Landfill tax and recycling[§]

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Abstract: This paper brings new empirical evidence on the role of landfill taxes on reducing landfill waste and promoting recycling. We focus on the impacts of the 2017 landfill tax law reform in Catalonia, a Spanish region, which increased the tax rate from 18€ to 47€ euros per ton over the extended period of 2017-2020. Using municipality-level data for Catalonia from the 2013-2020 period, we contrast municipalities that differed in the use of door-to-door (DtD) waste collection by the beginning of our study period. As DtD waste collection is advocated as especially efficient in reducing waste, and landfill waste in particular, we hypothesize that municipalities that had not yet adopted this system had greater leeway in responding to the tax changes. Based on a two-way fixed effects design, our findings reveal large differential responses to the tax hike. Compared to municipalities that had implemented DtD waste collection by 2013, we estimate that those that had not responded to the tax hike by reducing landfill waste by an additional 12%, reducing total waste by 4%, increasing the share of recycled waste by 6 percentage points, and increasing the share of waste that is sorted and processed as organic by 2.5 percentage points. We provide suggestive evidence that the adoption of DtD waste collection is the main mechanism driving these responses.

JEL Codes: H23, Q53.

Keywords: Circular economy, recycling, landfill taxes, solid waste.

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1. Introduction

Climate change is one of the most pressing challenges facing the world today. It is caused by the increase of greenhouse gases emissions, largely due to human activity. There is clear evidence that solid waste is a contributing factor, estimated to account for 3% of all greenhouse gas emissions with in EU (Eurostat, 2022). Moreover, solid waste that is delivered to landfill sites is the main contributor to greenhouse gases emissions. Therefore, waste management in general, and reuse, reduce and recycle policies, in particular, are key to fight climate change (UN, 2015a; UN, 2015b; EEA, 2018). At the European level, the Circular Economy Action Plan aims at recycling 55, 60 and 65% of municipal waste by 2025, 2030 and 2035 (EC, 2015).[1] Spain, the country in which this paper focuses, only recycled 40% of municipal solid waste in 2020. Pigouvian taxes, as the landfill tax, are a public policy instrument that can affect behavior causing a reduction of solid waste and increasing recycling rates.[2]

This paper estimates the effects of the landfill tax on waste generated and recycled at the municipality level using a major tax reform in Catalonia, a Spanish region. In 2017, the landfill tax rate was increased from 18 to 30€ per ton and it was announced that between 2018 and 2020 this rate would increase linearly to reach 47€ in 2020. Since the tax hike affected all municipalities, there is not an obvious control group.[3] Municipalities that did less in the past to reduce landfill waste and increase recycling are expected to have more leeway to respond to the tax hike. The descriptive analysis of the data shows that the door-to-door (DtD) collection is a key technology to recycle more and send less waste to landfill sites (see Graph 2 below). Therefore, we define as the control group those municipalities that had

[1] The EU defines the circular economy as a model of production and consumption that involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials. In practice this strategy requires the reduction of waste to the minimum by adopting the reuse, reduce and recycle strategy (the 3Rs).

[2] Another widespread instrument is the unit-based pricing, also known as Pay-As-You-Throw (PAYT) systems. While the early literature found modest effects of the PAYT on household solid waste (Fullerton and Fullerton and Kinnaman, 1996; Kinnaman, 2006; Kinnamanm 2009; Bel and Gradus, 2016), more recent contributions have found larger responses (Carattini et al 2018; Colussi et al, 2022). The landfill tax typically coexists with several taxes that directly or indirectly also tax greenhouse emissions. Adam et al (2022) study the inconsistencies that arise in this setting focusing on the UK economy.

[3] We cannot use as control group Spanish municipalities from other regions due to the lack of detailed waste data at the municipality level available for other regions.

adopted the DtD waste collection system by the first year of the time period considered in our study (2013-2020). Thus, we estimate the differential impact of the tax change on municipalities that had not yet adopted the DtD collection system (by 2013) as compared with those that had.

The first outcome that we examine is the tax base of the landfill tax, namely, solid waste delivered to a landfill site by each municipality. We express this variable in terms of annual kilograms per inhabitant. We then examine total waste (annual kg per inhabitant) to analyze if landfill taxes have effects on the overall amount of waste generated. The third outcome we investigate is the share of total waste that is recycled, often a policy goal in itself. Finally, we consider the share of total waste that is sorted and processed as organic waste, considered to be the primary factor behind the greenhouse gas emissions in landfill sites.

Our event-study Two-Way Fixed-Effects and difference-in-differences estimates indicate that the differential tax responses between municipalities that had not yet adopted the DtD collection system (by 2013) as compared with those that had are large. Our preferred estimates of the differential tax responses imply reductions in landfill and total waste by 12% and 4% respectively, along with increases in the share of recycled waste and in the share of waste that is sorted and processed as organic by 6 and 2.5 percentage points, respectively.

We provide suggestive evidence that the main mechanism at work is the adoption of the DtD by some municipalities.[4] More specifically, we descriptively show that the changes in the waste generated and recycled are entirely driven by the group of municipalities adopting the DtD during our study period. In contrast, we observe very little change in outcomes in municipalities that did not adopt the DtD in our study period.

To provide further evidence on this mechanism, and focusing on the sample of municipalities that were not using the DtD at the beginning of our period (i.e. the treatment group), we estimate the causal effect of adopting DtD on generated and recycled waste. More specifically, we apply recent econometric methods developed to deal with staggered treatment timings.[5] Our causal results indicate that the DtD collection system has a large

[4] We cannot estimate the causal effect of the tax hike on the adoption of the DtD as, by construction, all municipalities in our control group were already using this collection system since the beginning of our study period.

[5] See de Chaisemartin and d'Haultfoeuille (2022) for a survey of these methods.

negative impact on landfill and total waste, reducing them by two-thirds and 20%, respectively. Similarly, it has a large and positive impact on the share of waste recycled and on the share of total waste that is sorted and processed as organic, increasing them by 35 and 20 percentage points, respectively.

Despite being present in many countries, the evidence on the effects of landfill taxes on waste generated and recycled is extremely scant.[6] Matheson (2022) shows using OECD country-level data that there is a strong and negative (cross-sectional) correlation between landfill tax rates and the proportion of solid waste delivered to landfill sites. Nicolli and Mazzanti (2013) study the effect of regional landfill taxes in Italy on landfill waste with data for the period 1999-2008. Using a difference-in-differences specification, the authors find that higher landfill tax rates lead to a reduction in the amount of waste delivered to landfill sites.

We make three contributions to this limited literature on landfill tax effects. First, we use event-study designs and difference-in-differences regressions to estimate the effects of a large tax reform. While we can only estimate the differential impact of the tax change on municipalities that had not yet adopted the DtD collection system (by the beginning of our study period) as compared with those that had, our study provides causal evidence that responses to landfill taxes can be large. Second, we study the effects of landfill taxes not only on landfill waste but also on total waste, the share of total waste that is recycled and the share of total waste that is sorted and processed as organic waste. Thus, we provide a more complete and policy-relevant assessment of the landfill tax effects. Third, and in contrast to previous studies, we shed light on the mechanisms at work by showing that the adoption of more efficient waste management technologies (i.e. the DtD collection system) is likely to be the main channel through which the landfill tax affects generated and recycled waste.[7]

[6] The landfill tax typically coexists with several other environmental taxes on greenhouse emissions. Adam et al (2022) study the inconsistencies that arise in this setting focusing on the UK economy. The UK introduced in 2004 a system of tradable permits for the landfill of municipal waste. A discussion of this policy is provided by Barrow (2003). At the EU level, 23 out of 27 Member States have a landfill tax.

[7] Using municipality-level data from Sweden, Andersson and Stage (2018) compare the effectiveness of unit-based pricing versus the effectiveness of different systems used to collect waste. They conclude that waste collection systems are more effective than unit-pricing schemes.

As part of this exploration into the mechanisms at work, we use recent econometric methods specifically developed to deal with staggered treatment timings to estimate the causal effect of adopting DtD on generated and recycled waste. In doing so, we also contribute to the literature that has descriptively shown the importance of waste collecting systems in explaining waste generation and recycling rates.[8]

How does the effectiveness of the landfill tax compare to other instruments used to reduce emissions such as the carbon tax or the cap-and-trade system?.[9] Andersson (2019) studies the effects of the carbon tax in the transportation sector in Sweden. The tax was introduced in 1990 at $30 per ton of CO_2 and reached $109 per ton in 2004. Using a synthetic control method, he finds that the tax reduced emissions by 10%. Colmer et al. (2023) study the effects of the introduction of a cap-and-trade system on emissions, specifically the European Union Emissions Trading Scheme (EU ETS). They find that in regulated sectors, where permits had an average cost of 18.9€ during their period of study, emissions were reduced by 16%. According to the Waste Agency of Catalonia, one ton of landfill waste is responsible for 0.88 tons of CO_2 emissions (Inedit, 2021), implying that the tax hike of 29€ per ton of landfill waste amounts to 25€ per ton of CO_2. Our estimates imply that this tax increase reduced emissions by 12% more on municipalities that had not yet adopted the DtD collection system as compared with those that had. Thus, taken together, the results suggest that the Catalan landfill tax has been more effective to reduce emissions than the carbon tax studied in Andersson (2019) but less effective than the ETS system studied in Colmer et al. (2023).

The rest of the paper is organized as follows. In Section 2 we present the institutional setting and describe the evolution of the land fill tax and waste collection systems. In Section 3 we describe the data and variables that we use in our analyses. In Section 4 we explain the empirical strategies and, in Section 5 we present and discuss our results. Section 6 provides some concluding remarks.

[8] See e.g. Andersson and Stage (2018) and Rossi et al. (2022).

[9] See Blanchard et al. (2023) for a discussion of the different policies (and their articulation) that can be implemented to fight climate change, and specially to reduce greenhouses gases emissions.

2. Waste collection and the landfill tax in Catalonia.

In Spain, local governments are responsible for waste collection and management within the legal framework established by regional governments. In Catalonia, it has been compulsory since 2009 for municipalities to implement a selective waste collection system, which can take two forms. In the first one, municipal governments place street bins to separately collect glass, paper, plastic, organic material and non-recyclable waste. In the second one, waste is collected door-to-door (DtD) on pre-established days and times for each type of waste.

The DtD collection system has both benefits and costs. On the one hand, as we will show below, it increases the share of waste that is recycled. In fact, it is difficult to avoid sorting the waste into its different types as these are collected at specific times and on specific days. Waste that is not properly sorted is typically not collected. Moreover, the proponents of this system argue that it increases awareness about the amount of waste that households generate and can encourage changes in consumption habits that lead to reductions in total waste. On the other hand, the system is less convenient because the disposal options for waste are limited. Additionally, in densely populated areas, placing large numbers of individual bins in the street poses challenges. Thus, the adoption of this policy typically meets with some opposition. As shown in Graph 1 (triangles), the DtD collection system was initially adopted by a handful of municipalities in the early 2000s. By 2020, 23,5% of municipalities in the region (225 municipalities) had implemented the system.

