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RESEARCH ARTICLE

# The effect of Door-to-Door on separate collection of plastic packaging: evidence from Catalonia

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## Abstract
In this article, we estimate the causal effect of the Door-to-Door waste collection policy on the collection of plastic waste in Catalonia. We use municipality-level data on the share of separately collected light packaging and apply a Difference-in-Differences framework. We find that Door-to-Door increased the share of separated light packaging by 80% compared to untreated units at the end of the sample period. Furthermore, our evidence indicates that there are no differences of Door-to-Door designs with source-separation of light packaging from other recyclable waste components compared to those where light packaging waste is collected with other materials and separated post-source. These findings highlight that Door-to-Door can be a highly effective measure to increase separate collection of light packaging, a precondition for ambitious plastics recycling goals legislated by policy makers.

**Keywords** Plastic waste · Door-to-Door · Recycling · Catalonia

**JEL Classification** K23; L65; Q53

## 1 Introduction

Environmentally sound waste management can have beneficial effects on climate change in several ways. These include reducing methane emissions from landfills; reduced industrial energy use and associated pollution; energy recovery from waste; and reduction of energy use in waste transport (Ackerman 2000). Reducing waste generation has long been recognized as a primary strategy for reducing environmental damage caused by waste. In addition to this, increased recycling -which reduces waste for disposal- was adopted as a major goal in the first systematic environmental programs for waste management, such as the Action Plan for Increased Recycling in Denmark in 1989 (Thøgersen 1994), the Solid Waste Master

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Plan in Massachusetts in 1990 (Callan and Thomas 2001), or the Container and Packaging Recycling Law enacted in Japan in 1995 (enforced in 1997; Kumamaru and Takeuchi 2023).

Indeed, waste management is directly mentioned in the Sustainable Development Goals (SDGs) defined by United Nations (UN 2015): goal 12 includes reduction of food waste (target 12.3) and environmental management of all waste by means of prevention, reduction, recycling, and reuse (targets 12.4 & 12.5). The guiding principles of the UN SDGs are analogous to those of solid waste management (SWM) based on the circular economy -CE- (Sharma et al 2021). In the same vein, the current policy in the European Union (EU) is based on ambitious targets for waste recycling established in 2018 (EC 2018), and requires EU Member States to increase the recycling target of municipal waste to 55% of all waste generated by 2025, 60% by 2030 and 65% by 2035.

Most studies in the literature find that recycling is generally superior to incineration in terms of social costs, i.e. including environmental externalities in costs and benefits (e.g., Morris 1996; Ferreira et al 2017), which is consistent with the fact that recycling is promoted by public policy around the world, as noted above. In this sense, the separation of waste is the most efficient way to increase effective recycling and reuse, and source-separated waste collection increases the efficacy of separation (Di Maria et. al, 2020; Degli Esposti et al. 2021), and avoids a significant amount of greenhouse emissions (Wünsch and Simon, 2018).

Plastic waste is of particular concern, due to its extraordinary environmental damage, both when it comes to climate change and local pollution (e.g., Li and Takeuchi 2023). Consequently, increasingly stringent regulations regarding plastic waste are spreading around the world. In that regard, the European Commission also introduced ambitious targets specifically for the recycling of plastics (EC 2018), which should reach a minimum of 50% by 2025, and 55% by 2030 (art 6 Directive). Furthermore, the EU adopted in 2019 the 'Single-Use Plastic Directive' (EC 2019), which contains a wide range of measures intended to reduce plastic waste (see a detailed overview in Kiessling et al. 2023). In addition to the reduction of plastic litter, other measures are being taken to encourage increased recycling of plastic waste. Moreover, the European Commission published its Circular Economy Action Plan (EC 2020) in which it was announced that further targeted measures will be taken to address the sustainability challenges posed by plastic waste.

However, there is intense debate as to whether in the specific case of household plastic, waste recycling is superior to incineration, when all benefits and costs are considered (e.g. Merrild et al. 2012; Gradus et al. 2017).[1] In addition to this, there is no unanimous agreement on the superiority of source separation of packaging plastics with respect to post-separation. According to Klingenberg et al (2024),

[1] As explained in Gradus et al. (2017: 22), the main benefit of recycling plastics is the avoidance of CO2 emissions that would otherwise occur during incineration and the production of virgin (new) plastic material, while the main benefit of incinerating plastic waste is the energy that can be recovered, which reduces emissions in the conventional energy production sector. On the other hand, the main costs associated with recycling are related to collection, separation, sorting, and recycling, and the main cost associated with incineration is that it requires a capital-intensive waste-to-energy plant.

the separation system -whether source or post-source- has only limited impact on the waste stream quality, although technological differences in the post-source separation—whether manual or automated, what washing procedure is used—can play a role in the quality obtained (Cecon et al. 2023; Luijsterburg & Goossens 2014). From a more general approach, Dijkgraaf and Gradus (2020) argue that post-source separation of plastic is preferable to source separation both economically and environmentally in the Netherlands.[2] Albizzati, Tonini and Gaudillat (2024) have recently noticed that in countries with most advanced recycling policies and waste management, the question may be arising whether there is a limit to sorting and separation (whether source or post-source), and whether there is an optimum, instead of a maximum, level of waste separation.

Regardless of the intense academic debates about the optimal extent and form of separation of household plastic waste, institutional policy pushes towards ambitious plastic recycling targets in the near future. In the case of the EU discussed previously, debates also revolve around the appropriate policy measures to bring the laggard member states closer to the leaders (EEA 2023). Against this backdrop, the Door to Door (DtD) collection system is attracting attention and interest (e.g., Degli Esposti et al. 2023). One of many advantages of this system is that it facilitates a more effective segregation of waste, thus making possible an increase in the recycling rate. In fact, Abeshev and Koppenborg (2023) found, by means of linear regression analysis, that promoting DtD bio-waste collection increased sorting of dry recyclables in several European cities. On the other hand, since waste collection costs typically increase in the number of collection points, DtD is likely to increase service costs (Dijkgraaf and Gradus 2015).

There are good reasons to expect that expanding DtD will especially increase plastics sorting: Existing empirical evidence on household waste sorting behavior shows a high preference for plastics sorting, because it is recognized as an important environmental problem (see, e.g., Niangolan et al., 2019 for Denmark; Mielinger and Weinrich 2024, for Germany). This is the hypothesis that we test in this article by empirically analyzing the effect of the expansion of DtD on the separation of light packaging waste. Note that the estimated composition of lightweight packaging is as follows (ARC 2024b): About half is plastic packaging, a third metal packaging and a sixth is mixed or composted packaging. Therefore, changes in lightweight packaging will largely affect plastics.

Environmentally sound management plays a relevant role in waste collection in Catalonia (see, Bel and Elston 2024; Jofre-Monseny and Sorribas-Navarro 2024). We take advantage of a large database with information on the adoption of DtD by municipalities in Catalonia between 2000 and 2022 (both the time of adoption and the degree of extension within each jurisdiction) and data for the same period for the detailed volumes of different waste components that are collected in each

[2] In the Netherlands, unit-based pricing for residual waste may have created incentives to contaminate separated plastics with other waste components, reducing the quality of source separated plastics and thus making source separation less effective. Therefore, the findings from the Netherlands may not be easily generalizable to systems with little or no unit-based pricing.

municipality. We adopt a quasi-experimental approach, using Differences-in-Differences estimators in the setting of staggered adoption. Our main results reveal that DtD increases the share of separated light packaging in total waste by about 2.9 percentage points, an increase of around 80% over non-treated municipalities *at the end of the period*.[3] Furthermore, we find that DtD schemes that exclude user-based light packaging sorting have a marginally bigger effect than DtD schemes that include user-based sorting of light packaging, but the difference is not statistically significant. Similarly, systems where light packaging continues to be collected outside of DtD but DtD is introduced for other waste components perform slightly better, indicating large spillover effects from the separation in other waste components to light packaging. However, the difference to other DtD versions is not statistically significant either.

With this article we make a two-fold contribution to the literature on waste management. First, we use the most up-to date quasi-experimental techniques to estimate the effect of DtD on light packaging sorting, pointing out the potential contribution of DtD to plastics recycling. Second, we provide evidence on the difference in the effect of DtD depending on whether light packaging separation is included in DtD, and if so, if separation is done by the user or post-source.

## 2 Institutional, regulatory and policy background for waste management

### 2.1 Institutions

Our analysis of the effect of DtD collection on the separation of plastic packaging is conducted on data from the municipalities of Catalonia. Municipalities are the lowest level of elected government and are required by Spanish law (Law 7/1985) to provide waste management services. Municipalities are responsible for both waste collection (which includes transportation) and treatment. Because of the type of facilities and equipment required, the treatment has become usually managed by supra-municipal local entities (such as the counties, or the metropolitan area of Barcelona -AMB-). Collection, however, remains a municipal responsibility. In that regard, it is the municipal government who decides how the service is provided (by the municipality itself, or cooperating with other municipalities), and how it is organized (whether public delivery is used, or it is contracted out, instead; also, the type of collection techniques). All this happens within the framework of environmental regulations.

[3] We use this conservative comparison because comparing to the untreated at the beginning of the period risks inflating the effect; baseline plastics separation rates were almost zero and there was a general upwards trend independently of the DtD policy.

### 2.2 Regulations

The Catalan legislator is responsible for the regulation of waste management, subject to European directives on environmental policies that affect waste management. *Agència de Residus de Catalunya* (ARC, Catalan Waste Agency) is the regulatory agency, which is in charge of regional monitoring and supervision of municipal compliance with regional regulations. Therefore, all municipalities in our study are subject to the same legislation and regulatory framework.

