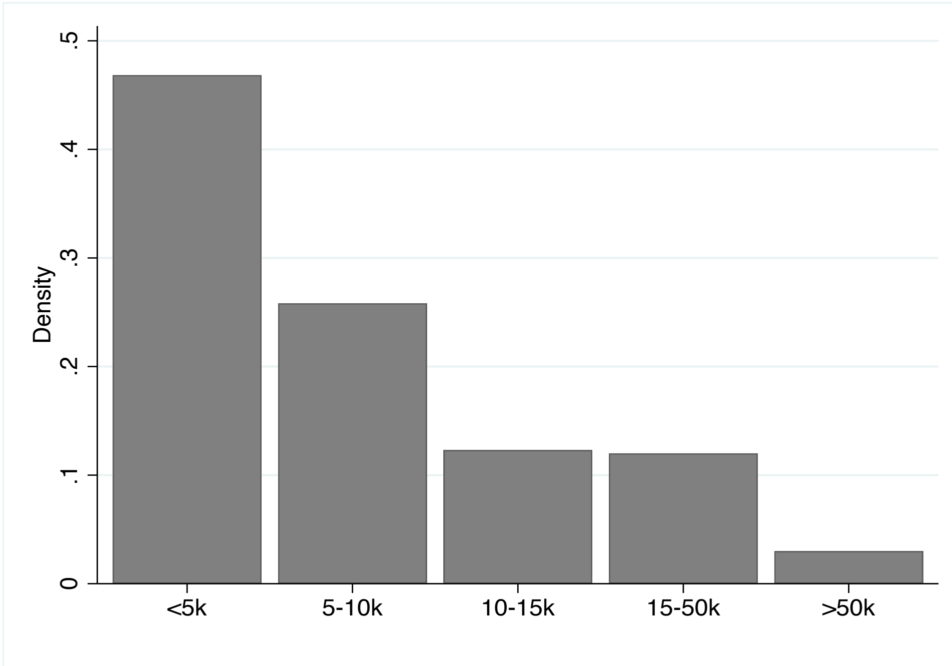
Notes: The Table reports descriptive statistics for municipal sorted waste, dis-aggregated by recycling item, before and after PAYT adoption. Waste amounts are measured in Kg per capita.

Table A.III: Robustness Checks

	Waste Production			Costs		Revenues				Expenditures			
	Total	Sorted	Unsorted	per Kg	per Capita	All	Tax	Non-Tax	Transfers	All	Current	Capital	Third-party
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	
Panel A: Including Controls													
Treated · Post	-0.0805***	0.0336*	-0.4192***	-0.0199	-0.0569**	-0.0552***	-0.0603***	-0.0278	0.1238	-0.0705***	-0.0407**	-0.1881*	-0.0011
	(0.0150)	(0.0188)	(0.0505)	(0.0310)	(0.0236)	(0.0170)	(0.0164)	(0.0438)	(0.0811)	(0.0174)	(0.0162)	(0.1124)	(0.0780)
Observations	10,212	10,212	10,212	4,231	4,231	10,616	10,616	10,616	10,616	10,616	10,616	10,430	10,496
Panel B: Conley Standard Errors													
Treated · Post	-0.0890***	0.0151	-0.4296***	-0.0246	-0.0585***	-0.0392***	-0.0579***	-0.0232	0.1260**	-0.0534***	-0.0338***	-0.0855	-0.0055
	(0.0122)	(0.0136)	(0.0395)	(0.0217)	(0.0159)	(0.0149)	(0.0141)	(0.0297)	(0.0495)	(0.0144)	(0.0124)	(0.1011)	(0.0599)
Observations	10,212	10,212	10,212	4,231	4,231	10,616	10,616	10,616	10,616	10,616	10,616	10,430	10,496
Panel C: Restricted Control Group													
Treated · Post	-0.0800***	0.0065	-0.3981***	0.0053	-0.0300*	-0.0442**	-0.0530***	-0.0182	0.1065*	-0.0598***	-0.0381***	-0.1422	0.0172
	(0.0140)	(0.0144)	(0.0450)	(0.0292)	(0.0174)	(0.0181)	(0.0160)	(0.0306)	(0.0577)	(0.0190)	(0.0134)	(0.1102)	(0.0759)
Observations	4,067	4,067	4,067	1,759	1,759	4,279	4,279	4,279	4,279	4,279	4,279	4,216	4,213