The Catalan government introduced a landfill tax in 2004 which is collected by the Waste Agency of Catalonia (*Agència Catalana de Residus*) and borne by local governments.[10] The tax bill is determined by the quantity of solid waste delivered to landfill sites.[11] Graph 1 shows that the tax rate (dots) was initially set at 10€ per ton of waste and it was increased several times afterwards. By 2020, the end of our study period, the tax rate was 47.10€ per ton. The largest tax increase took place in 2017 when it went from 18.10 to 30€ per ton,

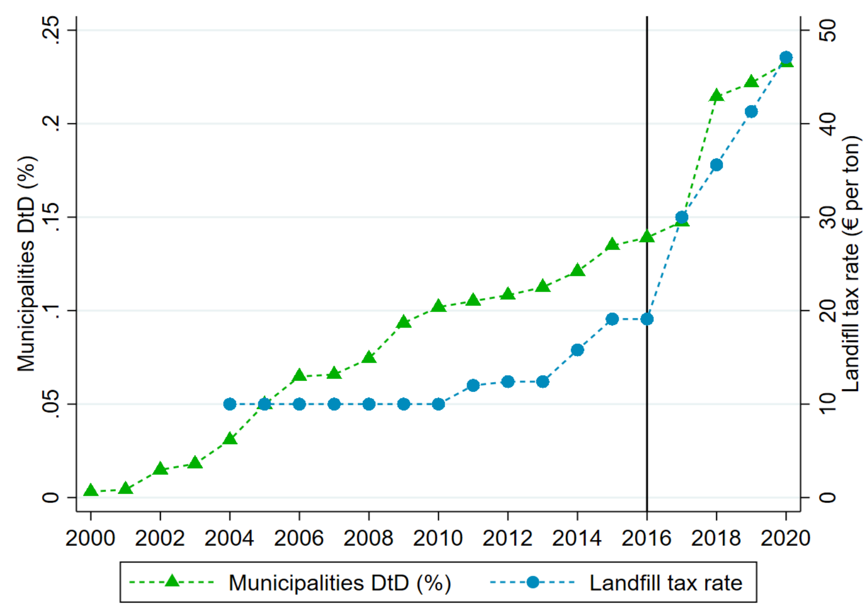
[10] A tax on incinerated solid waste was created in 2009. Its tax rate has always been lower than that of the landfill tax and it experienced a similar increase in the 2017-2020 period. We focus on the landfill tax because in the region only a small fraction of solid waste is incinerated.

[11] Part of the tax revenue is returned to local governments through a formula that considers the tons of different solid waste generated by each local government, incentivizing practices with lower environmental footprints. Importantly for our analysis, the formula has not changed in the period of our study and, therefore, it has not altered the incentives of municipalities with regards to waste management practices.

which represents a 57% increase in the tax rate. Moreover, at that time it was announced that between 2018 and 2020 the tax rate would increase linearly to reach 47.1€ in 2020.

This tax hike increases the incentives for municipalities to reduce the amount of waste delivered to landfill sites. Graph 1 illustrates that the landfill tax rate hike in the 2017-2020 period coincides with a sharp increase in the number of municipalities adopting a DtD waste collection system, which, as we will see below, favors recycling rates. Between 2017 and 2020, the proportion of municipalities using this system increased from 15% to 22%. Thus, this evidence suggests that the landfill tax hike increased the adoption of greener waste collection system.

Graph 1. Share of municipalities with a door-to-door collection system (left axis) and landfill tax rate (right axis).



Notes: This Graph considers all municipalities in Catalunya (947). Triangles are the share of municipalities that have adopted the DtD collection system each year (y-axis on the left). Dots represent the tax rate, expressed in euros per ton, of the landfill tax each year (y-axis on the right).

How does the Catalan landfill tax rate compare to the social cost of carbon? One ton of landfill waste is responsible for 0.88 tons of CO_2 emissions according to the computations of the Waste Agency of Catalonia (Inedit, 2021). Thus, the 2020 landfill tax rate of 47.1€ per ton amounts to a tax of 41.5€ per ton of CO_2 emissions. This value is probably lower than the social cost of carbon, which is very likely to be well above $51 per ton - the value which is currently used by the Biden Administration.[12] The Catalan landfill tax in 2020 (41.5€ per ton) is also low when compared to the price of emission allowances in the EU ETS market, which has been in the 60€-100€ per ton range in the 2022-2023 period. Thus, the Catalan landfill tax rate at the end of our study period is probably still low from a normative point of view.

3. Data

We use data from the Waste Agency of Catalonia that collects detailed information on the waste generated by each municipality.[13] We examine four outcome variables. Landfill waste is the annual per capita kilograms of waste that each municipality delivers to a landfill site. Similarly, total waste is annual kg of total waste per inhabitant. To measure recycling rates, we compute the share of total waste that is recycled, which is often a policy target. For instance, the Circular Economy Action Plan for the EU aims at recycling 55% of municipal solid waste by 2025. Finally, we examine the share of total waste that is sorted and processed as organic waste. This outcome is important because non-sorted organic waste that ends up at landfill sites is the main cause of greenhouse gas emissions (Jaglo et al, 2021).

Data on the municipalities that have adopted the DtD waste collection system has been provided by an association of municipalities that promotes this garbage collection system.[14] The dummy variable DtD_{it} is equal to one if municipality i implements the DtD waste collection in year t and zero otherwise.

Our study period is 2013 to 2020. Since the landfill tax hike occurred in 2017, we have four years before and four years after the tax reform. We restrict the sample to municipalities with more than 1,000 inhabitants in 2013, and we exclude the municipalities of Barcelona, Lleida and Girona because they only adopted the DtD system in parts of the city. Our final sample comprises 459 municipalities over 8 years. Table 1 shows the summary statistics of our main variables for the first and last years in the sample. Over the study period, total waste and

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[12] Rennert et al. (2021) argue that $51 per ton is too low a value. Similarly, the Environmental Protection Agency proposed raising this value to $190 in November 2022.

[13] The data does not include waste generated by industrial, construction or demolition activities.

[14] *Associació de Municipis Catalans per la recollida selectiva Porta a Porta* (www.portaaporta.cat).

landfill waste (annual kg/inhabitant) has been reduced while the share of recycled waste and the share of total waste that is sorted and processed as organic have increased.

Table 1: Descriptive statistics

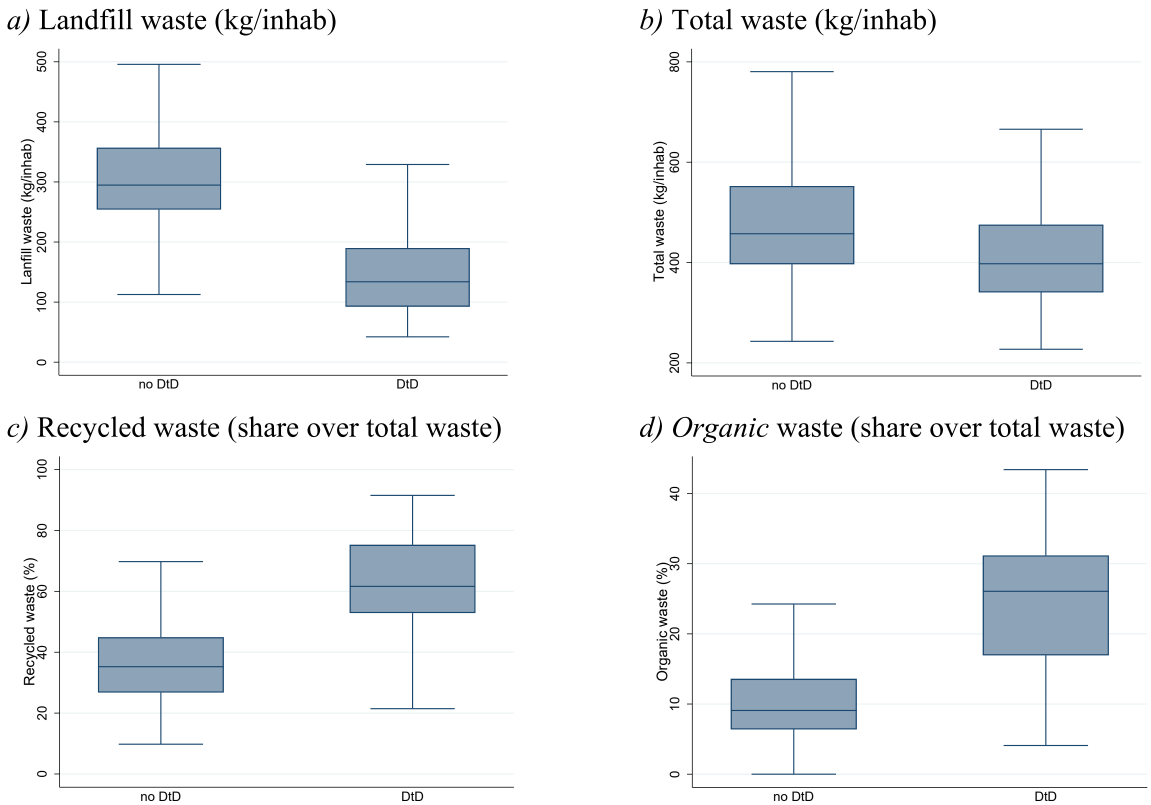
Variable	Mean	Std. Dev.	Min	Max
***a*) year 2013**				
Landfill waste (kg/inhab)	303.74	155.20	42.19	1385.26
Total waste (kg/inhab)	501.05	195.54	227.14	1853.69
Recycled waste (%)	40.03	15.99	9.78	91.53
Organic waste (%)	12.36	8.76	0.00	43.40
Door-to-door dummy (DtD)	0.15		0.00	1.00
Population	11,998	26,263.67	1,000	254,056
***b*) year 2020**				
Landfill waste (kg/inhab)	272.31	138.90	23.05	961.81
Total waste (kg/inhab)	551.96	187.96	262.95	1734.17
Recycled waste (%)	51.66	16.41	9.30	93.16
Organic waste (%)	14.08	9.48	0.00	45.69
Door-to-door dummy (DtD)	0.26		0.00	1.00
Population	12,360	27,180.37	902	269,382

Notes: Number of observations is 459 municipalities per year.

Graph 2 provides descriptive statistics for 2013 when we break down the sample between municipalities that implemented the DtD system (control group) and those that did not (treated group). Municipalities with a DtD collection system generated significantly less landfill waste (panel *a*, on average 160.5 versus 328.7 kg per inhabitant per year), recycled a much larger share of total waste (panel *c*, on average 61.8 versus 36.2%) and were able to sort and process more organic solid waste (panel *d*, on average 24.6 versus 10.2%). Total waste is also lower in the DtD system although the difference is much smaller in size (panel *b,* on average 413.3 vs 516.3 kg per inhabitant per year). These differences are substantial in magnitude and suggest that waste generated and recycled vary substantially between municipalities that use street bins and municipalities in which households sort waste at home in a DtD system. [15] In Section 5.4 we provide causal evidence of the impact of DtD on waste generated and recycled.

[15] Similar descriptive evidence for Italy is provided by Rossi et al. (2022).

Graph 2. Waste generated and recycled in door-to-door versus other municipalities in 2013.



Notes: First, median and second quartile values and adjacent values outside the box. 459 municipalities.

4. Empirical specifications

Our objective is to estimate the effect of the landfill tax hike on waste generated and recycled. Since the tax hike occurred simultaneously across all Catalan municipalities, there is not an obvious control group.[16] Municipalities that did less in the past to reduce landfill waste and increase recycling are expected to have more leeway to respond to the tax hike. As shown in Section 2, the DtD collection system is a key technology to recycle more and send less waste to landfill sites. Thus, we define as the control group those municipalities that had adopted the DtD waste collection system by 2013, the first year of our study period. Therefore, we estimate the differential impact of the tax change on municipalities that had not yet (by the beginning of our study period) adopted the DtD collection system as compared with those

[16] We lack comparable waste data at the municipality level from other Spanish regions that could constitute an alternative control group and could allow to estimate the causal effect of the tax hike.