Among the legal norms passed in recent times that have relevant effects on environmental management of waste management, two are worth mentioning for our purposes.[4] Firstly, with Law 16/2003 (on the financing of waste treatment infrastructures and the creation of a landfill tax) a landfill tax was introduced. Secondly, Legislative Decree 1/2009 (which integrated the previous legislation in force on waste management) made compulsory the establishment of a system that allows selective collection, and a tax on incinerated solid waste was created in the same year.

### 2.3 Environmental management of waste collection

Since 2009, municipalities in Catalonia must have selective collection schemes. To that purpose, they can choose into what categories users separate their waste. Street collection with containers is the most common technique, and it requires residents to drop their sorted waste outside of their homes, usually within a few minutes of walking distance. The most widespread system consists of five components (glass, paper/cardboard, organics, light packaging, and refuse).[5] Therefore, there is no separate collection of plastic only in Catalonia. Instead, light packaging such as milk packages, cans, PET bottles and other plastic materials are sorted into the same bins by households. Further sorting is then done manually or mechanically at industrial waste selection plants. Finally, those components suitable for recycling are sent to recycling plants. The process of interest for our research is selection by households into the light packaging category ("source separation") or into a larger category which includes light packaging, which is then sorted further (post-source).

As previously mentioned, environmentally sound management of waste has been promoted in Catalonia in the last two decades. Local governments in charge of waste management have increased their ambition for selective collection and recycling (Bel and Elston 2024), and the regional regulator has introduced and expanded

[4] While Unit-Based Pricing (UBP) is being used in a variety of countries, with effective results in reducing waste generation (see Bel and Gradus 2016). However, it is only marginally used in Catalonia, where the only experience properly designed as UBP was that of the small municipality of Torrelles de Llobregat, started in January 2003, and terminated in September 2003, after the local elections in May of that year changed the local government (Puig Ventosa, 2008).

[5] Some municipalities, however, collect light packaging together with cardboard, and some collect it in the same bins as refuse (ARC 2024a). For purposes of recycling, these municipalities later sort out light packaging manually or mechanically (ARC 2022). The interpretation of the data may vary slightly depending on the configuration applied in a municipality.

fiscal measures to encourage recycling (Jofre-Monseny and Sorribas-Navarro 2024). Consequently, waste separation has increased in the period under study, as shown in Fig. 1. While overall separation (right vertical scale) was less than 15% of total municipal waste at the beginning of the century, it had grown to nearly half of the total waste collected in 2021. In the same line, the category including plastic packaging (left vertical scale) experienced rapid growth, particularly also compared to the growth of other waste components. Separated light packaging grew from just above 0.5% to 5% of all waste.

### 2.4 Door to Door collection

While street containers are the dominant collection technique in Catalonia, DtD collection has experienced a remarkable growth since its adaption began in the early 2000s. Under DtD, separated waste is collected directly at the households' doorstep, in distinct household-size containers for the different components and at specified times. According to Fig. 2, the share of municipalities adopting the DtD waste collection technique has increased steadily from 2000 to about 2017. In the two periods between 2017 and 2018, and between 2021 and 2022, there were jumps of about 7 and 6 percentage points, respectively. The same qualitative pattern can also be seen for those municipalities adopting a Door-to-Door version which includes source-separation of collection of light packaging. Notably, the share of these municipalities more than doubled after 2017. One potential driver of accelerated DtD adoption are the significant increases of the landfill tax in Catalonia, starting in 2017 (Jofre-Monseny and Sorribas-Navarro 2024).

An early study with linear panel regression by Saldivia Gonzatti et al. (2022) found that DtD increases the share of separated waste by about 27 percentage points compared to street bins. Jofre-Monseny and Sorribas-Navarro (2024) find even larger effects of about 35 percentage points or a 90% increase compared to the mean in 2013. Jofre-Monseny and Sorribas-Navarro (2024) use the DtD policy in their identification strategy of the effect of landfill tax increases on waste volume and separation. It is interesting to notice that while the share of separated collection of light packaging in overall waste also increased steadily over time, it grew faster before 2010, while DtD was adopted particularly fast after 2017.

## 3 Data

We use a panel of 943 municipalities in Catalonia from 2000 to 2022: Due to a separation and merger, 948 municipalities existed at one point during the sample period (today 947). We exclude three municipalities that were already treated at the beginning of our sample period, and two where we do not observe the outcome variable. We additionally remove some observations with implausibly high volatility in selection rates between years. Namely, we remove observations when selection rates increase (decrease) at least by factor five from *t-1* to *t*, and then decrease

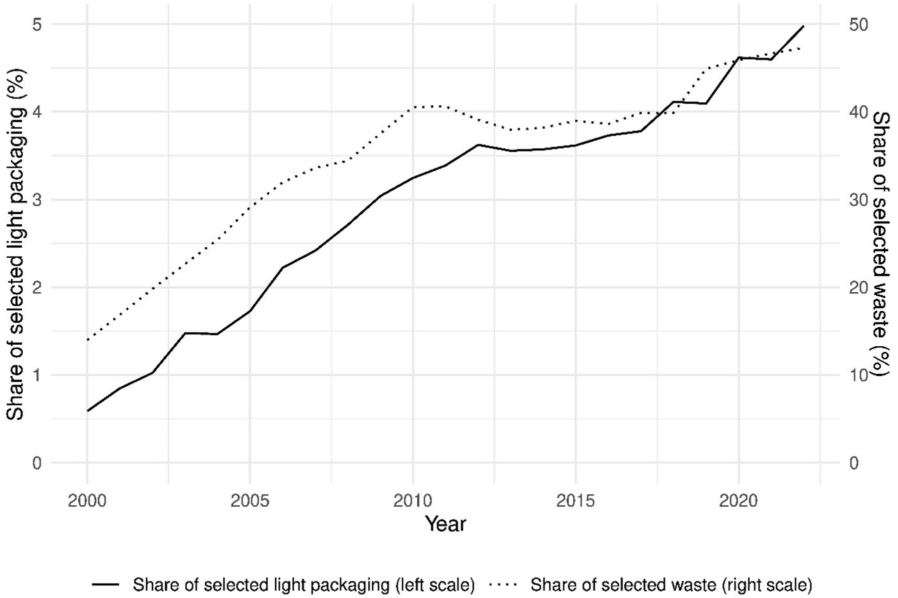


**Fig. 1** Evolution of overall sorted and light packaging sorted collection

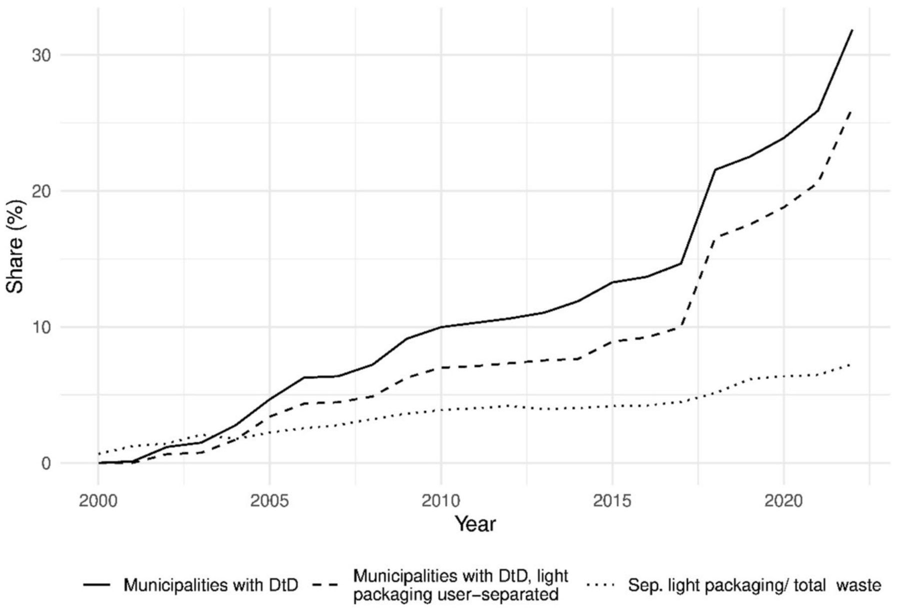


**Fig. 2** Trends in Door-to-Door policy adoption and separation of light packaging in the period of observation

(increase) again by at least factor 5. We think that these observations are typically errors in the data collection process, most likely where a misplaced decimal comma changed plastic volumes by an order of magnitude. Our data set includes the variables documented below.

*Door-to-Door collection.* The non-profit "porta a porta" publishes on its website an updated list of all municipalities applying a DtD waste collection policy, including the implementation date and treatment intensity (the share of the population served by "door-to-door" collection). The earliest implementations were in June 2000, the most recent ones in 2023 (Porta a Porta 2023).

*Door-to-Door of light packaging.* The data set by Porta a Porta (2023) also provides information on the different types of waste collected through "door-to-door" collection, namely all "five components", light packaging together with paper / cardboard, or light packaging collected with refuse. If neither of those is indicated, light packaging continues to be collected with street bins while other components become part of DtD. We use this information to identify municipalities that have implemented DtD versions where light packaging is collected separately by users ("source separation of plastics"), where it is collected together with another waste component ("post-source"), as well as those where plastics are not part of the DtD scheme.

*Share of separated light packaging in overall waste.* This outcome can be calculated from a variable which measures volume of separately collected light packaging (plastic bottles and packaging, cans, wooden fruit containers) in tons per municipality. The data set is provided by the Catalonian Waste Agency (ARC 2023) and covers all municipalities in Catalonia ranging from 2000 to 2022. Note that the volume of light packaging in those municipalities applying "five fractions" is measured after user selection and before further sorting (post-source selection). In contrast, where light packaging is collected together with cardboard or refuse, it is measured right before entry into recycling plants, and therefore after manual or mechanical sorting (ARC 2022).