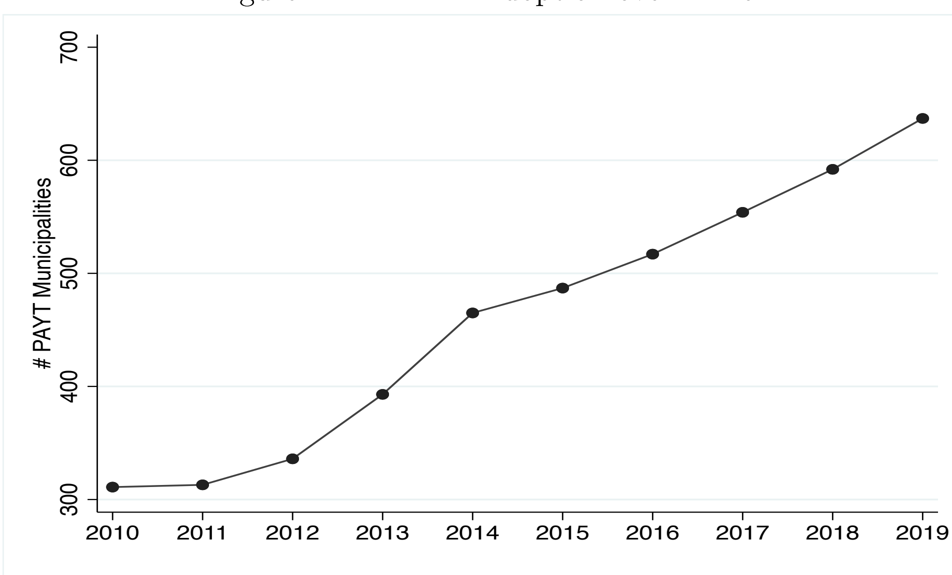
Notes: The Table reports estimates of the average effect in post-treatment period, as of equation 2. All estimates include county by year and municipality fixed effects. Panel A further includes municipality's characteristics interacted with year dummies, these controls are: 2001 Census variables (population, density, household size, % of school dropouts, % of secondary and tertiary educated, labor force participation, unemployment rate), average per capita income in 2010, electoral results from 2009 European Elections (turnout and vote for the Green party). Panel B reports estimates of equation 2 where Conley standard errors are used. Panel C restrict the sample of control municipalities to the ones that adopted the policy within 2 years after the treated ones.

Figure A.I: Share of PAYT Municipalities by Population Size



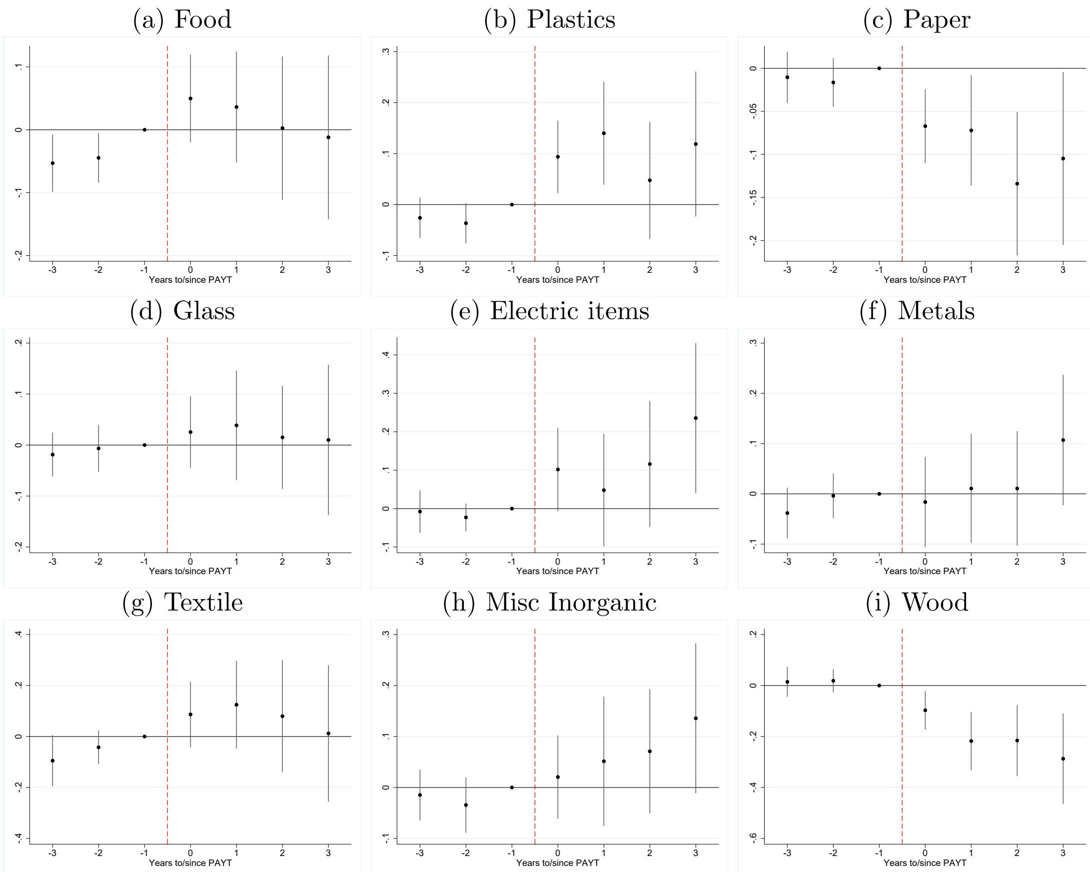
Notes: The Figure displays the share of municipalities that introduced PAYT schemes by municipal population size.

Figure A.II: PAYT Adoption over Time



Notes: The Figure displays the margins of variations used in the empirical analysis. The line shows the cumulative number of municipalities that introduced PAYT schemes.

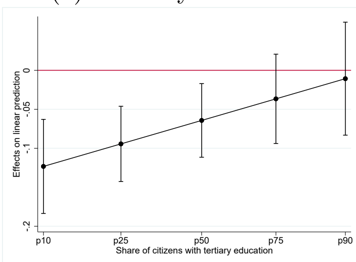
Figure A.III: PAYT and Sorted Waste by Material



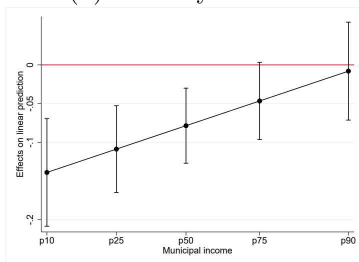
Notes: The Figure displays estimates of the changes in sorted waste by recycled material around the timing of PAYT introduction, as of equation 3. Waste outcomes are measured in Kg per capita. The vertical line indicates the timing of PAYT introduction.