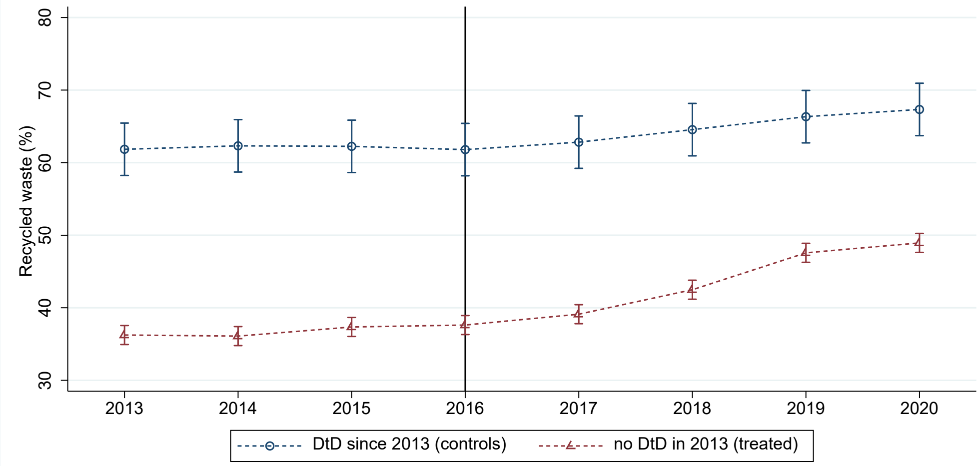
that had. Our main empirical specification is the following Two-Way Fixed-Effects (TWFE) event-study specification:

$$y_{it} = \sum_{j=-T}^{j=K} \beta_j \times d_{it-j} + \delta_i + \delta_t + \varepsilon_{it} \tag{1}$$

where y_{it} is a measure of waste generated or recycled in municipality i in period t. The indicator variable d_{it-j} identifies treated municipalities (all that had not adopted the DtD in 2013) in period $t - j$. The β_j's are lead and lag coefficients measuring the difference between treatment and control groups relative to its difference in 2016 which is the normalization period. The terms δ_i and δ_t denote municipality and time-period fixed effects. Clustered standard errors at the municipality level allow for serial correlation within municipalities.

Our identification strategy makes two assumptions. First, in the absence of the tax hike, landfill waste and recycling would have evolved similarly for treated and control municipalities. Second, the adoption of the DtD by the treated municipalities is a response to the tax hike. To assess the validity of the first assumption, Graph 3 shows the share of recycled waste between 2013 and 2020 for the two groups of municipalities, i.e., those that were using the DtD system by 2013 (the control group) and those that were not (the treatment group). While the share of recycled waste increases more in the treatment than in the control group when the tax hike occurs (2017-2020), the trends in the pre-treatment period (2013-2017) are similar. The second assumption, that the adoption of the DtD system by treated municipalities is a response to the tax hike, is harder to assess because we cannot check for differential pre-trends because, by construction, all municipalities in the control group had adopted the DtD system by 2013. Nevertheless, note that Graph 1 clearly shows that the adoption of the DtD system accelerates exactly when the landfill tax occurs, which lends some credibility to the second assumption.

Graph 3. Evolution of the share of recycled waste for the treated and control groups



Notes: The control group (dots) is composed of (68) municipalities that had adopted the DtD system in 2013. The treated group (triangles) is composed of (391) municipalities that had not adopted the DtD collection system in 2013. The graph represents mean values by groups and 95% confidence intervals.

We also estimate if the differential responses to the tax are heterogenous in urban landscape characteristics or political costs as these factors might determine the relative benefits and costs of alternative garbage collection practices. To do so, we estimate equation (1) splitting the sample in two according to its population density, the height of the residential buildings, population size, the proportion of individuals with college degrees and the characteristics of the local government (i.e. majority government or left-wing mayor).

For completeness, we will also estimate the following difference-in-differences specification in which we replace the lead and lag terms for the landfill tax rate in place each year interacted with the treatment indicator d_i which equals to one for municipalities with no DtD collection system in 2013:

$$y_{it} = \beta \cdot tax\ rate_t \cdot d_i + \delta_i + \delta_t + u_{it} \tag{2}$$

This exercise allows us to directly estimate the differential effect of 1€ per ton increase on each outcome of interest. One assumption behind this econometric exercise is that the outcome of interest is determined by the tax rate in place in every period. This assumption is not particularly realistic in this application given that tax rates up to 2020 were announced back in 2017. Therefore, some outcome changes in 2017, 2018 or 2019 might be anticipating future but known tax increases.

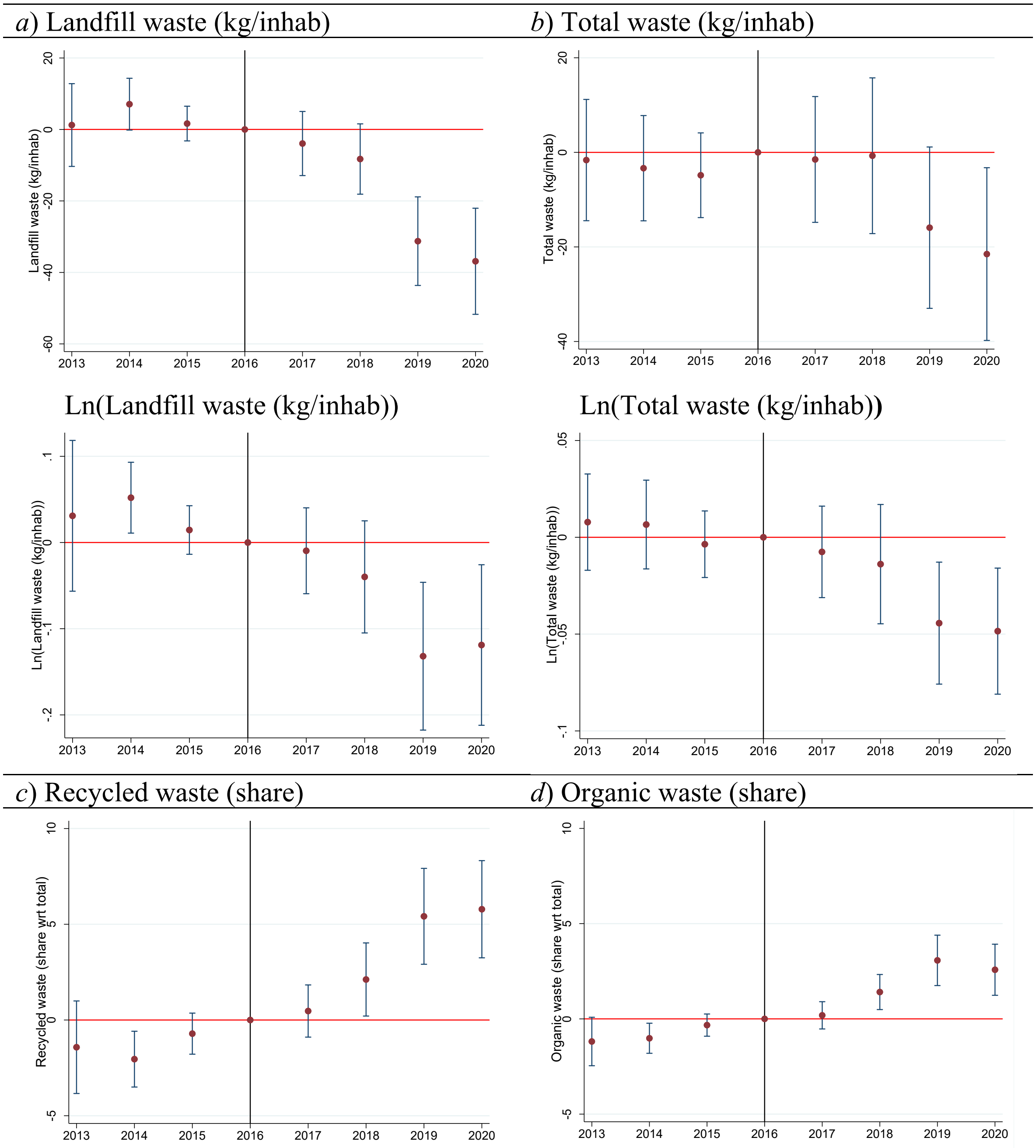
5. Results

5.1 Main results

Graph 4 shows the event-study TWFE results for landfill waste, total waste, share of waste recycled and share of total waste that is sorted and processed as organic waste. For the first two outcomes, we present results when the variable is specified in levels (top row) and in logs (second row). The coefficients plotted in Graph 4 reflect the differential effect of the tax hike in municipalities that had not adopted the DtD system by 2013 relative to those that had. Coefficients for the pre-tax hike period are generally not statistically significant, indicating that between 2013 and 2016, the evolution of waste generated and recycled was similar between municipalities that did DtD in 2013 and those that did not.

The two groups of municipalities start to evolve differently in the years after the tax hike was implemented. As explained in Section 2, the tax rate was increased from 18€ to 30€ per ton in 2017 and it was announced that between 2018 and 2020 this rate would increase linearly to reach 47€ per ton in 2020. The tax hike has led to both a greater reduction in waste generated and a larger increase in recycled waste in municipalities that were not implementing the DtD system in 2013 in comparison to those that had already adopted it. Differences in outcomes tend to become larger and statistically significant in 2019 and 2020. Starting with panel *a*), by 2020, compared to municipalities that had not adopted the DtD by 2013, the tax hike reduced landfill waste by about 37 additional kg per person and year in those municipalities that had not adopted the DtD collection system by 2013. This amounts to an additional reduction of 12% of its mean value in 2013. This effect is very similar in magnitude to that of the log specification reported in the bottom figure in panel *a*) which stands at 0.12 log points. As for total waste, the results in panel *b*) imply a differential tax impact on total waste of 22 kg per person and year in 2020, which amounts to 4% of its mean level in 2013. Again, this magnitude is very close to the 0.05 log points on the bottom figure in panel *b*). These results indicate that the tax hike did not only generate an additional reduction in the amount of waste deposited at landfills but also additionally reduced the total amount of waste generated. This last result suggests that the tax hike encouraged changes in consumption habits that led to reductions in total waste.

Graph 4. Effects of landfill tax on waste generation and waste recycling



Notes: Estimates of equation 1 with 95% confidence intervals based on standard errors clustered at the municipality level. N= 3672.

Moving to recycling outcomes, panel *c*) shows that the share of total waste that is recycled had increased by about 6 additional percentage points by 2020 in municipalities that had not adopted the DtD by 2013 relative to those that they had adopted it. This effect is quantitatively large if we consider that in our base year (2013) the average share of recycled waste was 40%. Finally, panel *d*) shows the effect on the share of total waste that is sorted and processed as organic. Here, the positive differential tax impact is 2.5 percentage points, which amounts to 20% of the baseline level (12.4%). These results suggest that landfill taxes levied on local governments can be an effective policy to promote recycling and significantly reduce organic waste that ends up in landfill sites, which is a major source of greenhouse gas emissions.

5.2 Differences in-differences estimates

Table 2 reports the results of the difference-in-differences specification (equation 2). The first column shows the estimated β coefficient for each outcome analyzed, which can be interpreted as the effect of 1€ per ton increase on the corresponding outcome. To ease interpretation, we also report the implied effect of a 29€ per ton increase (the tax hike) and this effect relative to the mean outcome in 2013.

Table 2: Difference-in-differences estimates of the effects of landfill tax on waste generation and waste recycling

	(1)	(2)	(3)	(4)	(5)	(6)
	Landfill waste (kg/inhab)		Total waste (kg/inhab)		Recycled waste (%)	Organic waste (%)
		Ln		Ln		
Landfill tax rate	-1.165***	-0.005***	-0.472*	-0.002***	0.223***	0.119***
	(0.242)	(0.002)	(0.262)	(0.000)	(0.044)	(0.024)
Effect of 29 euros per ton increase:						
	-33.8	-0.145	-13.7	-0.058	6.47	3.451
Effects of 29 euros per ton increase relative to mean value in 2013:						
	-11.1%		-2.7%		16.1%	28.1%
Mean in 2013:						
	303.7		501.1		40.0	12.36

Notes: Difference-in-differences estimates (equation 2) with standard errors clustered at the municipality level. N= 3672. ***, ** and * denote statistical significance at 1, 5 and 10% levels.