*Separated light packaging per capita.* We calculate tons per capita using the light packaging and population data from the same dataset (ARC 2023), which is used to calculate other per capita metrics in the data set.

*Population and surface area.* These municipality characteristics are obtained from the Statistical Institute of Catalonia (IDESCAT).

We document descriptive statistics in Table 1 below. There are 19,965 *time* × *municipality* observations, of which 2161 periods got DtD treatment (1744 of which including light packaging collection at the user). Those units with user-based light packing sorting were treated a bit later on average than those with post-source separation.

In Fig. 3, the three treatment groups are compared to the control group in terms of population, surface area of the municipality and population density (Table 6 in the Appendix A1 displays the corresponding data). In general, the control group tends to be somewhat skewed towards municipalities with lower population and higher surface area, resulting in lower densities than in most treatment groups. Those municipalities which implemented DtD with user-based light packaging sorting are also at low levels of population density, whereas those with post-user separation in DtD

**Table 1** Descriptive statistics

| Variable | n | min | max | med | q1 | q3 | iqr | mean | sd |
|---|---|---|---|---|---|---|---|---|---|
| Per capita plastics volume, tons | 19,965 | 0 | 0.158 | 0.016 | 0.009 | 0.026 | 0.017 | 0.018 | 0.013 |
| Separated plastics/total waste | 19,965 | 0 | 0.220 | 0.03 | 0.016 | 0.051 | 0.035 | 0.037 | 0.028 |
| DtD | 19,965 | 0 | 1 | 0 | 0 | 0 | 0 | 0.108 | 0.311 |
| DtD, source separated | 19,965 | 0 | 1 | 0 | 0 | 0 | 0 | 0.087 | 0.282 |
| DtD, post-source separated | 19,965 | 0 | 1 | 0 | 0 | 0 | 0 | 0.006 | 0.08 |
| Treatment year | 6348 | 2002 | 2022 | 2018 | 2009 | 2021 | 12 | 2015.17 | 6.394 |
| Treatment year, source separated | 5474 | 2002 | 2022 | 2018 | 2010 | 2021 | 11 | 2015.67 | 6.325 |
| Treatment year, post-source separated | 322 | 2003 | 2022 | 2014 | 2009 | 2020 | 11 | 2013.93 | 6.328 |
| Population | 21,667 | 19 | 1,664,182 | 912 | 313 | 3516 | 3203 | 7692 | 55,451 |

tend to be dense, and those where plastics remain collected out of the DtD scheme can be found at both quite high and low densities. Municipalities with post-source separation inside DtD are very heterogenous with respect to their surface area.

## 4 Empirical Strategy

Our empirical setting is in the context of panel data with staggered adoption of DtD over time. Traditionally, researchers used static Two-Way Fixed-Effects (TWFE) estimators in these settings, where they controlled for unobserved time-invariant heterogeneity between individuals and individual-invariant heterogeneity over time. The reasoning for this strategy was that it was very similar (arguably identical) to the well-known Difference-in-Difference setting with a treatment and a control group (de Chaisemartin and D'Haultfoeuille 2023). In this setting, under a parallel trends assumption (treated groups would have evolved the same as untreated groups after treatment), the researcher can identify the Average Treatment Effect on the Treated (ATT) (Butts and Gardner 2022). Using our data, this would imply we could estimate the following equation,

$$p_{it} = \tau\, DtD_{it} + \beta X_{it} + \alpha_i + \gamma_t + \in_{it} \tag{1}$$

where $p_{it}$ refers to the share of separately collected plastics in overall waste for municipality $i$ at time $t$, $\tau$ is our parameter of interest, which measures the effect of Door-to-Door (with or without user-separated plastic, respectively) on the outcomes. $X_{it}$ are time- and individual specific controls and $\alpha_i$ captures municipality and $\gamma_t$ time fixed-effects.

The TWFE estimator $\tau$ from the equation above is only equivalent to a Difference-in-Difference estimator with just *one* treated group (all treated units treated at the same time) and an untreated group under very strong conditions which are generally

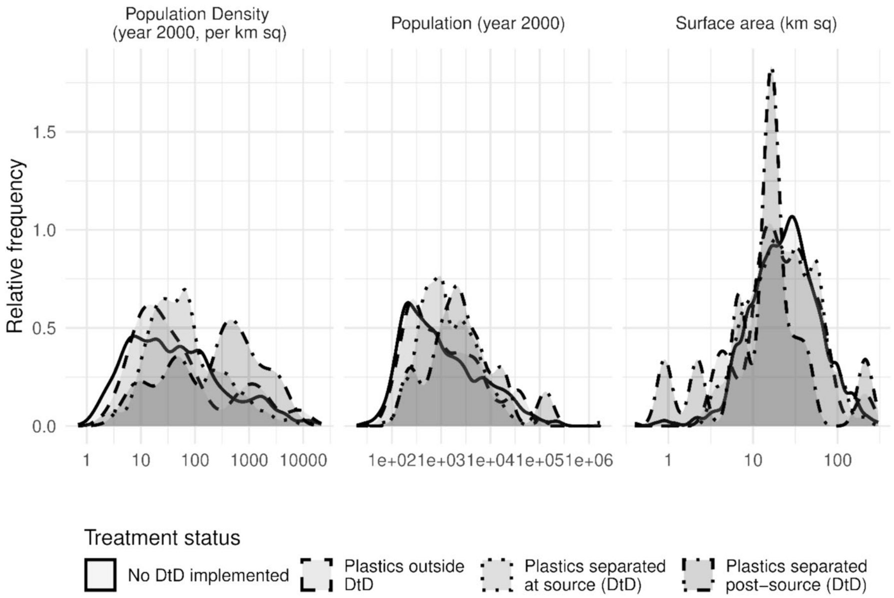


**Fig. 3** Treatment and control group balance with respect to demographic and geographic variables

not met in the case of staggered adoption (Gardner 2022; De Chaisemartin and D'Haultfœuille 2020). A number of approaches have been developed to mitigate these problems (Sun and Abraham 2021; Callaway and Sant'Anna, 2021; Borusyak et al. 2024, Gardner 2022). These rely on slightly varying assumptions and differ in their strengths and weaknesses.[6]

The following four assumptions are the key ingredients for DiD methods in staggered settings. (1) *The parallel trends assumption* which states that treated and control groups would have evolved in parallel absent the treatment.; (2) *No (or limited) anticipation.* It implies that the effect of the treatments cannot start before the treatment period, or that the anticipation horizon is known – that is, we know the maximum number of periods previous to treatment where effects of the policy could start to be present (Callaway and Sant'Anna, 2021); (3) *Stable unit treatment value assumption.* Typically, this assumption is violated when there are general equilibrium effects, spillovers or externalities between units. (4) *Correct model specification for Y (0).* Imputation methods for staggered DiD (Borusyak et al. 2024; Gardner 2022) require an additional assumption: They apply a model to impute the

[6] However, we expect these estimators to arrive at similar results, as differences in assumptions are small and because the estimators mainly differ in the way they deal with treatment effect heterogeneity in the staggered setting: Borusyak et al. (2024) and Gardner (2022) calculate the same point estimate after imputing the same untreated unobserved outcomes and only differ in their standard errors, while the two estimators by Sun and Abraham (2021) and Callaway and Sant'Anna (2021) use different ways to aggregate 2×2 DiD comparisons. For more details, see Butts and Gardner (2022). Besides, there are some differences in how the estimators calculate pre-treatment trends (see Roth 2024).

counterfactual (untreated) outcome. To correctly identify the causal effect of the treatment, this model used for imputation must not be misspecified.

## 5 Main results

For our estimates to recover the ATT of the DtD collection policy on plastic selection, we need to make the following key assumption (de Chaisemartin and D'Haultfoeuille 2023): Parallel trends between all groups (groups of municipalities where DtD was implemented at the same time, including those where it was never implemented) on the potential outcome without treatment for all *t*. Note that this assumption can only be scrutinized statistically to a very limited extent.[7]

### 5.1 Effect of DtD on the share of selected light packaging waste

Table 2 provides the results of DtD on the volume of light packaging separated. The four estimators suggest that there is an increase of about 2.85 to 2.88 percentage points in separately collected light packaging waste as share of all municipal waste. With t-statistics of between 13 and 16, these effects are significant on the 1‰ level. Relative to the baseline of selected light packaging of 3.43% per capita in the untreated sample at the end of the observation period, this implies an increase in selection of between 83 and 84%. We compare the results to the end of the baseline period, because other municipalities have also been on an upward trajectory over the more than 20 years of our analysis. Comparing the effect to the start of the sample would thus inflate the possible impact in the real world.

The event study plot in Fig. 4 indicates that there are no significant and systematic pre-trends in four of the five estimators. The only doubts remaining are about the Sun and Abraham (2021) estimator, where the pre-treatment coefficients are mostly slightly positive and significant. But since the pre-trends are calculated as long differences, the accumulated divergence between treatment and control group does never exceed a very narrow range.[8] The estimators also all agree on the dynamics of the effect post-treatment. They all show an effect of about 4 percentage points in the first periods right after treatment, and a decline to between 2.5 and 3 percentage points after about five years. These are economically meaningful effects, suggesting that introducing DtD collection in general is a highly effective measure to achieve increased rates of plastics separation.