Figure A.IV: Heterogeneous Effects

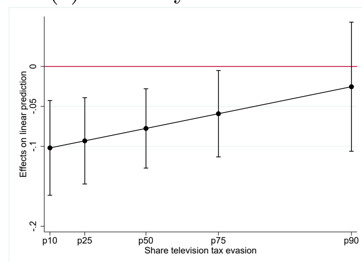
(a) Total by education



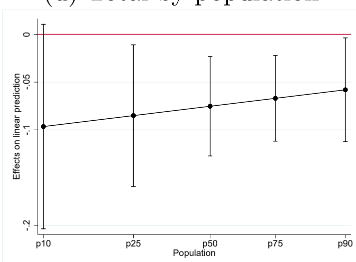
(b) Total by income



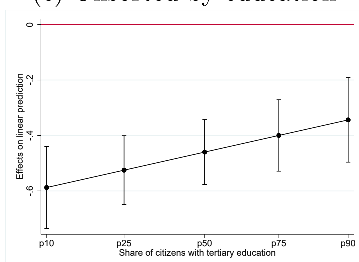
(c) Total by tax evasion



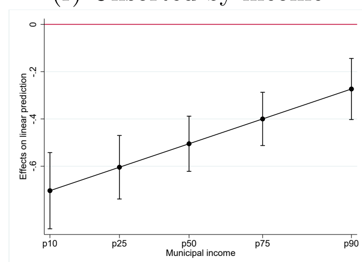
(d) Total by population



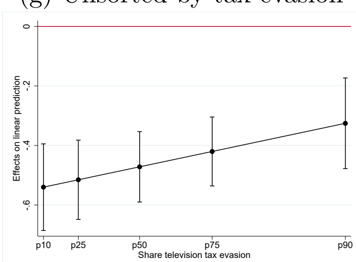
(e) Unsorted by education



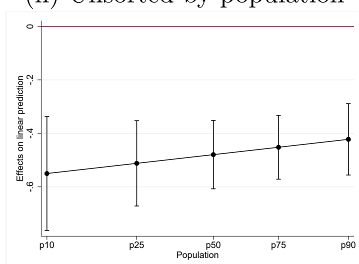
(f) Unsorted by income



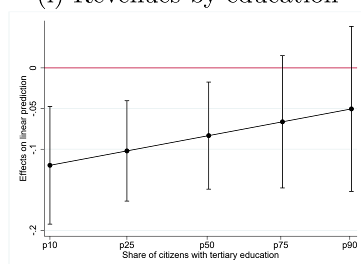
(g) Unsorted by tax evasion



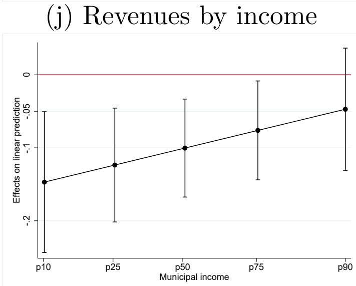
(h) Unsorted by population



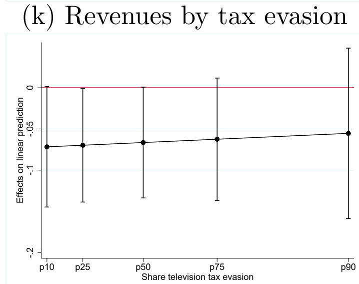
(i) Revenues by education



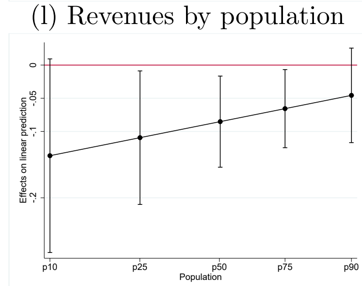
(j) Revenues by income



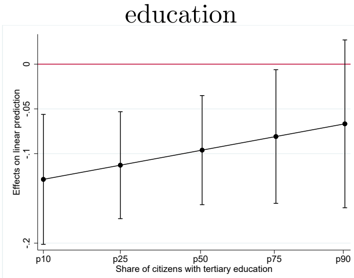
(k) Revenues by tax evasion



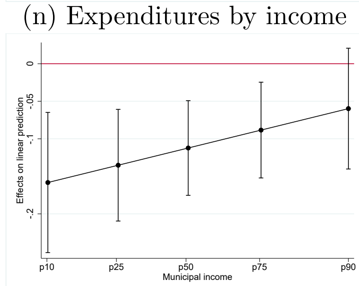
(l) Revenues by population



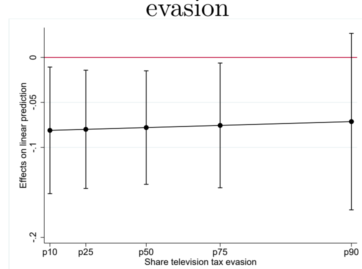
(m) Expenditures by education



(n) Expenditures by income



(o) Expenditures by tax evasion



(p) Expenditures by population

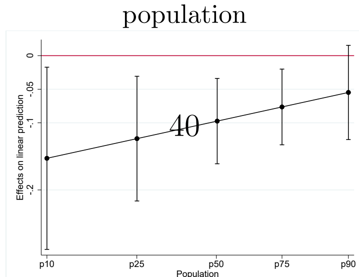
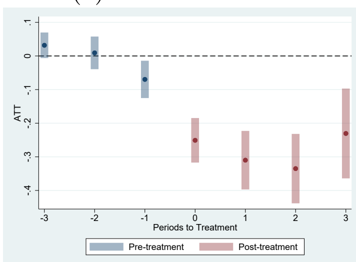
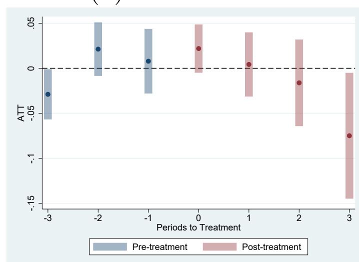