The results on landfill waste in levels (column 1) imply that a 29€ per ton increase is expected to reduce landfill waste by an additional 33.8 kg per person and year in municipalities that had not adopted the DtD by 2013 relative to those that had, which corresponds to a 11.1% reduction with respect to its mean value in 2013. The results in column 2, where the same outcome has been logged, are slightly larger in absolute value (0.145 log points). Columns 3 and 4 present the analogous results for total waste. In column 3, the estimated coefficient (which is only statistically significant at the 10% level) implies that the tax hike reduced total waste by 13.7 kg more in municipalities that had not adopted the DtD by 2013 or 2.7% of the mean value. The results in column 5 indicate that the 29€ per ton increase in the landfill tax rate increased the share of recycled waste by 6.5 additional percentage points in treated municipalities relative to municipalities in the control group. Finally, the tax hike increased the share of total waste that is sorted and processed as organic waste by 3.45 additional percentage points in municipalities that had not adopted the DtD by 2013, which amounts to a 28% increase. Overall, the implied differential tax effects reported in Table 2 are largely consistent with the event-study results reported in Graph 4.

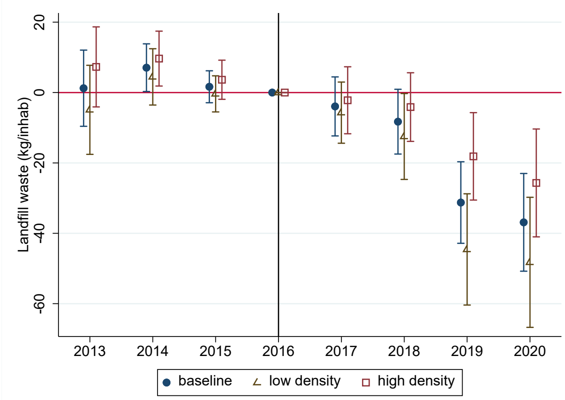
5.3 Heterogeneity analysis

In this section we explore if the differential impact of the tax change on municipalities that had not yet adopted DtD collection (by 2013) as compared with those that had are heterogeneous in various dimensions. First, since the suitability of waste collection practices depends on factors related to population density, we estimate equation 1 for municipalities below and above median population density, defined as population over the municipality's area. The results are presented in Graph 5.

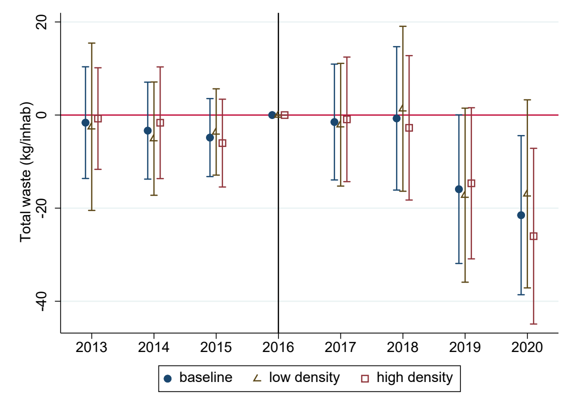
With the exception of total waste (panel *b*), the estimated differential effects are larger (in absolute value) for low density municipalities for landfill waste (panel *a*), the share of waste recycled (panel *c*) and the share of total waste that is sorted and processed as organic (panel *d*). These differences are quantitatively important. For example, as shown in panel *c*, by the end of the period, among municipalities with low density, those that had not adopted the DtD by 2013 increase the share of recycled waste by 8.5 additional percentual points relative to those that had adopted the DtD while the analogous estimate for the sample of high density municipalities is only 2.8 percentual points. The precision of the estimates when splitting the sample is not high. With the exception of the share of recycled waste at the end of the period, these differences are generally not statistically significant despite being large in size. The results obtained are similar if instead of population density, we consider the share of tall residential buildings (defined as 4-storey buildings or taller) or population size. The results are reported in Graphs A1 and A2 in the annex. Overall, these results indicate that municipality responses to landfill taxes are determined by the urban landscape with smaller responses in denser municipalities where the choice of waste collection systems might be more constrained.

Graph 5. Effects of landfill tax on waste generation and recycling for low and high population density municipalities

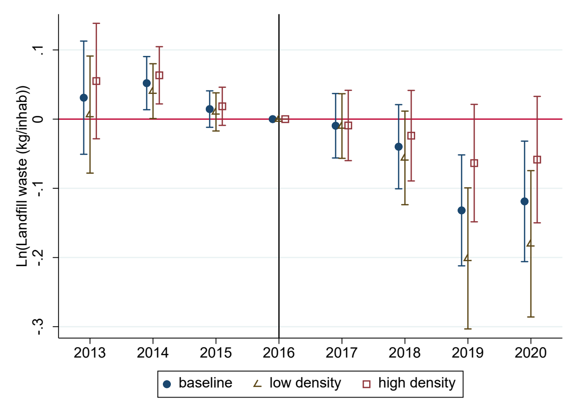
a) Landfill waste (kg/inhab)



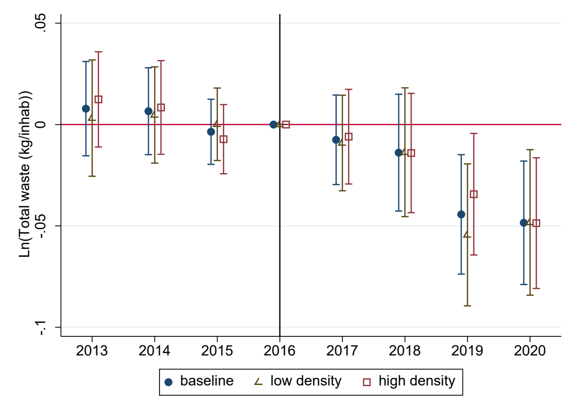
b) Total waste (kg/inhab)



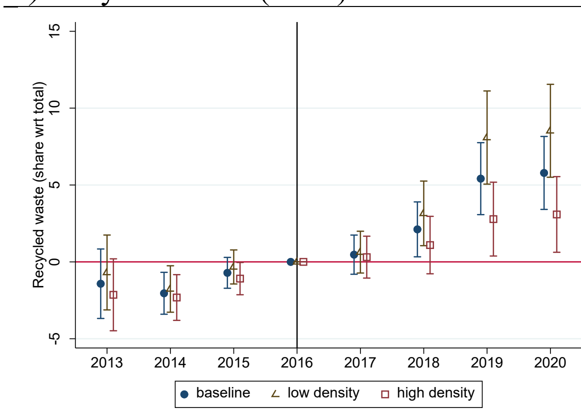
Ln(Landfill waste (kg/inhab))



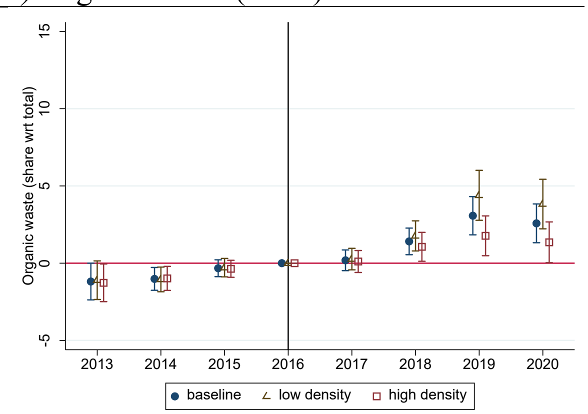
Ln(Total waste (kg/inhab))



c) Recycled waste (share)



d) Organic waste (share)



Note: Estimates of equation 1 with 95% confidence intervals based on standard errors clustered at the municipality level. Low (high) density are municipalities with density (population over total area) below (above) the median in our sample. N= 3672.

We also explore whether the estimated tax effects differ with municipality characteristics that can capture different political costs associated with adopting changes that favor recycling. More specifically, we estimate heterogeneous effects for municipalities with different proportions of individuals with college degrees (Graph A3), municipalities where the mayor has the majority of seats in the council or not (Graph A4) and municipalities where the mayor belongs to a left-wing party or not (Graph A5).[17] All these analyses suggest that the tax effects that we estimate are not heterogeneous with respect to variables that capture differences in political costs to green policy implementation.

5.4 The role of the waste collection system as a mechanism

As we have seen in Graph 1 in Section 2, the tax hike coincides in time with a surge in the proportion of municipalities that implement a DtD waste collection system. Thus, the tax effects documented in Graph 4 might be partly driven by the adoption of the DtD system as it fares better in terms of waste generated and recycled (see Graph 2). To explore this channel, in Graph 6 we plot landfill waste (panel *a*), total waste (panel *b*) and the shares of recycled and organic waste (panels *c* and *d*) for three groups of municipalities. Namely, those that adopted DtD by 2013 (the control group), those that took it up between 2013 and 2020 and those that had still not adopted the system by 2020.[18]

The graphs for all four outcomes convey the same messages. Municipalities that adopted DtD by 2013 and municipalities that had not adopted the DtD system by 2020 evolve similarly over the study period. This suggests that the tax effects that we estimate might be driven by municipalities that adopted the DtD as a response to the landfill tax hike. Consistent with this intuition, the changes in outcomes in municipalities that adopted the DtD system between 2013 and 2020 start to materialize around 2017 and not before.

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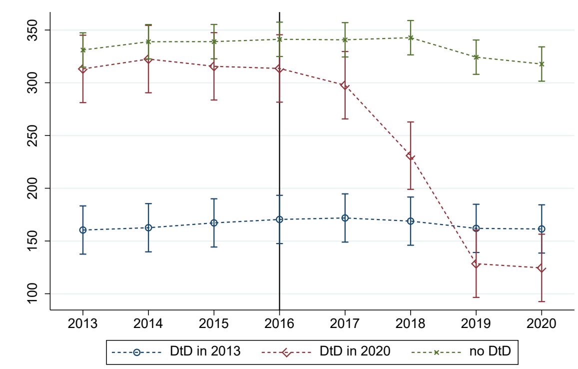
[17] In a related study, Gainza and Montes-Nebreda (2023) study the local political costs of the DtD system. They show that the adoption of the DtD affected the vote share of the two main contenders in municipal elections (EH Bildu and PNV) in Guipuzkoa, a Basque province. After the 2011 local elections, EH Bildu implemented DtD in municipalities they governed with absolute majority. The authors show that this policy had an electoral cost in the following elections.

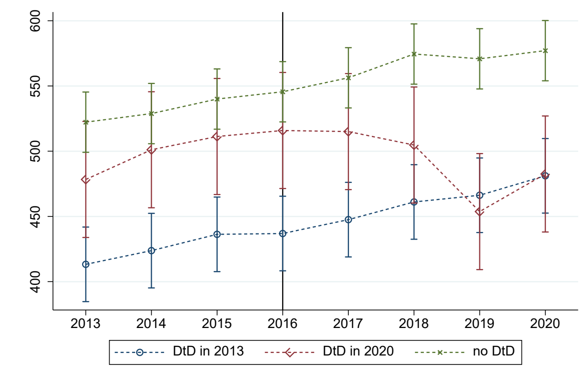
[18] Note that by construction all municipalities in our control group are already using DtD at the beginning of our study period. Thus, we cannot estimate the effect of tax hike on the adoption of the DtD collection system. Therefore, in this section, we cannot provide formal causal evidence that the DtD is the main driver of our results.

Graph 6. Waste generated and recycled for municipalities with door-to-door in 2013, taking it up in 2013-2020 and not taking it up at all.