[7] Pre-trends cannot be used to test for parallel trends in a direct way, as parallel trends is an assumption about unobserved potential outcomes. However, conceptually in line with formal test in De Chaisemartin and D'Haultfœuille (2020), we use a visual test on the pre-trends to test jointly for the presence of non-parallel trends pre-treatment and anticipation of the treatment. Once the treatment time is redefined to the earliest time where anticipation could arguably become a problem, still rejecting this "placebo test" would give a serious warning about the presence of non-parallel trends.

[8] Remember that comparisons of pre-trend estimates of different estimators must be taken with caution, because the ways how they are constructed differ markedly (Roth 2024).

**Table 2** Average Treatment Effect on the Treated (ATT) of Door-to-Door on selected light packaging waste

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Estimator | Callaway & Sant'Anna | Sun & Abraham | Borusyak et al | Gardner |
| Estimate | 0.028522*** | 0.028522*** | 0.028814*** | 0.028814*** |
| SE | (0.002174) | (0.001993) | (0.001826) | (0.00197) |
| t-statistic | 13.12044 | 14.308928 | 15.779961 | 14.627612 |

Standard Errors in parentheses. *** $p<0.001$; ** $p<0.01$; * $p<0.05$; † $p<0.10$

We estimated the effect of *any* type of Door-to-Door waste collection so far. However, some municipalities chose to implement DtD, but to require users to collect light packaging together with paper/cardboard or with refuse, instead of doing so in a separate category. It is not a priori clear whether this should increase or decrease the separate collection of plastics. Furthermore, some municipalities continue to collect plastics in street containers, while they use DtD for other waste components. In order to investigate differences between these three DtD types, we will estimate the Average Treatment Effect on the Treated separately for the three setups in a next step.

### 5.2 Effect with user-selected light packaging

Table 3 provides the results for DtD with user-separated light packaging on the volume of collected light packaging. The three estimators suggest that there is an increase of about 2.8 percentage points in separately collected light packaging waste as share of all municipal waste after adoption of DtD. With t-statistics of between 11 and 14, these effects are significant on the 1‰ level. Relative to the baseline of selected light packaging of 3.43% per capita in the untreated sample at the end of the observation period, this implies an increase in selection of 81%. However, the event study plot in Fig. 5 suggests that there are some concerns about pre-trends, particularly in the Borusyak et al. (2021) and Sun and Abraham (2021) estimators, and in Gardner (2022) to a lesser extent. Since even accumulated (long differences) pre-trends such as those in Borusyak et al. (2021) are quite small compared to post-treatment long-differences, we think that we can still trust that parallel trends hold sufficiently pre-treatment for this estimator to provide a credible estimate of the effect.

The dynamics of the effect post-treatment are very similar across estimators. These estimates are on average very similar, but a bit smaller than those for all types of DtD.[9] In order to arrive at a more complete picture, we report the results for municipalities implementing DtD with post-source separation of plastics next, and then also for those where DtD was implemented, but only for materials besides plastics.

[9] Note that while this allows us to say something about the effect in municipalities with different designs of the policy, we cannot reliably attribute this effect to the two types of DtD in a causal sense, as we do not observe any switchers from one DtD design to the other.

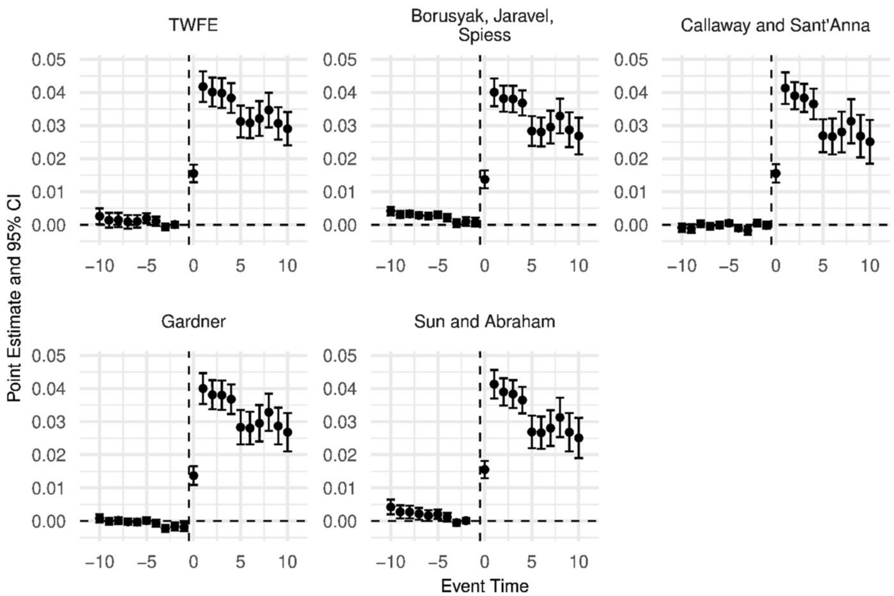


**Fig. 4** Event-study plot of the effect of Door-to-Door collection on the share of separated light packaging

**Table 3** Average Treatment Effect on the Treated (ATT) of Door-to-Door including light packaging on the share of selected light packaging waste

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Estimator | Callaway & Sant'Anna | Sun & Abraham | Borusyak et al | Gardner |
| Estimate | 0.027821*** | 0.027821*** | 0.02771*** | 0.02771*** |
| SE | (0.002553) | (0.002158) | (0.001995) | (0.002196) |
| t-statistic | 10.897666 | 12.892708 | 13.888239 | 12.620813 |

Standard Errors in parentheses. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; † $p < 0.10$

## 5.3 Effect with post-user separation of light packaging.

Some municipalities implemented DtD but do report not collecting light packaging separately. Namely, these municipalities either use a "multi-product category" (paper / cardboard /light packaging) or collect light packaging with refuse. They therefore measure the separated light packaging only after further manual or mechanical separation. Since this step will remove some of the waste materials due to impurities, we might expect light packaging shares to increase less than where they are collected separately at source, at least in these municipalities which changed from "five fractions" street collection to a "multi-product" DtD. However, the extent of this is not obvious, as we do not possess information on what type of street bins were used previous to DtD. The same qualification also needs to be applied to the spillover-type explanation for differences between the systems, namely that waste

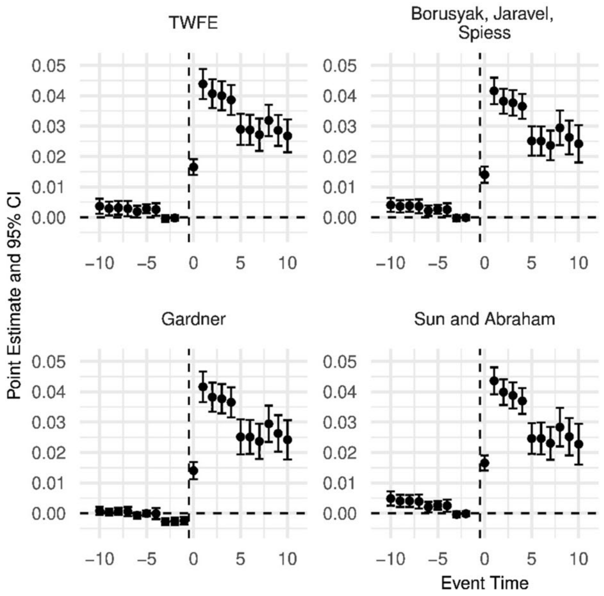


**Fig. 5** Event-study plot of the effect of Door-to-Door with source-separated light packaging collection on the share of separated light packaging

separation which is stricter and into more different categories leads to more careful separation in general, increasing plastic separation.

According to Table 4, the t-statistics of the effects are between 4 and 18, and separated light packaging waste (after mechanical or manual industrial separation) increases between 2.78 and 3.23 percentage points, depending on the estimator. This results in an increase in selection of between 81 and 94% relative to the baseline of 3.43% in the untreated sample at the end of the observation period. Note that all estimators report larger effect sizes than for DtD where light packaging is already separated from paper/cardboard or refuse by the users.

As can also be seen in the event study in Fig. 6, all estimators agree on the post-treatment pattern, with relatively stable treatment effects around 3–4 percentage points for all post-treatment periods. While the pre-trends are slightly noisier compared to the previous estimations, they are not systematically statistically significant. In the case of Callaway and Sant'Anna (2021), the short difference pre-trends are neither systematically positive nor negative, implying that there is no strictly increasing or decreasing pre-trend present either.

### 5.4 Effect with separation of light packaging remaining outside DtD.

We now consider whether there is an effect of the DtD policy on separately collected plastic waste, even if plastics were not part of DtD. That is, where plastics were neither separated at the source, nor in a larger category and post-source *as part of DtD*. To do so, we restrict our treatment group sample to those

**Table 4** Average Treatment Effect on the Treated (ATT) of Door-to-Door with post-user separation on the share of selected light packaging waste

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Estimator | Callaway & Sant'Anna | Sun & Abraham | Borusyak et al | Gardner |
| Estimate | 0.02784*** | 0.02784*** | 0.032331*** | 0.032331*** |
| SE | (0.006436) | (0.002016) | (0.00175) | (0.006066) |
| t-statistic | 4.325591 | 13.811809 | 18.47017 | 5.329961 |

Note: Standard Errors in parentheses. *** p < 0.001; ** p < 0.01; * p < 0.05; † p < 0.10

municipalities where neither a light packaging, nor a multi-product or a general non-organic waste category was integrated into the DtD setup. Our results in Table 5 suggest that in municipalities only introducing DtD for other waste components, the spilloveres are so large that the effect is at least similar in size to municipalities introducing DtD directly for a category including plastics (whether already source-separated or together with other components). More precisely, the share of separately collected plastics increases by 3.30 to 3.41 percentage points or 96 to 99% relative to the average in the untreated sample at the end of the observation period.