Figure A.V: PAYT, Waste Production, Waste Costs and Municipal Finances - Callaway and Sant'Anna Estimator

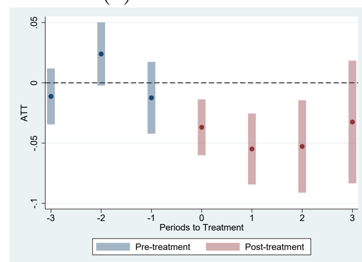
(a) Unsorted waste



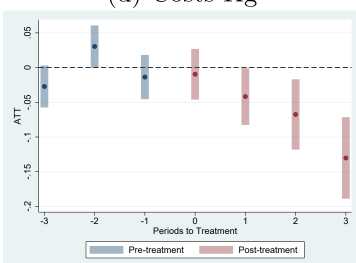
(b) Sorted waste



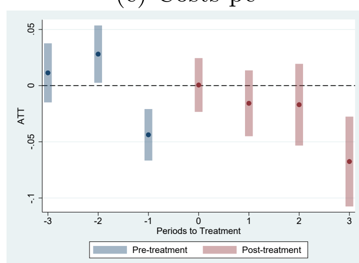
(c) Total waste



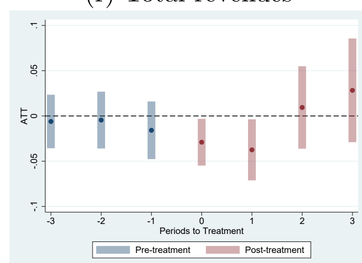
(d) Costs Kg



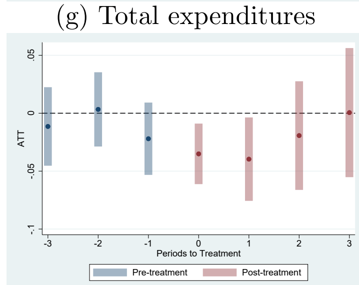
(e) Costs pc



(f) Total revenues

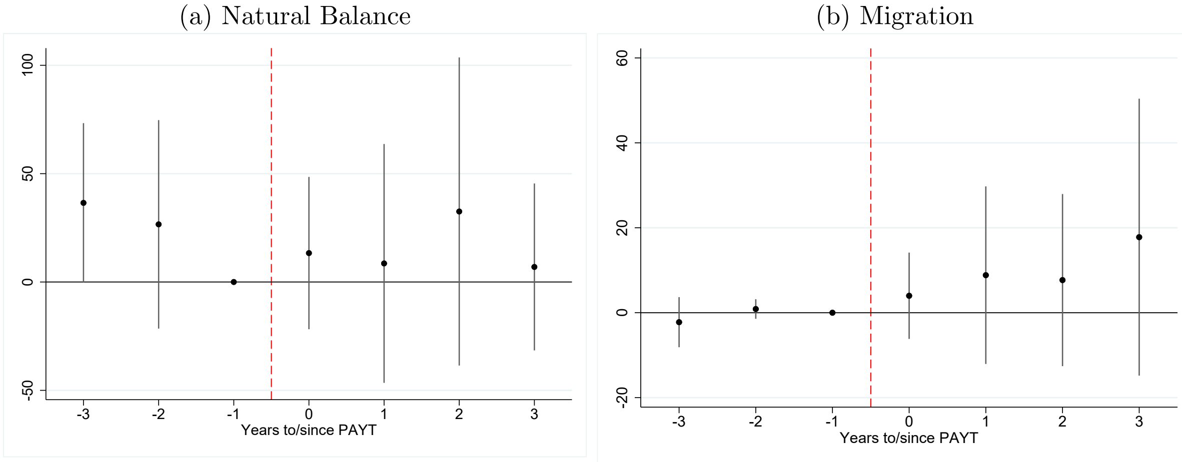


(g) Total expenditures



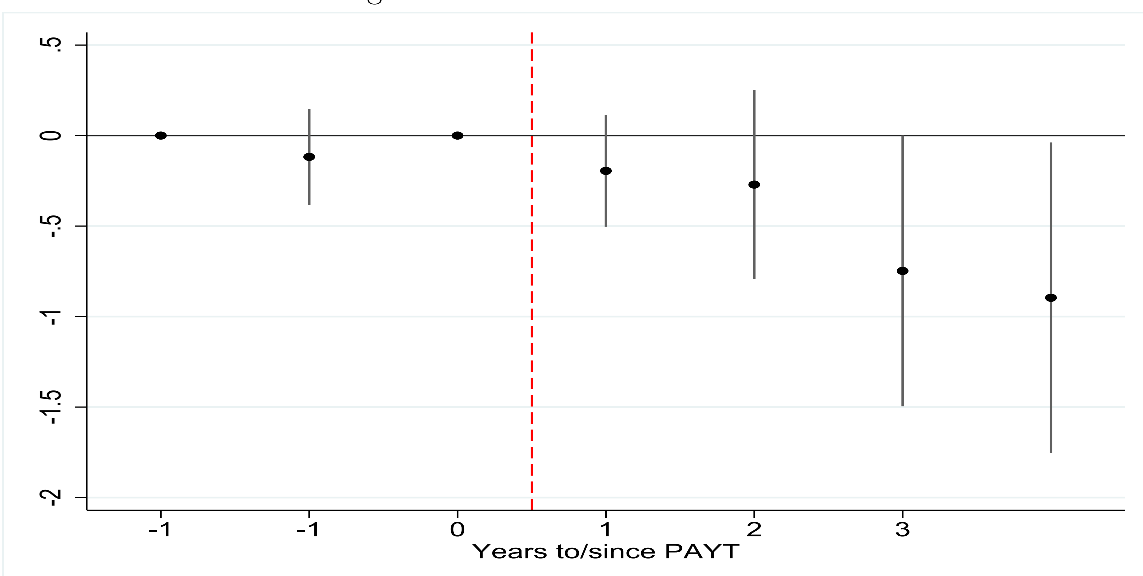
Notes: the Figure displays results of estimates using the Callaway and Sant'Anna estimator.

Figure A.VI: Changes in Municipal Population



Notes: The Figure displays estimates of the changes in municipal population around the timing of PAYT introduction, as of equation 3. The vertical line indicates the timing of introduction.

Figure A.VII: Street Waste Collection



Notes: The Figure displays estimates of the changes in street waste collection around the timing of PAYT introduction, as of equation 3. The vertical line indicates the timing of introduction.

Online Appendix B: Methodological Notes

Goodman-Bacon decomposition

The standard version of Difference-in Differences designs involves two periods and two groups, the *"canonical 2x2 DiD"*. One group, the untreated/comparison group, never receives the treatment, while the other, the treated group, gets the treatment in the second period. However, much applied work deals with cases where there are more than two time periods, implying that different units can be treated in different points in time. Regardless the number of treatment periods, by far the main approach tried to estimate the treatment effect using a two-way fixed effects, TWFE, estimator. In our case, the TWFE equation would be the following:

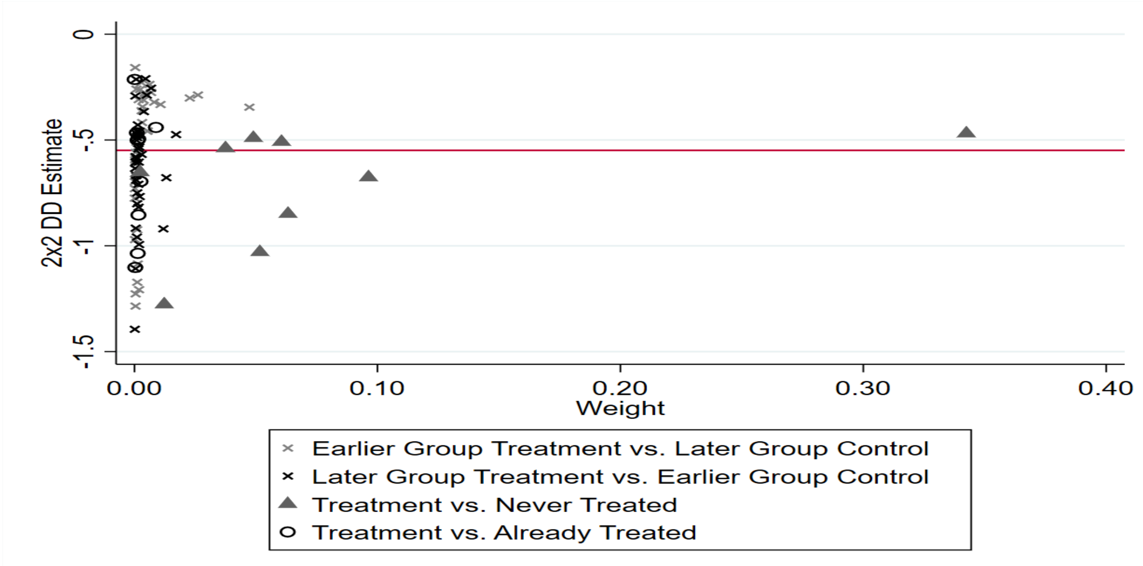
$$Y_{mt} = \alpha_m + \nu_t + \delta Treated_{mt} + \varepsilon_{it} \tag{B1}$$

where Y_{mt} is one of the possible outcomes measured at the municipality level, $Treated_{mt}$ is an indicator variable equal to 1 if a municipality has introduced PAYT, α_m are municipality fixed effects, while γ_t are year fixed effects.

Although this is essentially a standard approach in applied work, there are a number of recent works that point out potentially severe drawbacks of TWFE estimations when treatment effects are heterogeneous and there is variation in treatment timing. Goodman-Bacon (2021) provides a decomposition of δ, showing that it is a weighted average of all possible 2x2 DD estimators that compare timing groups to each other. The weights on the 2x2 DDs are proportional to group sizes and the variance of the treatment dummy in each pair. Variance is highest for units treated in the middle of the panel. If treatment effects vary over time some weights can be negative. Even under random treatment assignment, in setups with variation in treatment timing and heterogeneous treatment effects, ATT estimated from TWFE can be biased. The bias is driven by comparisons of *late-treated* units with *early-treated* units, the so called forbidden 2x2: when *late-treated* are compared with units that already received the treatment the parallel trends assumption is not likely to hold.