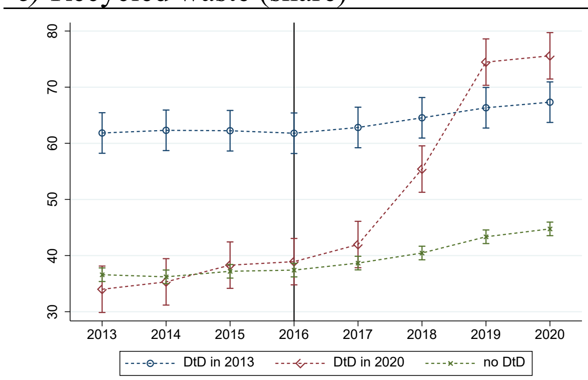
a) Landfill waste (kg/inhab)



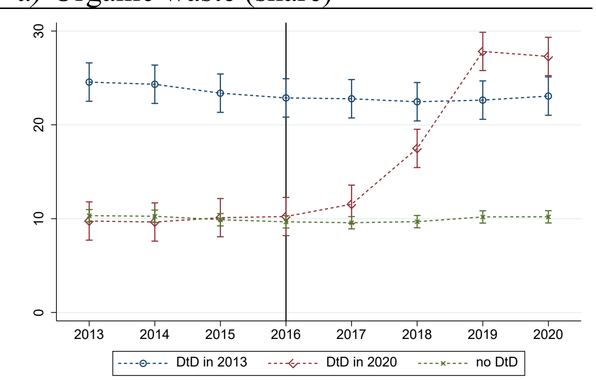
b) Total waste (kg/inhab)



c) Recycled waste (share)



d) Organic waste (share)



Notes: The graph reports the averages and 95% confidence interval for the three groups of municipalities. 68 municipalities had adopted the DtD in 2013, 53 municipalities adopted DtD between 2014 and 2020 (DtD in 2020) and 338 municipalities had not adopted it by 2020 (no DtD).

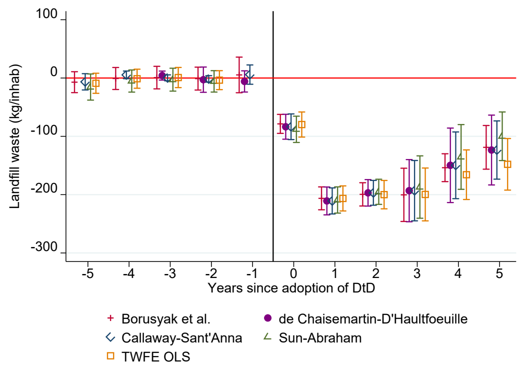
To provide further evidence on this mechanism, and focusing on the sample of municipalities that were not using the DtD at the beginning of our period (i.e. the treatment group), we estimate the causal effect of the adoption of DtD on the outcomes of interest. More specifically, we estimate variants of the following Two-Way Fixed-Effects event-study specification:

$$y_{it} = \sum_{j=-T}^{j=K} \beta_j \times DtD_{ih-j} + \delta_i + \delta_t + \varepsilon_{it} \quad (3)$$

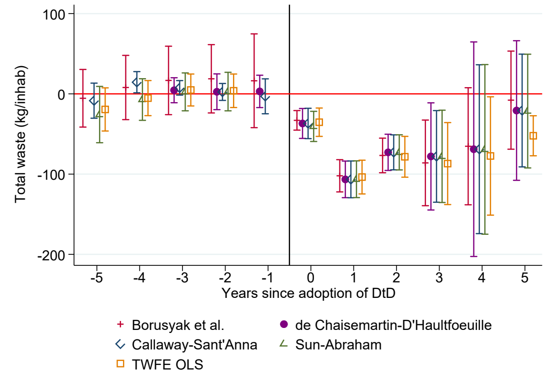
where h denotes the time period municipality i has adopted the DtD system and, therefore, each β_j coefficient captures the effect of a specific year since the adoption of the DtD system.

Graph 7. The effect of Door-to-door adoption on waste generated and recycled

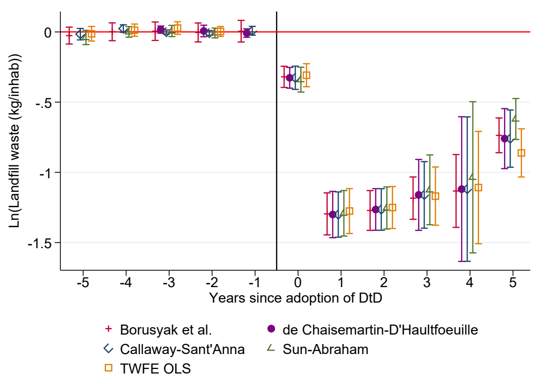
a) Landfill waste (kg/inhab)



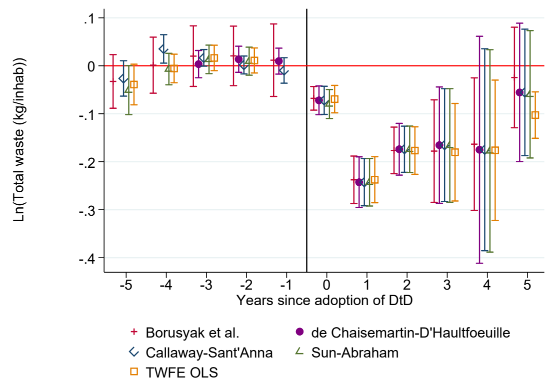
b) Total waste (kg/inhab)



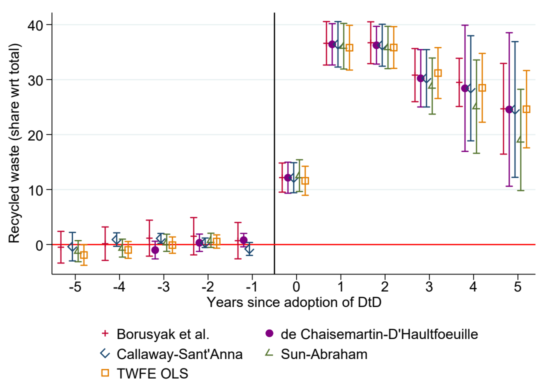
Ln(Landfill waste (kg/inhab))



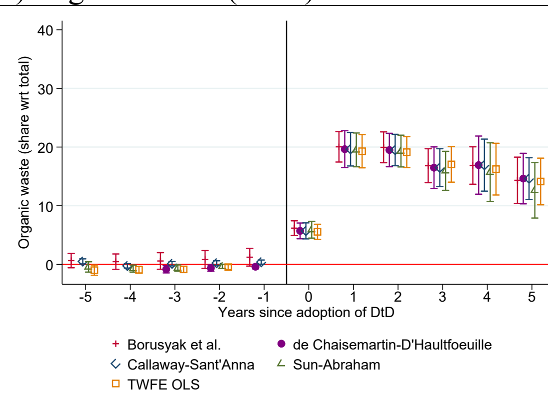
Ln(Total waste (kg/inhab))



c) Recycled waste (share)



d) Organic waste (share)



Notes: Estimates of equation 3 with 95% confidence intervals based on standard errors clustered at the municipality level. Sample composed of the 53 treated municipalities that adopted the DtD during our study period (i.e. 2013-2020) and 338 control municipalities that have not adopted the DtD system by 2020. This figure overlays the event-study plots of five different estimators: Borusyak et al. (2021), de Chaisemartin and d'Haultfoeuille (2020), Callaway and Sant'Anna (2021), Sun and Abraham (2021), and the TWFE model (equation 3).

Here, the identification strategy is based on the assumption that, in the absence of the adoption of the DtD system, the waste generated and recycled should have evolved similarly. In contrast to the specification outlined in equation 1, in equation 3 the treatment is the adoption of the DtD system and it takes place at different points in time for different municipalities. Thus, the treatment timing is staggered. Recent research in econometrics has shown that the TWFE estimator outlined in equation 3 can perform poorly in the presence of heterogeneous effects (de Chaisemartin and d'Haultfoeuille, 2022).

Graph 7 reports different estimators that have been recently developed to overcome this limitation.[19] The results show that, in our analysis, the coefficient estimated by these alternative estimators do not differ substantively. The evidence in Graph 7 indicates that adopting the DtD system has very large causal effects on all four outcomes analyzed. Two years after adopting this collection system landfill waste is reduced by about 200 kg per person compared to municipalities that did not adopt the DtD, which corresponds to two-thirds of the mean landfill waste in 2013 (303 kg). Total waste is reduced by about 100 kg per person, representing 20% of the mean value in 2013 (501 kg). As for recycling rates, adopting the DtD increases the share of waste recycled by 35 percentage points which is almost 90% of its mean in 2013 (40%). Finally, the share of waste that is sorted and processed as organic increases by 20 percentage points which is significant given that the mean value in 2013 is 12.3%. For all outcomes, the effects become smaller after the second year suggesting that the stringency of the DtD system is relaxed in the years following its implementation. Nevertheless, the effects are still substantial five years after its adoption. Landfill waste and total waste have been reduced by 150 and 50 kg per person while the recycled share and the share of waste that is sorted and processed as organic have been increased by 27 and 15 percentage points. Coefficients for the time periods that precede the adoption of the DtD system are not statistically significant. This indicates that before the

[19] The five estimators reported are: Borusyak et al. (2021), Sun and Abraham (2021), Callaway and Sant'Anna (2021), de Chaisemartin and d'Haultfoeuille (2020) and the TWFE model of equation 3. These estimates mainly differ on how the control group is defined, on whether they allow to include covariates (additionally to the fixed effects) and on how the treatment effects are aggregated. The fact that we have a large pool of never-treated units in our setting, i.e. 338 units never-treated units vs. 53 treated units, might explain why all estimators yield similar results.

adoption of the DtD system, the evolution of waste generated and recycled was similar between the treated and the control groups of municipalities.

In Graph A.7, deferred to the annex, we show the evolution of the share of municipalities using the DtD collection system depending on the baseline municipality characteristics considered in the heterogenous analysis section (5.3). Namely, population density (low versus high), share of tall residential buildings (low versus high), population size (small versus big), proportion of college degree individuals (low versus high), majority of seats in council (no versus yes) and left-wing mayor (no versus yes). The municipality characteristics associated with a higher adoption of the DtD system are a low population density, a low share of tall residential buildings and small population size. As expected, these are the same municipal features associated with larger impacts of the tax hike on waste generated and recycled (see Graph 5 and Graphs A.1-A.5). This evidence supports the hypothesis that the main driver of the tax effects that we estimate is the adoption of the DtD collection system.

6. Concluding remarks

Landfill solid waste poses a considerable environmental challenge given that it is a significant source of greenhouse gas emissions. Consequently, effective waste management and the implementation of policies promoting reuse, reduction and recycling are crucial in the fight against climate change. One tax instrument available to reduce landfill waste and increase recycling rates is the landfill tax, which is typically paid by local governments for the waste deposited in landfills.

This paper analyzes the effects of the landfill tax on waste generated and recycled at the municipality level using a tax hike that took place in Catalonia, a Spanish region, in the 2017-2020 period. Municipalities that have historically done less to reduce landfill waste and increase recycling are expected to have more leeway to respond to the tax hike. The DtD collection system is a key technology to increase recycling and reduce waste sent to landfill sites. We define those municipalities that had already adopted the DtD at the beginning of our study period as the control group. Therefore, our estimates identify the differential impact of the tax change on municipalities that had not yet adopted the DtD collection system (by the beginning of the study period) as compared with those that had. We apply event-study designs and difference-in-differences estimates and find large differential responses to the tax increase. Compared with municipalities that had adopted the DtD by 2013, increasing the tax rate from 18€ to 47€ per ton causes a 12% and 4% reduction in landfill and total waste, respectively. Additionally, it raises the share of total waste that is recycled by 6 percentage points and the share of waste that is sorted and processed as organic by 2.5 percentage points. In terms of mechanisms, these effects seem to be driven by the adoption of DtD waste collection by some municipalities.

Overall, our findings support the notion that the landfill tax can be an effective policy to promote a circular economy and reduce greenhouse emissions. The large responses to the tax hike that we document seem to be driven by local governments changing waste management practices which, in turn, have very large effects on waste generation and recycling rates. Our results also imply that the impact of landfill taxes may be more limited in contexts where most municipalities are already implementing the DtD collection system. Consequently, our study uncovers important complementarities between environmental taxation and waste management practices.

References

Adam S, Delestre I, Levell P and Miller H. (2022). "Tax policies to reduce carbon emissions". Fiscal Studies 43(3), 235-263.

Andersson C, Stage J (2018), "Direct and indirect effects of waste management policies on household waste behavior: The case of Sweden", Waste Management 76, 19-27.