Note, however, that for this treatment group, we lack information whether the plastics collected outside DtD were separated at source or post-source. While the spillovers we find seem surprisingly large, the fact that there are such spillovers is in line with the literature (see Alacevich et al. 2021; Abeshev & Koppenborg 2023) – although this effect has sometimes been shown to fade over time, which is not the case according to our results in the event studies in Fig. 7. These show insignificant pre-trends and a very stable treatment effect over time.

## 5.5 Robustness checks

To investigate the robustness of our results, we restrict our sample in different ways; all results are provided in the Appendix. First, we estimate the main specifications with a different outcome variable, the logarithm of the volume of plastics selected (in kg) per capita. This variable is less dependent on the accuracy of measurement in the overall collected waste volume. Instead, it only relies on population in the denominator, which typically evolves in a much steadier way. The downside is that it is a bit further away from what we are interested to measure, as an increase in per capita plastics could be driven just as well by increases in overall waste volumes, which also increase plastics. Figures 8, 9, 10 and 11 in Appendix 2 show that the qualitative patterns remain the same.

Second, Porta a Porta (2023) also includes a variable for the share of population served by DtD collection. We test whether excluding all municipalities with less than 25%, 50%, 75% or 100% of DtD treatment changes the results. The results remain qualitatively the same, as can be seen in Appendix 3, Figs. 12, 13, 14, 15.

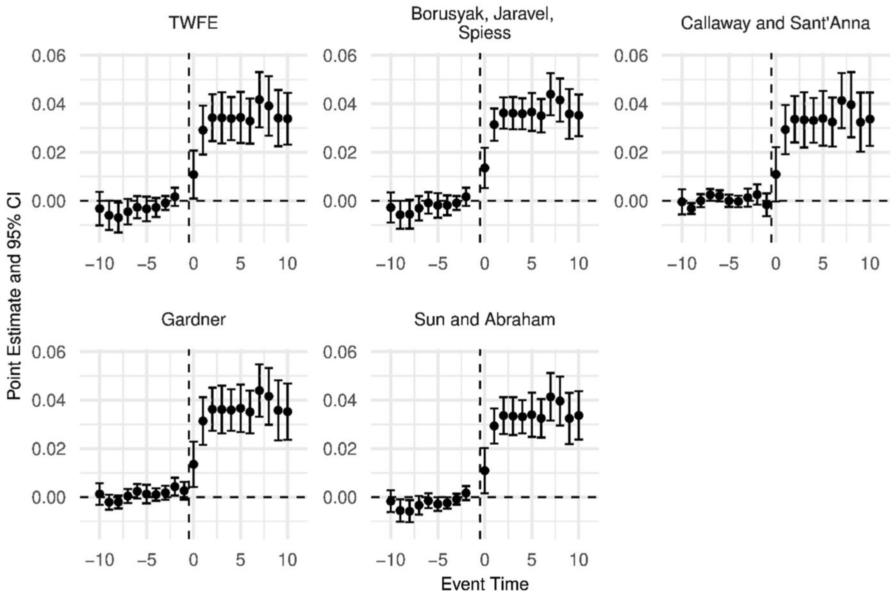


**Fig. 6** Event-study plot of the effect of Door-to-Door with post-source separation of light packaging on the share of separated light packaging

**Table 5** Average Treatment Effect on the Treated (ATT) of Door-to-Door with post-user separation on the share of selected light packaging waste

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Estimator | Callaway & Sant'Anna | Sun & Abraham | Borusyak et al | Gardner |
| Estimate | 0.033037*** | 0.033037*** | 0.034093*** | 0.034093*** |
| SE | (0.005379) | (0.003944) | (0.003576) | (0.005079) |
| t-statistic | 6.141646 | 8.375797 | 9.532629 | 6.712329 |

Standard Errors in parentheses. *** p < 0.001; ** p < 0.01; * p < 0.05; † p < 0.10

## 6 Extension: Comparison of source and post-source separation in DtD systems

We extend our analysis by estimating also a TWFE event study specification including both treatments at the same time. That is, we estimate the following equation:

$$\begin{aligned} y_{it} = & \alpha_i + \lambda_t + \sum_{k=T_0}^{-2} \beta_k^S DtD_{ik}^S + \sum_{k=0}^{T_1} \beta_k^S DtD_{ik}^S + \sum_{k=T_0}^{-2} \beta_k^{PS} DtD_{ik}^{PS} \sum_{k=0}^{T_1} \beta_k^{PS} DtD_{ik}^{PS} \\ & + \sum_{k=T_0}^{-2} \beta_k^O DtD_{ik}^O + \sum_{k=0}^{T_1} \beta_k^O DtD_{ik}^O + \in_{it} \end{aligned} \tag{2}$$

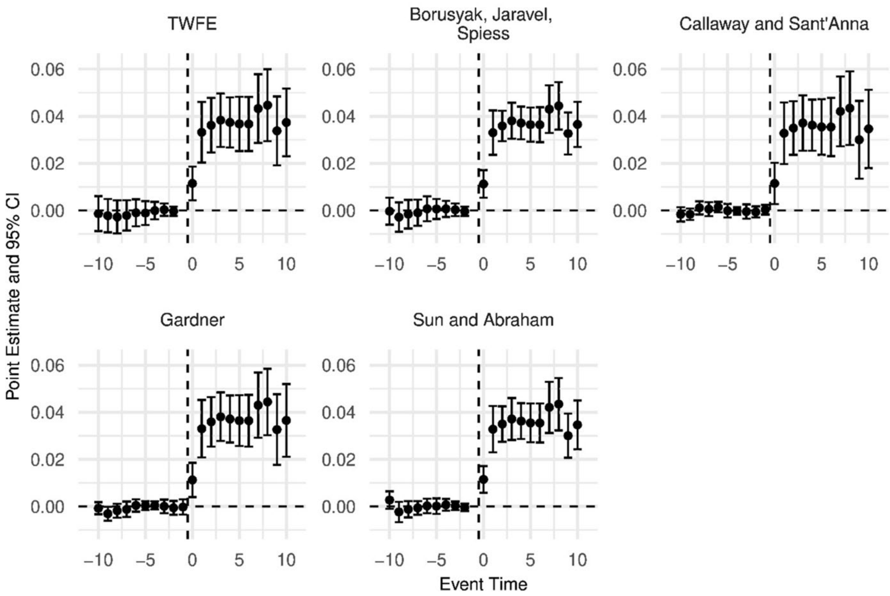


**Fig. 7** Event-study plot of the spillover effect of Door-to-Door excluding collection of light packaging on the share of separated light packaging

where $\alpha_i$ are individual fixed effects, $\lambda_t$ are time fixed effects, $DtD^{\mathrm{S}}$, $DtD^{PS}$ and $DtD^{O}$ are indicator variables for the DtD policy with source separation (indicated by S), post-source separation (PS) of light packaging or with plastics still being collected outside of DtD (O) within municipality $i$ in period $k$ relative to treatment. $\beta^{\mathrm{S}}$, $\beta^{PS}$, $\beta^{\mathrm{O}}$ are treatment effects for each time span before or after treatment $k$ ($\beta$ with negative $k$ represent the pre-trends). Notice that this specification allows the pre-treatment periods of the other not-yet-treated groups to be included in the control.

Figure 16 shows the estimated treatment effects for the DtD policy designs. There is a positive and persistent effect of DtD with user-separated light packaging on the share of separated light packaging, while the estimates of the effect of DtD policy post-source separation suffer from serious pre-trends. The DtD policy with plastics remaining outside of the scheme shows no pre-trends and a comparable effect post-treatment. The estimates analogous to Eq. (1) show that the aggregated effect over all periods is slightly larger for municipalities using post-separation DtD and those with DtD without plastics compared to DtD with a separate light packaging category, but both of these differences are not statistically significant.

The lack of significant differences between the three policy designs should be taken with caution. Firstly, actual effect heterogeneity between the policy variants could be cancelled out by differences in the municipalities opting for one or the other policy, if these differences are also correlated with the individual effect sizes of DtD. Furthermore, our plastic outcome variable is measured *before* further manual or mechanical processing in municipalities where plastics are separated at the user, but after sorting out unsuitable materials for recycling in those municipalities where it

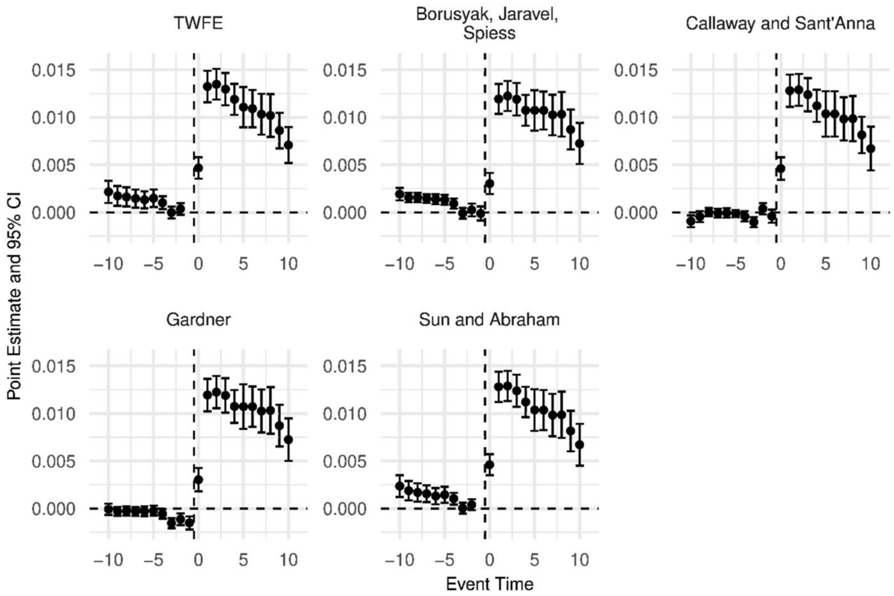


**Fig. 8** Event-study plot of the effect of Door-to-Door on per capita separated light packaging

is collected with paper / cardboard or refuse. There could be slight differences in the actual composition of the packaging materials measured here, so that one method may outcompete the other in quality of the sorted material. In any case, the literature so far does not provide conclusive evidence that the quality of selected plastic is superior in any one of the two designs.