Since in our setting units turn on the treatment in different years, a standard TWFE estimation can lead to biased results. In order to assess the relevance of the issue, we performed the Goodman-Bacon decomposition when the outcome of interest is unsorted waste. Figure B.I shows the decomposition. The δ estimated through TWFE - indicated by the horizontal line (-49%) is a weighted average of four comparisons: i) early-treated *vs* late-treated; ii) late-treated *vs* early-treated; treated (PAYT municipalities) *vs* never-treated (we focus on PAYT municipalities only, the never-treated are the municipalities that introduce PAYT at the baseline); treated *vs* already-treated (pre-2010 PAYT municipalities). In practice, the δ equals the average of the y-axis values weighted by their x-axis value.

Figure B.I: Goodman-Bacon Decomposition



Notes: The Figure plots each 2x2 DD components from the decomposition against their weight. The open circles are terms in which one timing group acts as treatment group and the pre-2010 PAYT municipalities act as controls. The closed triangles are terms in which one timing group acts as treatment group and PAYT municipalities that introduce treatment at baseline act as controls. The x's are the timing-only terms. The horizontal line indicates the average DD estimate.

Table B.I further shows the details of the decomposition. For each of the four DD components, it reports the estimated δ and the relative weight. It is relevant to notice that the weight associated with the forbidden-two comparisons, the late *vs* early treated, is very low, 0.092.

Table B.I: Goodman-Bacon Decomposition: details

(1) DD Comparison	(2) Weight	(3) DD estimate
Earlier T. vs Later C	0.175	-0.352
Later T. vs Earlier C.	0.092	-0.596
T. vs Never T.	0.715	-0.594
T. vs already T.	0.018	-0.575

Notes: The Table reports the details of the Goodman-Bacon decomposition. For each of the four types of comparisons point DD estimates (δ from equation 1 and the relative OLS weight are reported

Table B.II compares results between estimates from the stacked-by-event design (as of equation 2), and the TWFE (as of equation 1). The most relevant difference between the two set of results is the finding on sorted waste, positive and significant when estimating the TWFE model, positive, but not significant, when estimating the stacked-by-event DD.

Table B.II: Stacked-by-event *vs* TWFE

	(1) Total	(2) Sorted	(3) Unsorted
Panel A: Stacked-by-event			
$Treated \cdot Post$	-0.088***	0.014	-0.429***
	(0.016)	(0.020)	(0.050)
Observations	10212	10212	10212
Panel B: TWFE			
$Treated \cdot Post$	-0.101***	0.078***	-0.540***
	(0.010)	(0.012)	(0.031)
Observations	6202	6202	6202

Notes: The Table reports estimates of the average effect in post-treatment period, as of equation 2 (Panel A) and equation 1 (Panel B). Column (1) reports results on total waste production, column (2) on sorted waste (recycled waste), while column (3) on unsorted waste (mixed waste). Estimates in Panel A include municipality and province-by-year fixed effects. Estimates in Panel B include municipality and year fixed-effects. Standard errors in parenthesis are clustered at the municipality level. All dependent variables are expressed in log per capita.

Rambachan and Roth (2020)

One of the most relevant results of our work, the PAYT effect on unsorted waste, shows a small, but significant pre-trend (Figure 2). Rambachan and Roth (2022) propose tools for robust inference when the parallel trends assumption may be violated.

In order to perform the analysis, we first need to specify the kind of violations of the parallel trend assumption that we are willing to consider. The first approach we implement bounds the worst-case post-treatment violation of parallel trends (between consecutive periods) by the product between a parameter $\overline{M}$ and the maximum pre-treatment violation of parallel trends. Following the notation in Rambachan and Roth (2020), we indicate with Δ the set of possible violation of the parallel trend assumption:

$$\Delta^{RM}(\overline{M}) = \{\delta : \forall t \geq 0, |\delta_{t+1} - \delta_t| \leq \overline{M} \cdot max_{s<0}|\delta_{s+1} - \delta_s|\}, \tag{1}$$

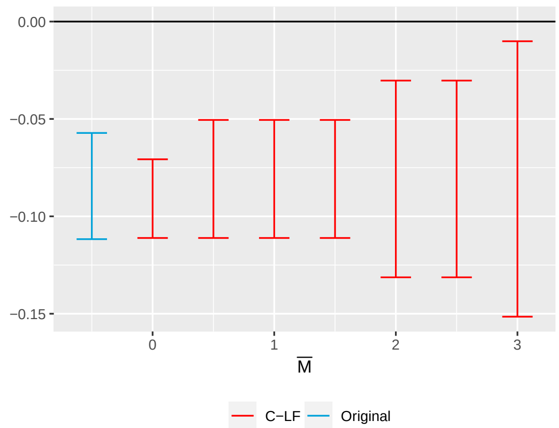
Another related approach is to bound the maximum deviation from a linear trend in the post-treatment period by $\overline{M}$ times the equivalent maximum in the pre-treatment period. Rambachan and Roth (2020) call this Δ^{SDRM}:

$$\Delta^{SDRM}(\overline{M}) = \{\delta : \forall t \geq 0, |(\delta_{t+1}-\delta_t)-(\delta_t-\delta_{t-1})| \leq \overline{M}\cdot max_{s<0}|(\delta_{s+1}-\delta_s)-(\delta_s-\delta_{s-1})|\}, \tag{2}$$