Andersson, J.2019. "Carbon Taxes and CO2 Emissions: Sweden as a Case Study." American Economic Journal: Economic Policy,11(4):1–30.

Barrow, M. (2003), "An economic analysis of the UK landfill permits scheme", Fiscal Studies 24(3), 361-381.

Bel i Queralt G, Gradus R. (2016), "Effects of unit-based pricing on household waste collection demand: a meta-regression analysis", Resource and Energy Economics 44, 169-182.

Blanchard, O, Gollier, C. And Tirole, J (2023): "The Portfolio of Economic Policies Needed to Fight Climate Change" Annual Review of Economics

Borusyak, K., Jaravel, X. and Spiess, J. (2021). "Revisiting event study designs: Robust and efficient estimation", arXiv preprint arXiv:2108.12419.

Callaway, B. and Sant'Anna, P.H. (2021). "Difference-in-Differences with multiple time periods", Journal of Econometrics 225(2), 200-230.

Carattini, S. Baranzini, A. and Lalive, R. (2018) "Is taxing waste a waste of time? Evidence from a supreme court decision", Ecological Economics 148, 131‑151.

Colmer, J., Martin, R., Muuls, M. And Wagner, U.J. (2023) "Does Pricing Carbon Mitigate Climate Change? Firm-Level Evidence from the European Uniona Emissions Trading Scheme", *Review of Economic Studies*, forthcoming.

Colussi T, Romagnoli M, Villar E (2022), "The intended and unintended consequences of taxing waste", CESifo Working Paper No. 9946.

de Chaisemartin, C. and d'Haultfoeuille, X. (2020). "Two-Way Fixed Effects Estimators with Heterogeneous Treatment Effects", American Economic Review 110(9), 2964-2996.

de Chaisemartin C, d'Haultfoeuille, X. (2022). "Two-way fixed effects and differences-in-differences with heterogeneous treatment effects: A survey" NBER Working Paper 29691.

EC (2015), European Commission. Closing the loop – An EU action plan for the circular economy. Brussels, COM/2015/0614 final.

EEA (2018), European Environment Agency. Environmental indicator report 2018. In support to the monitoring of the Seventh Environment Action Programme. No 19/2018, 29 pp. Luxembourg: Publications Office of the European Union.

Eurostat (2022), Climate change-driving forces 2022: Figures and Tables.

Fullerton D, Kinnaman, TC (1996), "Household Responses to Pricing Garbage by the Bag", The American Economic Review 86(4), 971–984.

Gainza, X. and Montes-Nebreda, A. (2023): "The Waste war: on the electoral costs of local sustainability policies", *Journal of Environmental Policy & Planning,* 25(5), 625-641.

Inèdit (2021), "Petjada de carboni de la gestió dels residus municipals de Catalunya, Generalitat de Catalunya.

Jaglo K, Kenny S and Stephenson, J. (2021). "From farm to kitchen: The environmental impacts of US food waste". US Environmental Protection Agency Office of Research and Development, 1-113.

Kinnaman TC (2006), "Policy Watch: Examining the Justification for Residential Recycling", Journal of Economic Perspectives 20 (4), 219-232.

Kinnaman, Thomas C (2009), "The Economics of Municipal Solid Waste Management", Waste Management: 2615-2617.

Matheson, T. (2022), "Disposal is not free: Fiscal instruments to internalize the environmental costs of solid waste", International Tax and Public Finance 29(4), 1047-1073.

Nicolli F, Mazzanti M. (2013), "Landfill diversion in a decentralized setting: A dynamic assessment of landfill taxes", Resources, Conservation and Recycling 81, 17-23.

Rennert K, Prest B, Pizer W, Newell R, Anthoff D, Kingdon C, Rennels L, Cook R, Raftery A, Ševčíková H, Errickson F. (2021), "The Social Cost of Carbon: Advances in Long-term Probabilistic Projections of Population, GDP, Emissions, and Discount Rates", Brookings Papers on Economic Activity, Fall. 223-275.

Rossi, M., Papetti, A., Germani, M. (2022). "A comparison of different waste collection methods: Environmental impacts and occupational risks". Journal of Cleaner Production 368, 133145.

Sun, L. and Abraham, S. (2021). "Estimating dynamic treatment effects in event studies with heterogeneous treatment effects", Journal of Econometrics 225(2), 175-199.

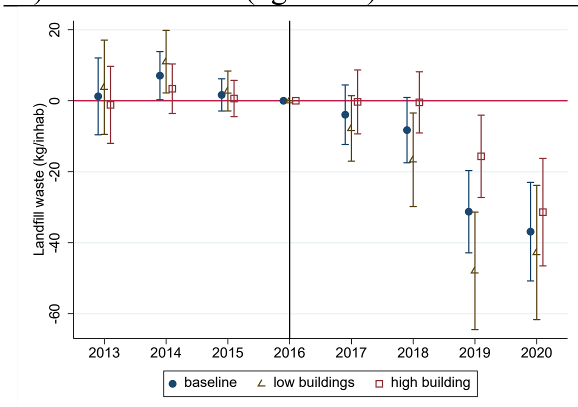
UN (2015a), United Nations. Paris Agreement to the United Nations Framework Convention on Climate Change.

UN (2015b), United Nations. UN General Assembly, Transforming our world: the 2030 Agenda for Sustainable Development, A/RES/70/1.

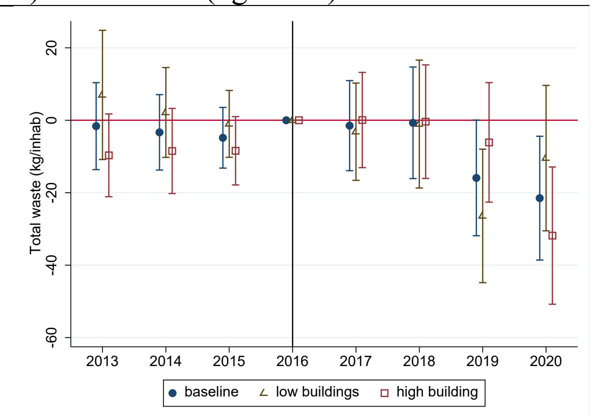
Annex. Graphs

Graph A1. Effects of landfill tax on waste generation and recycling for municipalities depending on the share of tall residential buildings (low versus high)

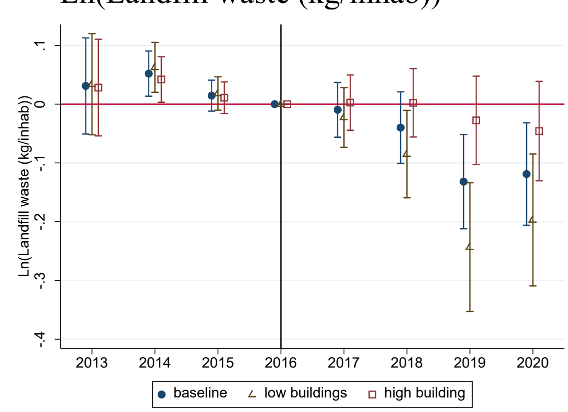
a) Landfill waste (kg/inhab)



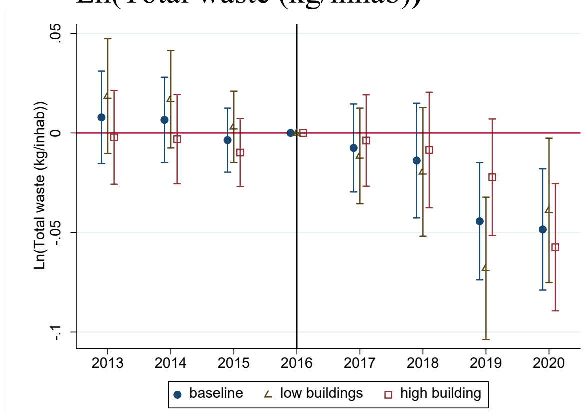
b) Total waste (kg/inhab)



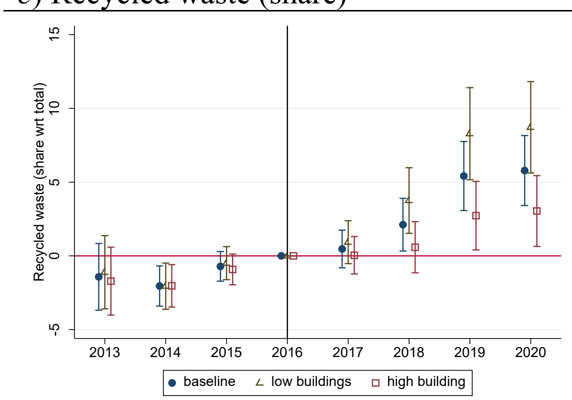
Ln(Landfill waste (kg/inhab))



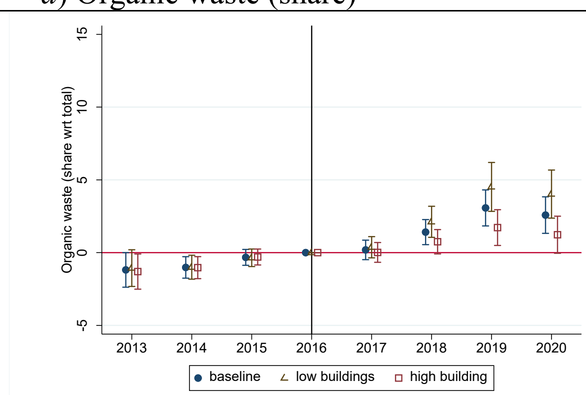
Ln(Total waste (kg/inhab))



c) Recycled waste (share)



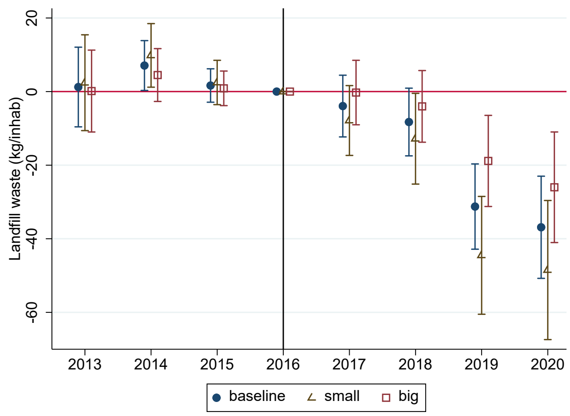
d) Organic waste (share)



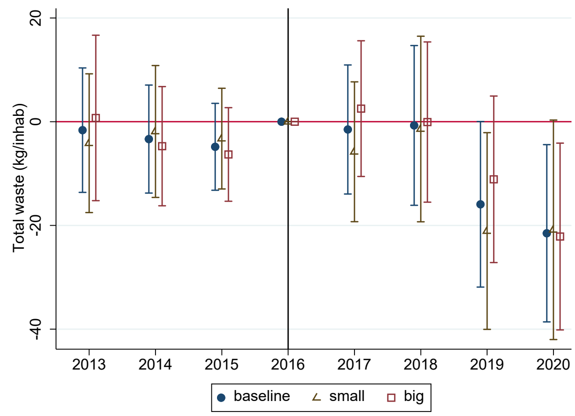
Notes: Estimates of equation 1 with 95% confidence intervals based on standard errors clustered at the municipality level. High (low) buildings are municipalities with a share of tall residential buildings (defined as 4-storey buildings or taller) above (below) the median in our sample.