## 7 Concluding Remarks

Our study shows very sizeable positive effects of Door-to-Door waste collection on the share of separately selected light packaging, even where separate collection of light packaging is well-established. More precisely, we estimate that DtD is highly effective even in a setting where light packaging separation had been promoted for a long time and was increasingly complied with even in the absence of DtD. Our results indicate that light packaging separation in municipalities with DtD increased by about 80% compared to untreated municipalities.

We provide suggestive evidence that these results are in a similar ballpark regardless of whether plastics are collected with other materials and selected post-source, or already by the user pre-source. Additionally, our evidence suggests that even spillovers from DtD collection of other waste components may be so large that DtD systems with continued street container collection of light packaging could achieve similar increases in separate light packaging collection. Thus, any type of DtD system seems to have large positive effects on the separate collection of light packaging. As a consequence, policymakers may consider using it as a useful measure to reach current ambitious policy goals for plastic recycling and to reduce environmental harm.

To further our understanding of the policy trade-offs, we see several avenues for further research: Future studies should consider the quality of the collected plastic material, particularly when further investigating different setups, for example those where different waste components are collected together. Furthermore, these insights also need to be combined with information on operating costs of the policy, because only an emerging complete cost–benefit picture can help policy makers decide whether DtD is the best measure both compared to other collection methods, and compared to interventions further up- or downstream like packaging regulations, unit-based pricing or technological solutions in incineration or other waste treatment. Last but not least, further research is also needed to better understand the mechanisms behind the spread of the DtD policy, the results of which may be particularly interesting for higher-level governance units (states, central governments) interested in supporting the spread of such a policy .

## Appendix

See Table 6..

### A2 Using light weight packaging per capita as an outcome

See Figures. 9, 10, 11 and 12.

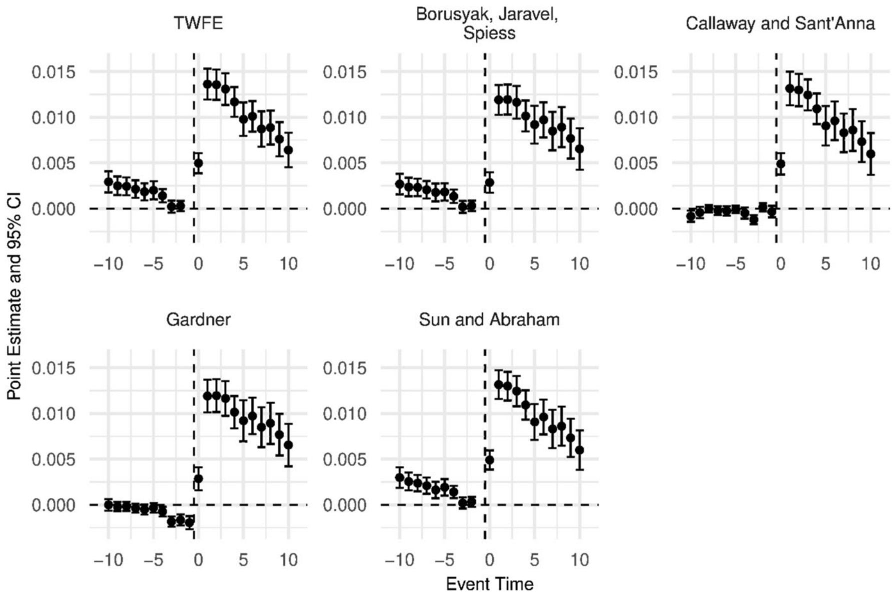


**Fig. 9** Event-study plot of the effect of Door-to-Door with source separation of light packaging on per capita separated light packaging

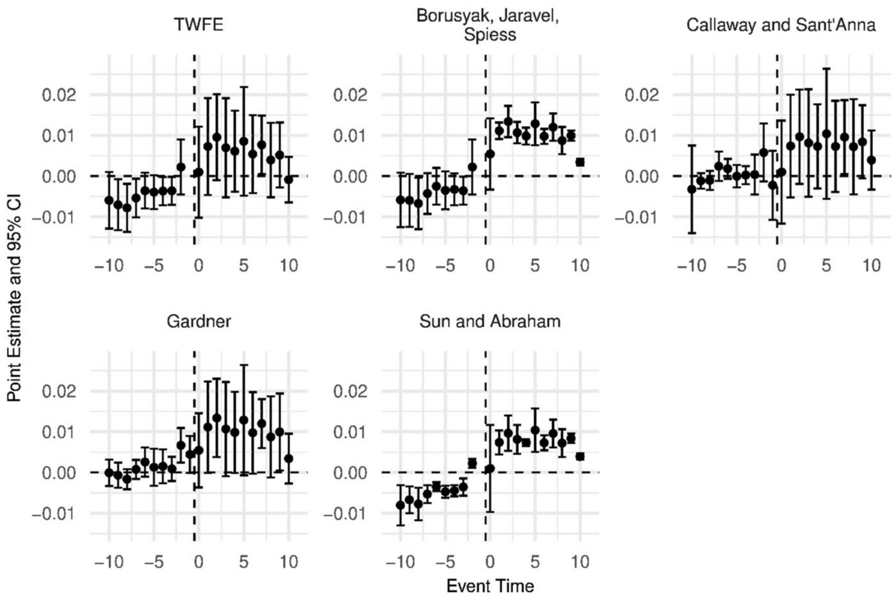


**Fig. 10** Event-study plot of the effect of Door-to-Door with post-source separated light packaging collection on per capita separated light packaging

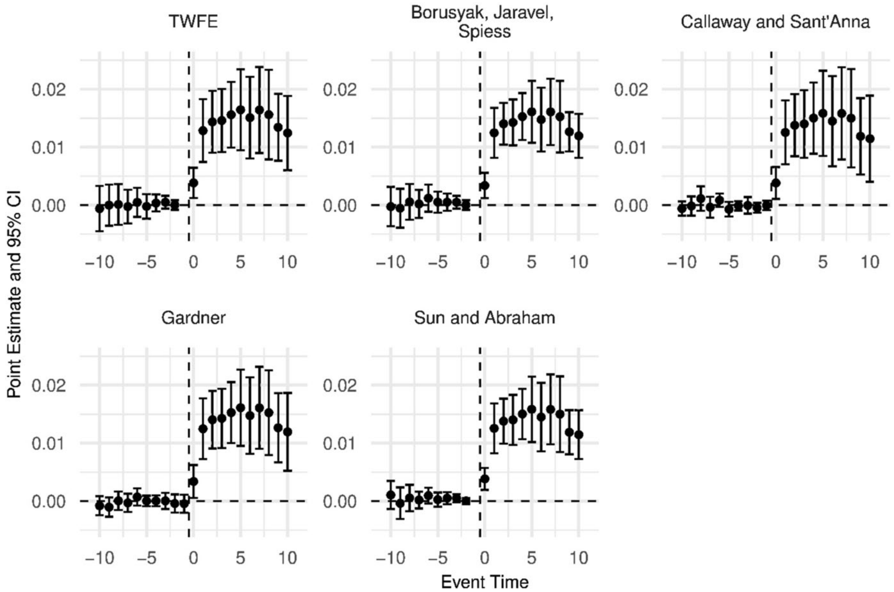


**Fig. 11** Event-study plot of the effect of Door-to-Door excluding light packaging collection on per capita separated light packaging

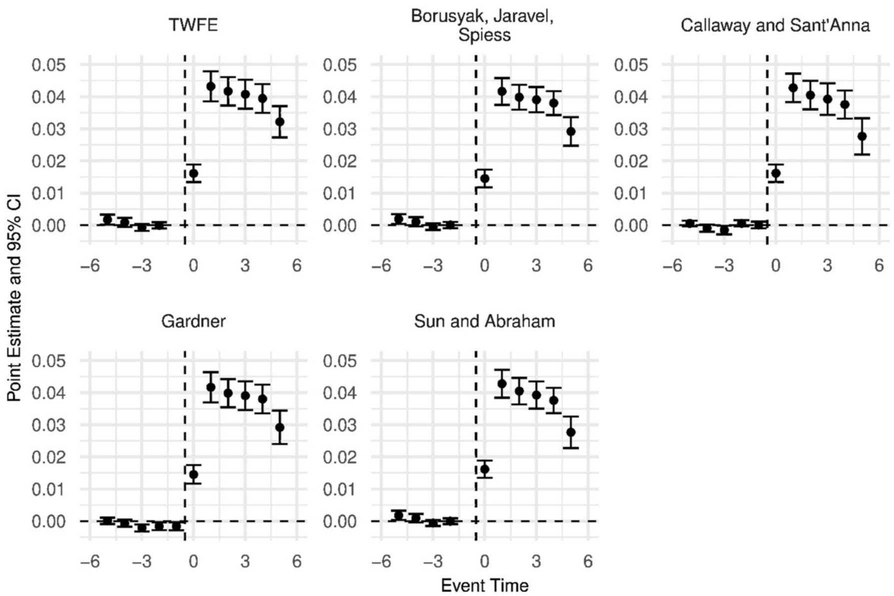


**Fig. 12** Event-study plot of the effect of Door-to-Door serving at least 25% of the population on selected light packaging