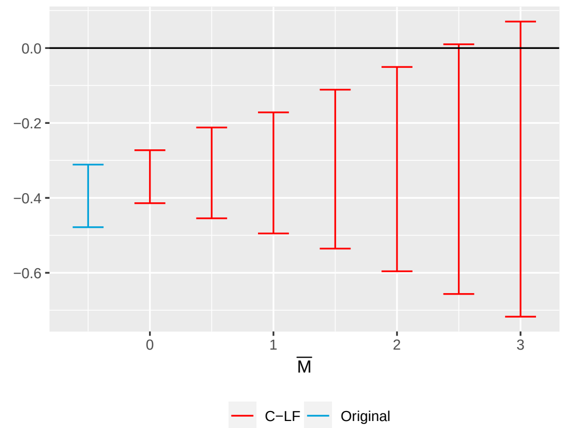
Given these definitions, it is natural to conduct a sensitivity analysis of our results to different values of the parameter $\overline{M}$, as well as the “breakdown” value at which particular hypotheses of interest can no longer be rejected. We will focus on the test of hypothesis on the estimated coefficient for the first year after the introduction of a PAYT scheme. Figure B.II presents the results for the variables Total Waste and Unsorted Waste. Panel (a) and (b) focus on violations of the kind described by Δ^{RM} and find that the ”breakdown” value of $\overline{M}$ is higher than 3, meaning that the effect we find in the first year after the introduction of a PAYT scheme is robust to allowing for a violation of the parallel trend assumption which is more than 3 times larger the maximum observed violation in the pre-treatment periods. Panel (c) and (d) plot instead the results for Δ^{SDRM}. In Panel (c) the breakdown value of $\overline{M}$ is 1, meaning that our results are robust to allowing for a non-linearity in the differential trend between treated and control groups which is 100% times higher than the maximum non-leariy observed in the pretreatment period. The result in Panel (d) can be interpreted in the same way, except now the breakdown point of $\overline{M}$ is 2. Results for Unsorted Waste appear to be more robust to possible violations of the Parallel Trend assumption than results for Total Waste. This is interesting because, of the two, we observe a pre-trend only for the former. The reason for this result is that the estimated effect on Unsorted Waste wis much higher, which makes the small violation we see in the pre-treatment period relatively minor. On the other hand, being the effect on Total Waste weaker, a smaller violation of the Parallel Trend assumption would be enough to invalidate the results.

Figure B.II

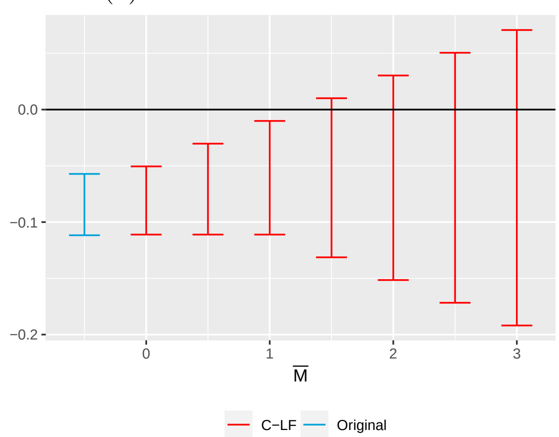
(a) Total waste - Δ^{RM}



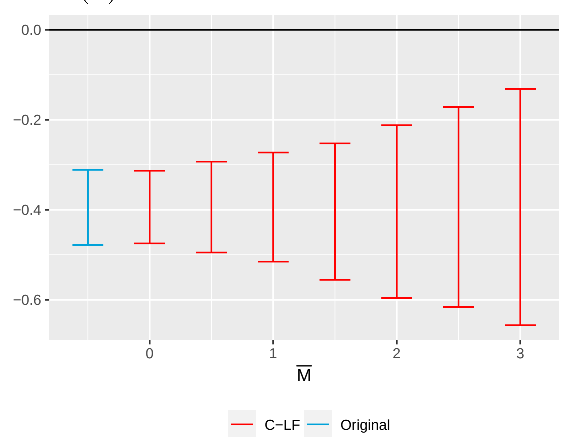
(b) Unsorted waste - Δ^{RM}



(c) Total waste - Δ^{SDRM}



(d) Unsorted waste - Δ^{SDRM}



Notes: Tests for possible violations of the parallel trends assumption as from Rambachan and Roth (2020) on total waste and unsorted waste. Sensitivity analysis on the estimated coefficient for the first year after the introduction of a PAYT scheme.

Online Appendix C: WARM Model

The WARM model calculates GHG savings from a baseline waste management scheme (before PAYT) to an alternative one (after PAYT). The two schemes are defined by the total amount of materials managed, which must be equal, and the management practices used. The waste management practices can be selected among the following: source reduction (i.e. waste avoidance), recycling, anaerobic digestion, combustion, composting and landfilling. Starting from our results, we have built three different scenarios – A, B, and C – to evaluate the GHG savings coming from a reduction of 370 tons in total waste and a reduction of 506 tons in unsorted waste. The three scenarios are described in Table C.1. For the sake of simplicity, in each scenario the only waste management practice considered as baseline is the use of landfills.