Graph A2. Effects of landfill tax on waste generation and recycling for municipalities depending on their population size (small versus big)

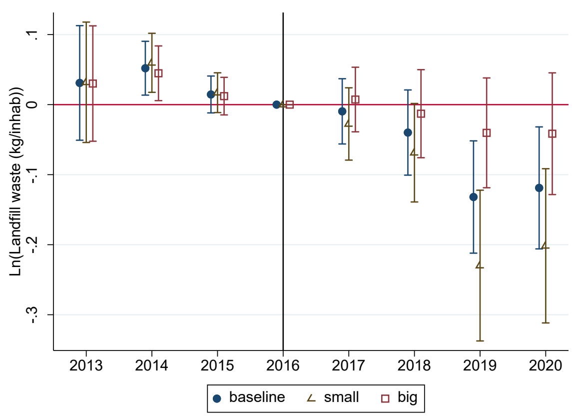
a) Landfill waste (kg/inhab)



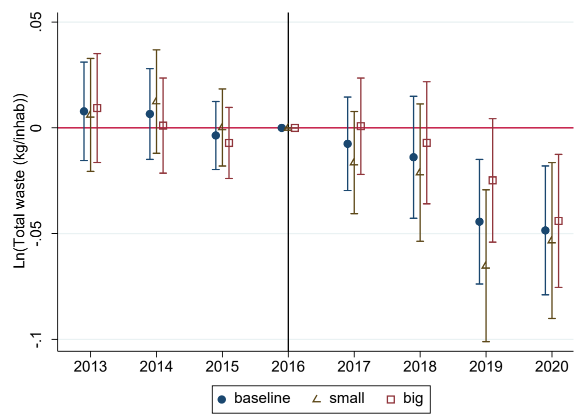
b) Total waste (kg/inhab)



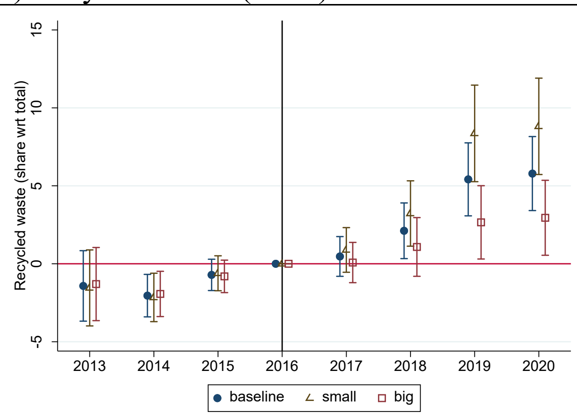
Ln(Landfill waste (kg/inhab))



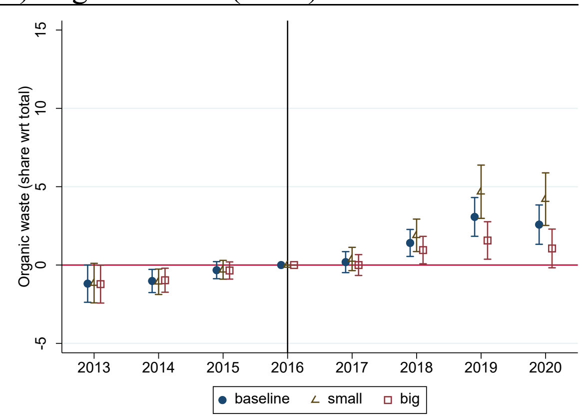
Ln(Total waste (kg/inhab))



c) Recycled waste (share)



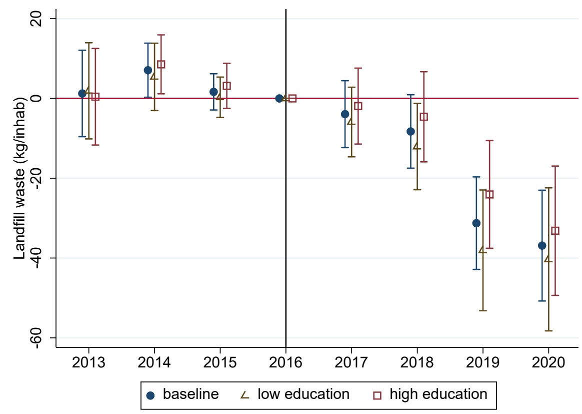
d) Organic waste (share)



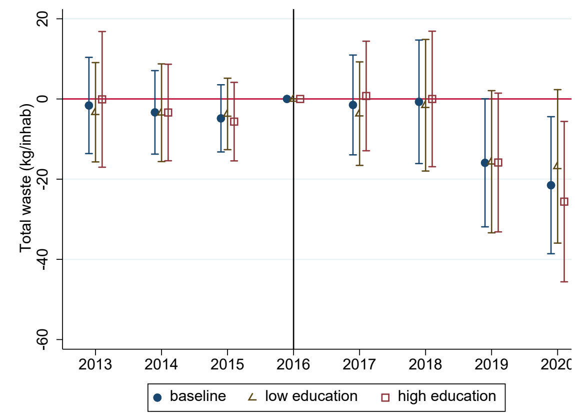
Notes: Estimates of equation 1 with 95% confidence intervals based on standard errors clustered at the municipality level. Small (big) municipalities are municipalities with population in 2013 below (above) the median in our sample.

Graph A3. Effects of landfill tax on waste generation and recycling for municipalities depending on the proportion of individuals with college degrees (low versus high)

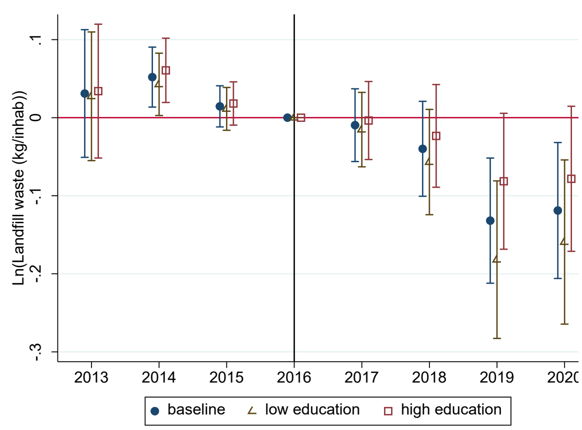
a) Landfill waste (kg/inhab)



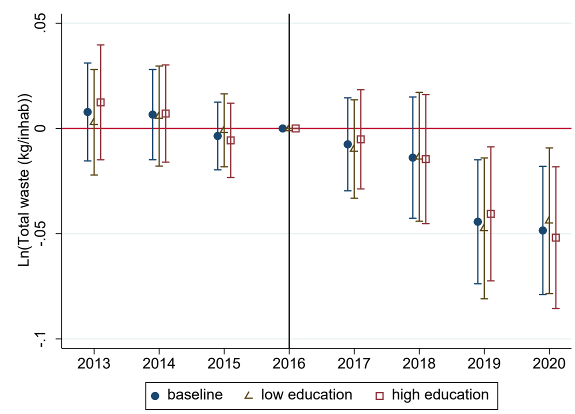
b) Total waste (kg/inhab)



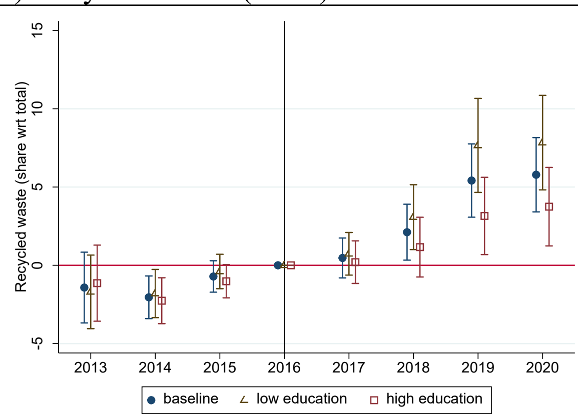
Ln(Landfill waste (kg/inhab))



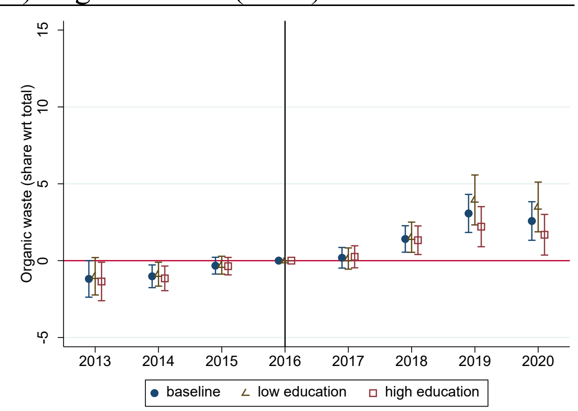
Ln(Total waste (kg/inhab))



c) Recycled waste (share)



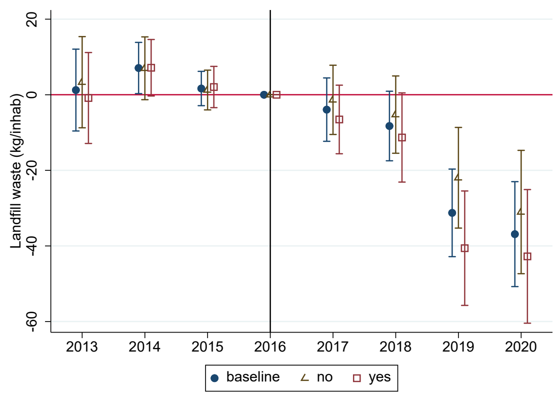
d) Organic waste (share)



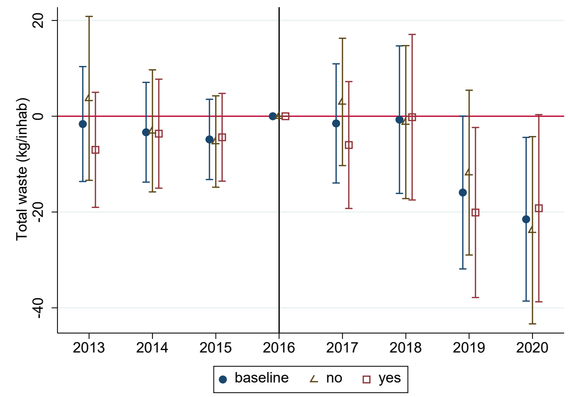
Notes: Estimates of equation 1 with 95% confidence intervals based on standard errors clustered at the municipality level. High (low) education are municipalities with a percentage of University education above (below) the median in our sample.

Graph A4. Effects of landfill tax on waste generation and recycling for municipalities depending on having a party with the majority of seats in council after the 2015 municipal elections (no versus yes)

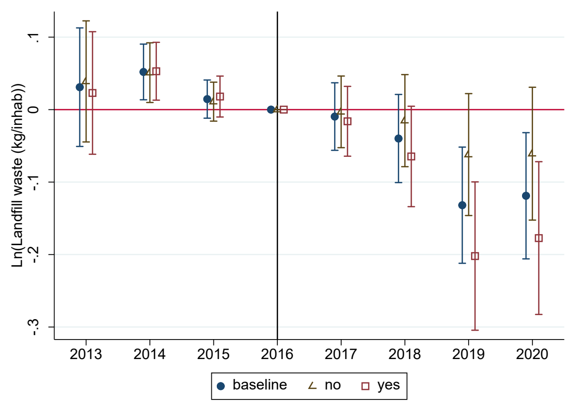
a) Landfill waste (kg/inhab)



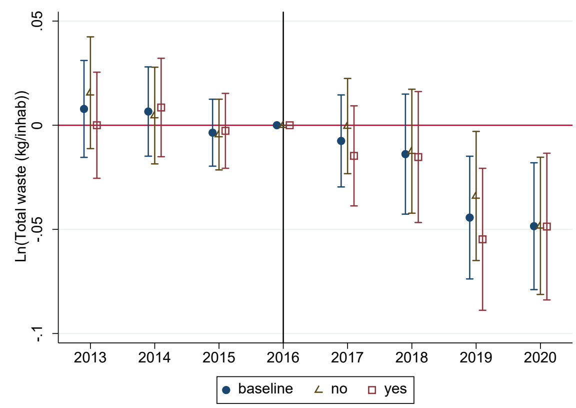
b) Total waste (kg/inhab)