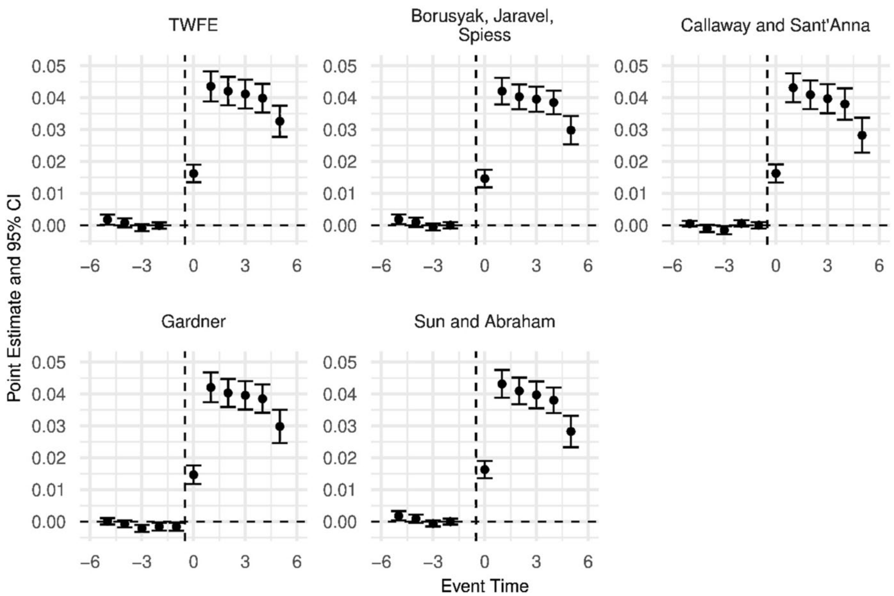


**Fig. 13** Event-study plot of the effect of Door-to-Door serving at least 50% of the population on selected light packaging

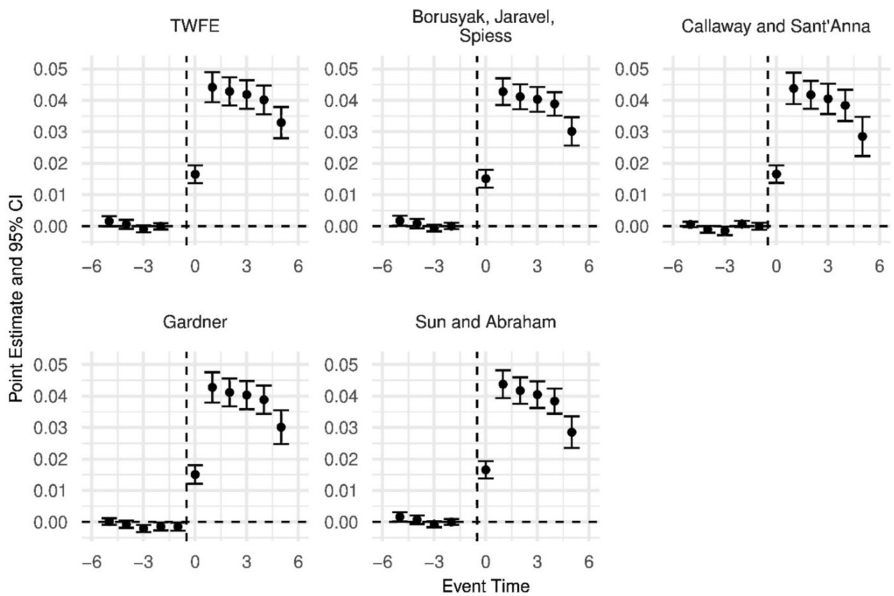


**Fig. 14** Event-study plot of the effect of Door-to-Door serving at least 75% of the population on selected light packaging

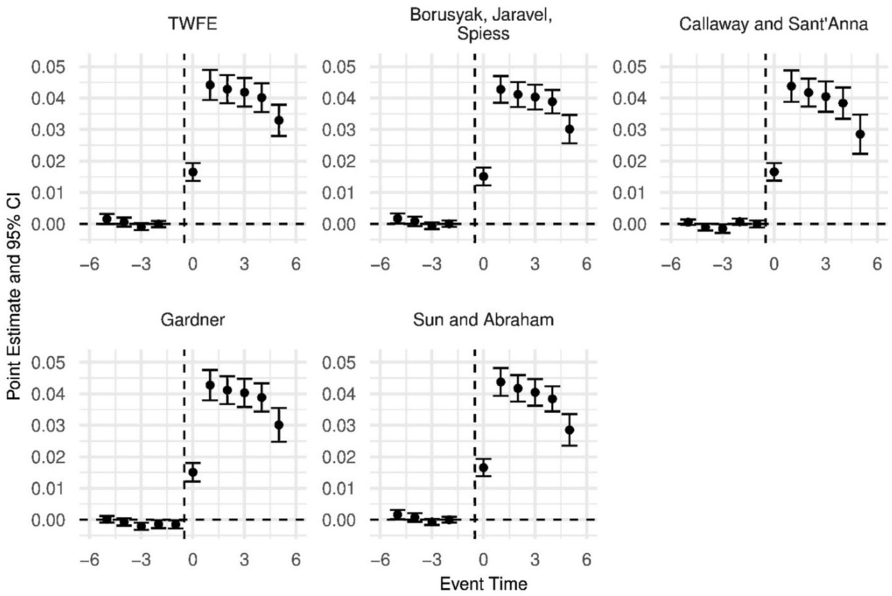


**Fig. 15** Event-study plot of the effect of Door-to-Door serving 100% of the population on selected light packaging

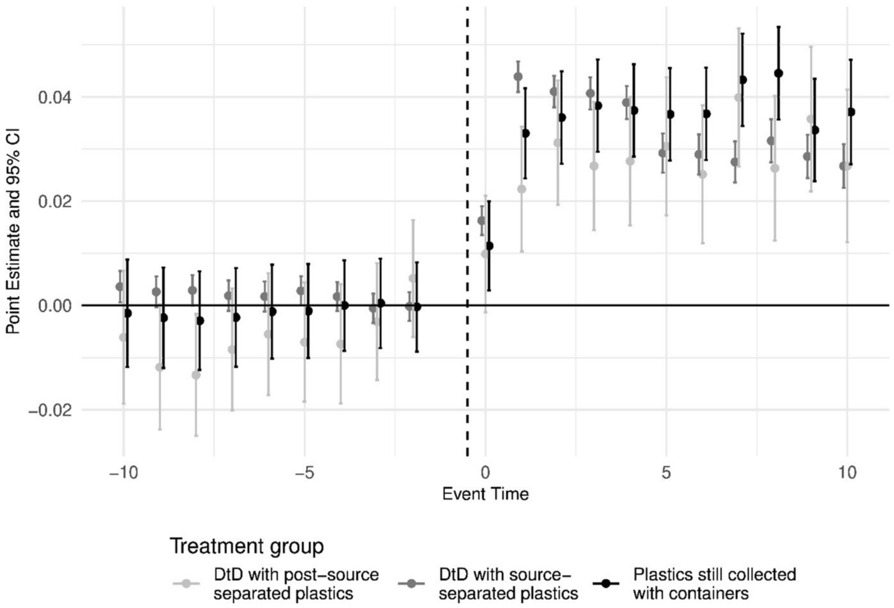


**Fig. 16** Event-study plot of the effect of the different Door-to-Door policies on the share of separated light packaging

**Table 6** Descriptive statistics for treatment and control, standard deviation in parentheses

| | No DtD implemented | Light packaging outside DtD | Light packaging separated at source (DtD) | Light packaging separated post-source (DtD) |
|---|---|---|---|---|
| Population | 5401.29 | 4050.44 | 9283.97 | 11,868.00 |
| | (19,374.59) | (7990.85) | (98,607.53) | (30,442.62) |
| Density | 375.17 | 488.70 | 251.74 | 641.85 |
| | (1595.13) | (1424.54) | (1128.26) | (995.47) |
| Surface area | 35.14 | 35.46 | 33.53 | 30.75 |
| | (35.91997) | (40.37671) | (31.32891) | (55.70) |
| #obs | 588 | 23 | 235 | 13 |

Note: Standard Errors in parentheses. *** $p<0.001$; ** $p<0.01$; * $p<0.05$; † $p<0.10$

## A3 Only including municipalities serving at least a certain threshold

See Figures 13, 14, 15, 16.

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**Data availability** All data used in the article are available online. Authors can make the dataset used available upon request.

## Declarations

**Conflict of interest** The authors have no relevant financial or non-financial interests to disclose. The authors have no competing interests to disclose.