Table C.I: Scenarios for the WARM Model

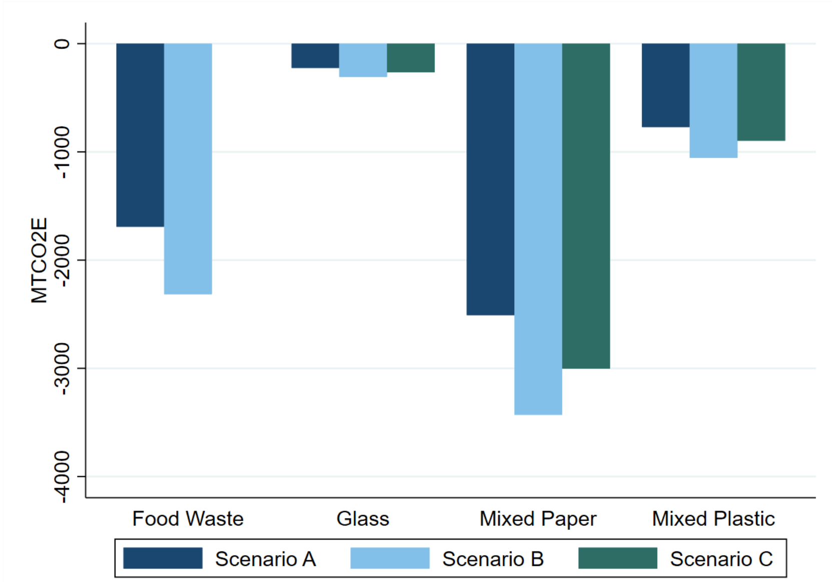
	(1) Tons of waste	(2) Baseline scenario	(3) Alternative scenario
A	370	Landfill	Waste avoidance
B	506	Landfill	Waste avoidance
C	506	Landfill	70% Waste avoidance and 30% Recycling

Notes: The Table describes the three scenarios used to run the WARM model.

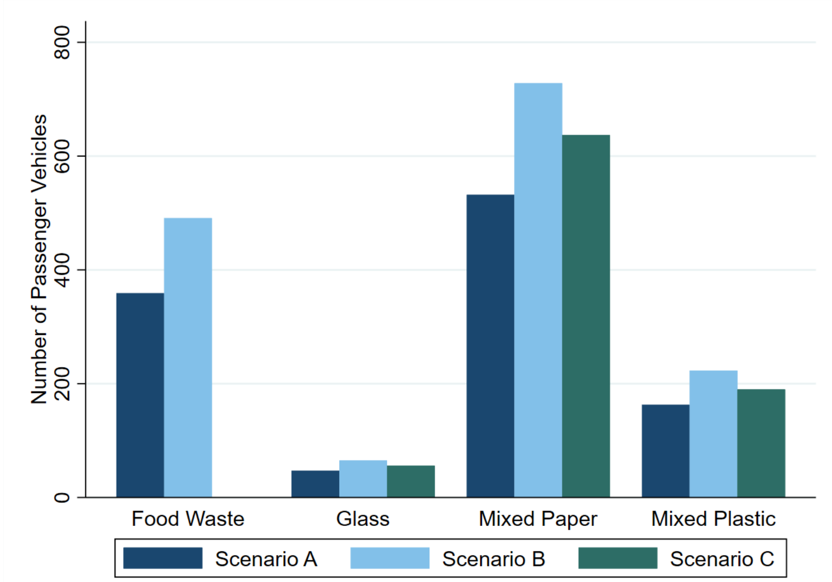
Scenario A estimates the greenhouse gas savings generated from a reduction of 370 tons in total waste. Since we are looking at total waste, recycling cannot play a role and therefore the only alternative waste practice considered is waste avoidance. Scenarios B and C, instead, focus on the 506 tons reduction in unsorted waste. Scenario B assumes that all the reduction is driven by waste avoidance, while scenario C assumes that 70% of the reduction is driven by waste avoidance (i.e., 354 tons) while the other 30% is driven by recycling. The rationale behind the latter is that it allocates most of the reduction to waste avoidance (as our results suggest) but it does not assume that the whole effect on unsorted waste is due to behavioural changes, leaving a smaller role to play also for recycling. The last input we need to specify is the kind of waste managed, the materials we are dealing with. For the sake of simplicity, and in order to avoid any assumption about the waste mix, we evaluate each scenario four time, focusing each time only on one particular material among mixed plastic, mixed paper, glass and food waste. Please notice that we can simply retrieve the greenhouse gas savings coming from any convex combination of these four by taking the weighted average of the results. For instance, taking the simple average of the savings across all four material is equivalent to the simulation of a scenario in which the overall quantity of waste is divided evenly among them. Scenario C is not computed for food waste, because the latter cannot be recycled. To perform, the WARM models requires assumptions and calibration of different parameters (e.g., GHG emissions from the production of different materials, the marginal electricity grid mix emission factor, the average distance of the municipality from the waste management options and the characteristics of the landfill the municipality has access to), which are based on the United States. We are aware that their value is likely different from the one we would observe in Italy. This can be a limitation for the interpretation of our findings. On the other hand, in our opinion, this exercise is still interesting and useful as it shows the benefits that similar effects in total and unsorted waste would have in the United States.

Figure C.I

(a) Total Change in GHG Emissions (MTCO2E)



(b) Change in GHG Emissions expressed as annual emissions from passenger vehicles



Notes: Results of the simulations using the WARM model for Scenario A, B and C described in Table C.1. Panel (a) shows the total change in GHG emissions (measured in MTCO2E) in each scenario while panel (b) quantifies this savings in terms of passenger vehicles' annual emissions. As way of example, the GHG saving estimated focusing on food waste in Scenario A are equivalent to removing annual emissions from 359 passenger vehicles.

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