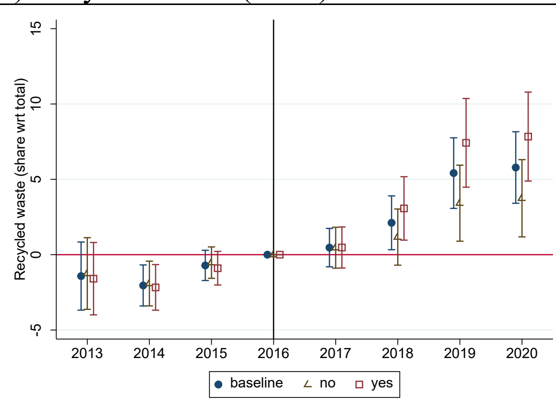
Ln(Landfill waste (kg/inhab))



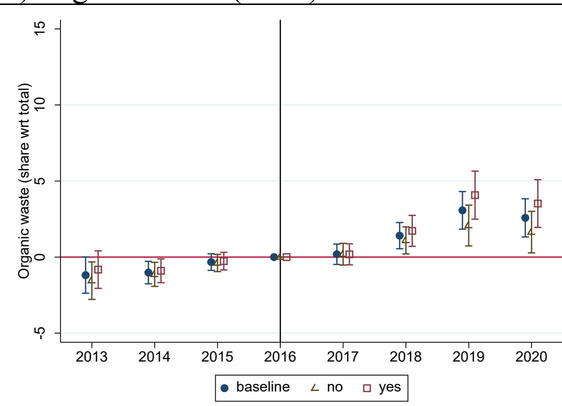
Ln(Total waste (kg/inhab))



c) Recycled waste (share)



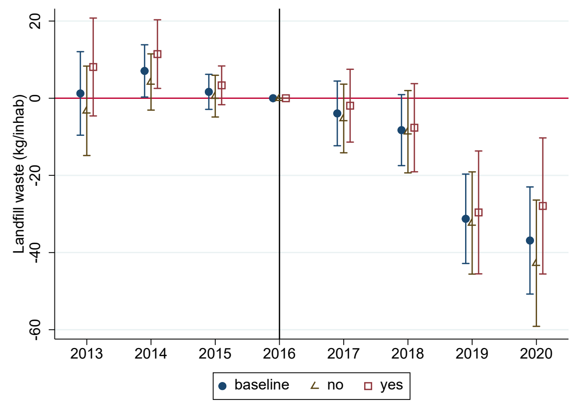
d) Organic waste (share)



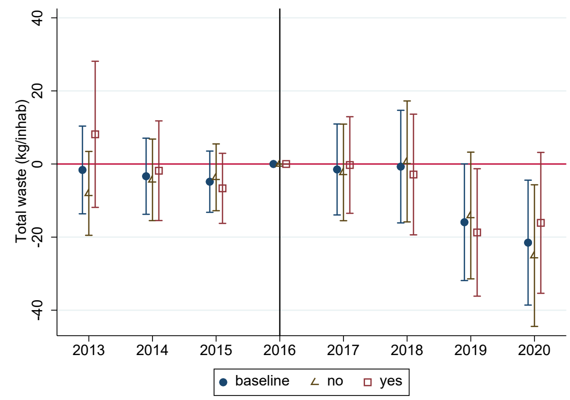
Notes: Estimates of equation 1 with 95% confidence intervals based on standard errors clustered at the municipality level. Absolute majority in terms of council seats in the 2015 local elections.

Graph A5. Effects of landfill tax on waste generation and recycling for municipalities depending on having a left-wing mayor after the 2015 municipal elections (no versus yes)

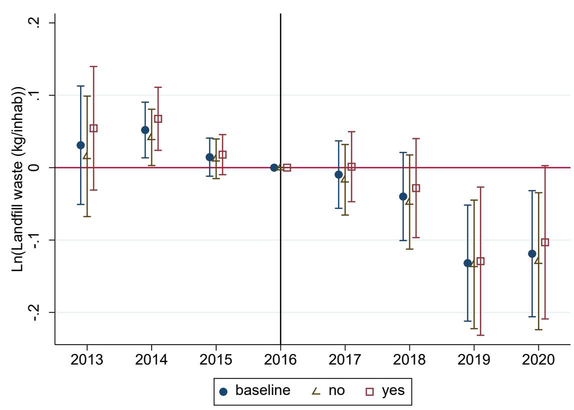
a) Landfill waste (kg/inhab)



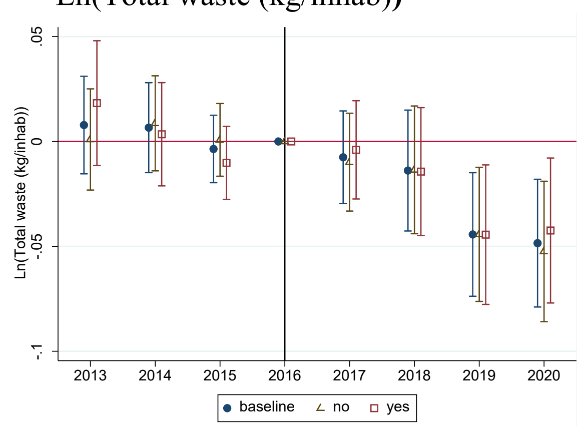
b) Total waste (kg/inhab)



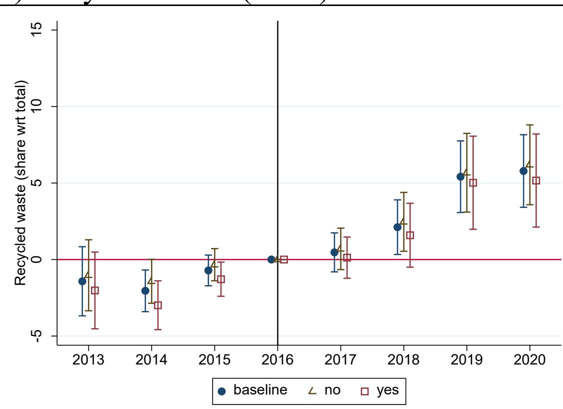
Ln(Landfill waste (kg/inhab))



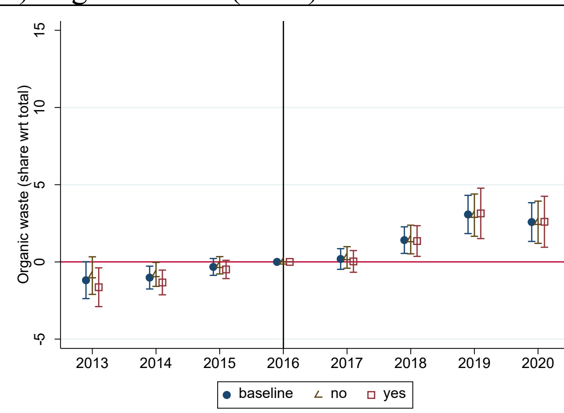
Ln(Total waste (kg/inhab))



c) Recycled waste (share)



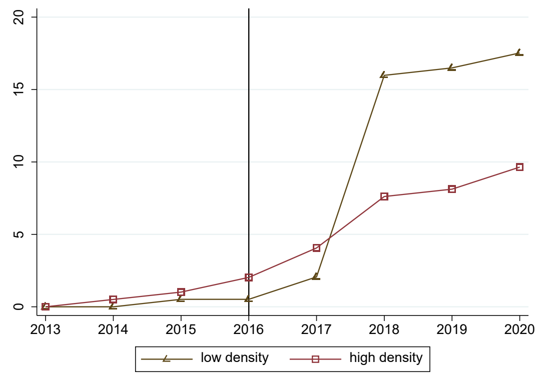
d) Organic waste (share)

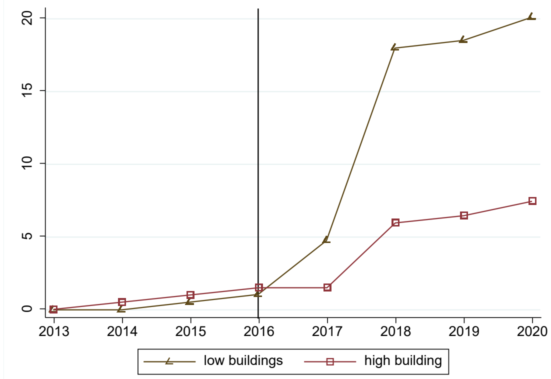


Notes: Estimates of equation 1 with 95% confidence intervals based on standard errors clustered at the municipality level. Left mayor defined as belonging to PSC, ERC, En Comú Podem and CUP parties. We have also defined it including local parties and the results do not vary substantively.

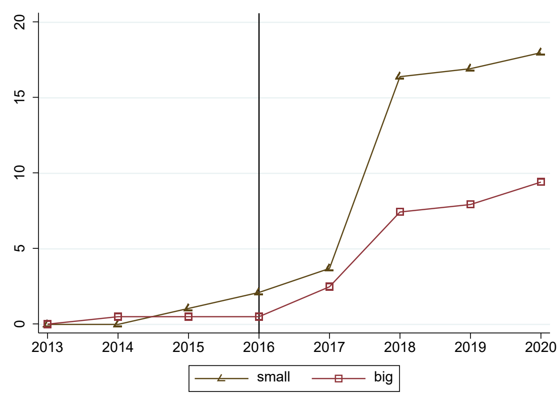
Graph A.6 Share of municipalities that have adopted the door-to-door collection system during the period 2013-2020 depending on municipality characteristics

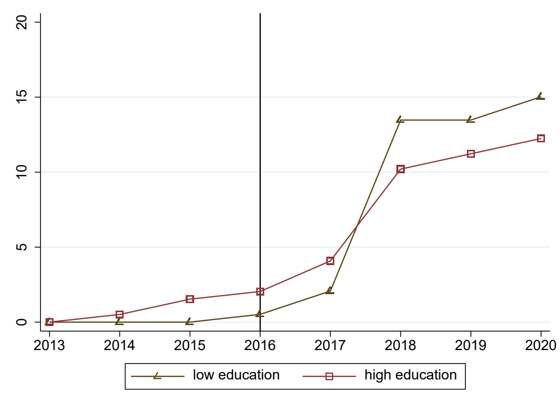
a) Population density: low versus high	*b*) Share of tall residential buildings: low versus high



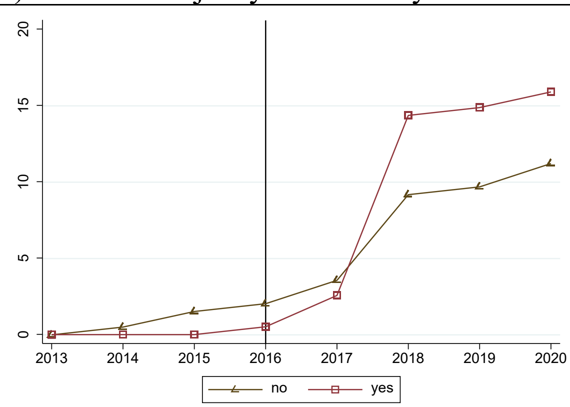


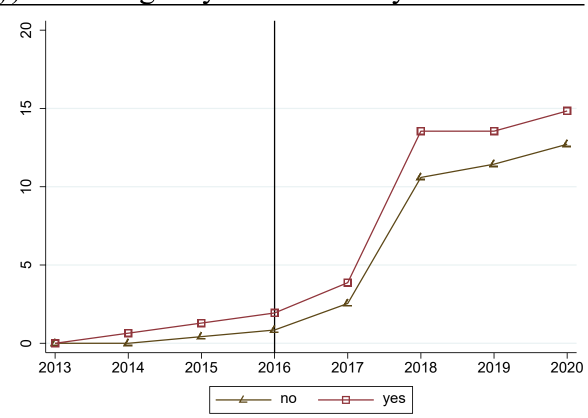
c) Population size: small versus big	*d*) Share of college degree individuals: low versus high





e) Absolute majority: no versus yes	*f*) Left wing mayor: no versus yes





Notes: Each dot represents the share (%) of municipalities that implements the DtD collection system by year. We consider the same characteristics used in the heterogenous analysis to split the sample.