## References


Abeshev K, Koppenborg F (2023) More than just organics: Boosting separate collection of dry recyclables with door-to-door bio-waste collection in EU capitals. Waste Manag 161:156–165. https://doi.org/10.1016/j.wasman.2023.02.026

Ackerman F (2000) Waste Management and Climate Change. Local Environment: Int J Justice Sustain 5(2):223–229. https://doi.org/10.1080/13549830050009373

Alacevich C, Bonev B, Söderberg M (2021) Pro-environmental interventions and behavioral spillovers: evidence from organic waste sorting in Sweden. J Environ Econ Manag 108:102470

Albizzati P, Tonini D, Gaudillat P (2024) Impacts of the collection and treatment of dry recyclables. Publications Office of the European Union, 2024, https://data.europa.eu/doi/https://doi.org/10.2760/4532 (retrieved 5 May 2024)

ARC (2022) Metodologia d'obtenció de les dades estadístiques de residus municipals a Catalunya. Agència de Residus de Catalunya. Technical report, Barcelona

ARC (2023) Estadístiques de residus municipals. Agència de Residus de Catalunya. http://estadistiques.arc.cat/ARC/

ARC (2024a) Segons fraccions. Agència de Residus de Catalunya https://residus.gencat.cat/ca/ambits_dactuacio/recollida_selectiva/models_de_recollida/segons_fraccions/

ARC (2024b) Characteristics of selective collection of light packaging https://residus.gencat.cat/en/ambits_dactuacio/recollida_selectiva/residus_municipals/envasos_lleugers/caracteristiques_de_la_recollida_selectiva_denvasos_lleugers/ (retrieved 4 September 2024)

Bel G, Elston T (2024) Disentangling the separate and combined effects of privatization and cooperation on local government service delivery. Public Adm 102(4):1624–1646. https://doi.org/10.1111/padm.12992 (Forthcoming)

Bel G, Gradus R (2016) Effects of unit-based pricing on household waste collection demand: a meta-regression analysis. Resource Energy Econ 44:169–182. https://doi.org/10.1016/j.reseneeco.2016.03.003

Borusyak K, Jaravel X, Spiess J (2024) Revisiting event-study designs: robust and efficient estimation. Rev Econ Stud 91(6):3253–3285. https://doi.org/10.1093/restud/rdae007

Butts K, Gardner J (2022) {did2s}: Two-stage difference-in-differences. R J 14(3):162–173

Callan SJ, Thomas JM (2001) Economies of scale and scope: a cost analysis of municipal solid waste services. Land Econ 77(4):548–560. https://doi.org/10.2307/3146940

Callaway B, Sant'Anna P H (2021) Difference-in-Differences with multiple time periods. J Econometrics 225(2):200–230. https://doi.org/10.1016/j.jeconom.2020.12.001

Cecon VS, Curtzwiler GW, Vorst KL (2023) Evaluation of mixed #3–7 plastic waste from material recovery facilities (MRFs) in the United States. Waste Manag 171:313–323. https://doi.org/10.1016/j.wasman.2023.09.002

De Chaisemartin C, D'Haultfœuille X (2020) Two-way fixed effects estimators with heterogeneous treatment effects. Am Econ Rev 110(9):2964–2996. https://doi.org/10.1257/aer.20181169

De Chaisemartin C, D'Haultfoeuille X (2023) Two-way fixed effects and differences-in-differences with heterogeneous treatment effects: a survey. Econom J 26(3):C1–C30. https://doi.org/10.1093/ectj/utac017

Degli Esposti A, Magrini C, Bonoli A (2021) Municipal solid waste collection systems: an indicator to assess the reusability of products. Waste Manag Res 39:1200–1209. https://doi.org/10.1177/0734242X211038195

Degli Esposti A, Magrini C, Bonoli A (2023) Door-to-door waste collection: a framework for the socio–economic evaluation and ergonomics optimization. Waste Manag 156:130–138. https://doi.org/10.1016/j.wasman.2022.11.024

Di Maria F, Sisani F, Contini S, Ghosh SK, Mersky RL (2020) Is the policy of the European Union in waste management sustainable? An Assessment Italian Context, Waste Manag 103:437–448. https://doi.org/10.1016/j.wasman.2020.01.005

Dijkgraaf E, Gradus R (2015) Efficiency effects of unit-based pricing systems and institutional choices of waste collection. Environ Resource Econ 61:641–658. https://doi.org/10.1007/s10640-014-9811-y

Dijkgraaf E, Gradus R (2020) Post-collection separation of plastic waste: better for the environment and lower collection costs? Environ Resource Econ 77:127–142. https://doi.org/10.1007/s10640-020-00457-6

EC, (2018) Directive (EU) 2018/852 of the European Parliament and of the Council of 30 May 2018 amending Directive 94/62/EC on packaging and packaging waste. Off J Eur Union L150:141–154
EC, (2019) Directive (EU) 2019/904 of the European Parliament and of the Council of 5 June 2019 on the reduction of the impact of certain plastic products on the environment. Off J Eur Union L155:1–19
EC (2020) A new Circular Economy Action Plan. For a cleaner and more competitive Europe. Communication from the commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. European Commission: COM(2020) 98 final
EEA (2023) Economic instruments and separate collection systems key strategies to increase recycling. European Environmental Agency, Copenhagen
Ferreira S, Cabral M, da Cruz NF, Simões P, Marques RC (2017) The costs and benefits of packaging waste management systems in Europe: the perspective of local authorities. J Environ Plan Manag 60(5):773–791. https://doi.org/10.1080/09640568.2016.1181609
Gardner J (2022) Two-stage differences in differences. arXiv preprint arXiv:2207.05943
Gradus RHJM, Nillesen PHL, Dijkgraaf E, van Koppen RJ (2017) A cost-effectiveness analysis for incineration or recycling of Dutch Household Plastic Waste. Ecol Econ 135:22–28. https://doi.org/10.1016/j.ecolecon.2016.12.021
Jofre-Monseny J, Sorribas-Navarro P (2024) Landfill tax and recycling. Fisc Stud Forthcoming. https://doi.org/10.1111/1475-5890.12360
Kiessling T, Hinzmann M, Mederake L, Dittmann S, Brennecke D, Böhm-Beck M, Knickmeier K, Thiel M (2023) What potential does the EU Single-Use Plastics Directive have for reducing plastic pollution at coastlines and riversides? An evaluation based on citizen science data. Waste Manag 164:106–118. https://doi.org/10.1016/j.wasman.2023.03.042
Klingenberg P, Brüll R, Fell T, Barton B, Soll M, Emans T, Bakker F, Geertz G (2024) Quality comparison of plastic packaging waste from different separation systems: Result enhancement with non-negative matrix factorization of FTIR spectra. Waste Manag 178:135–143. https://doi.org/10.1016/j.wasman.2024.02.020
Kumamaru H, Takeuchi K (2023) The recycled content of plastic products: estimating the impact of a recycling law on the input mix. Environ Econ Policy Stud 25(3):355–376. https://doi.org/10.1007/s10018-023-00360-6
Li J, Takeuchi K (2023) Import ban and clean air: estimating the effect of China's waste import ban on ozone pollution. Environ Econ Policy Stud 25(4):471–492. https://doi.org/10.1007/s10018-023-00365-1
Luijsterburg B, Goossens H (2014) Assessment of plastic packaging waste: material origin, methods, properties. Resource Conserv Recycl 85:88–97. https://doi.org/10.1016/j.resconrec.2013.10.010
Merrild H, Larsen AW, Christensen TH (2012) Assessing recycling versus incineration of key materials in municipal waste: the importance of efficient energy recovery and transport distances. Waste Manag 32(5):1009–1018. https://doi.org/10.1016/j.wasman.2011.12.025
Mielinger E, Weinrich R (2024) Insights into plastic food packaging waste sorting behaviour: a focus group study among consumers in Germany. Waste Manag 178:362–370. https://doi.org/10.1016/j.wasman.2024.02.038
Morris J (1996) Recycling versus incineration: an energy conservation analysis. J Hazard Mater 47(1–3):277–293. https://doi.org/10.1016/0304-3894(95)00116-6
Nainggolan D, Pedersen AB, Smed S, Zemo KH, Hasler B, Termansen M (2019) Consumers in a circular economy: economic analysis of household waste sorting behaviour. Ecol Econ 166:106402. https://doi.org/10.1016/j.ecolecon.2019.106402
Porta a Porta (2023) Els Municipis. Associació de Municipis Catalans per la recollida selectiva Porta a Porta, https://www.portaaporta.cat/ca/municipis.php.
Puig-Ventosa I (2008) Charging systems and PAYT experiences for waste management in Spain. Waste Manag 28(12):2767–2771. https://doi.org/10.1016/j.wasman.2008.03.029
Roth J, Sant'Anna P H, Bilinski A, Poe J (2023) What's trending in difference-in-differences? A synthesis of the recent econometrics literature. J Econometrics 235(2):2218–2244. https://doi.org/10.1016/j.jeconom.2023.03.008
Roth J (2024) Interpreting Event-Studies from Recent Difference-in-Differences Methods. arXiv preprint arXiv:2401.12309 Accessed 15 April 2024
Saldivia Gonzatti I, Jannes G, Barreal J (2022) Factors influencing the rate of sorted solid waste collection: An empirical analysis towards local management in Catalonia (NE Spain). Cities 131:104038. https://doi.org/10.1016/j.cities.2022.104038

Sharma HB, Vanapalli KR, Samal B, Cheela VRS, Dubey BK, Bhattacharya J (2021) Circular economy approach in solid waste management system to achieve UN-SDGs: Solutions for post-COVID recovery. Sci Total Environ 800:149605. https://doi.org/10.1016/j.scitotenv.2021.149605
Sun and Abraham (2021) Estimating dynamic treatment effects in event studies with heterogeneous treatment effects. J Econometrics 225(2):175–199. https://doi.org/10.1016/j.jeconom.2020.09.006
Thøgersen J (1994) A model of recycling behaviour, with evidence from Danish source separation programmes. Int J Res Mark 11(2):145–163. https://doi.org/10.1016/0167-8116(94)90025-6
UN (2015) Transforming our world: the 2030 Agenda for Sustainable Development, A/RES/70/1, 21 October 2015, UN General Assembly. https://www.refworld.org/legal/resolution/unga/2015/en/111816 Accessed 4 May 2024