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Analysis

When green turns costly: The fiscal fallout of EU waste management funds in Italian municipalities☆

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ABSTRACT

This paper investigates the fiscal consequences of EU-funded waste management projects on local taxation in Italian municipalities. Using a matched framework combined with the staggered difference-in-differences estimator of Sun and Abraham (2021) on panel data from 2007 to 2023, we find that municipalities receiving EU cohesion funds experienced an increase in per-capita waste taxes, driven by rising service costs. This increase is primarily associated with higher costs in the management of residual waste, while costs related to separate waste collection do not rise in a statistically significant manner. A decomposition of waste management costs shows that, despite declining volumes, disposal costs for residual waste increase markedly, consistent with a deterioration in the quality and complexity of the remaining fraction. At the same time, EU-funded interventions lead to a substantial expansion of separate waste collection without a corresponding increase in its operating costs. To assess whether observed cost dynamics reflect inefficiency or technological progress, we estimate changes in total factor productivity using a non-parametric Malmquist index. The results indicate moderate productivity gains in sorted waste management, largely driven by technological advancement, whereas productivity in residual waste management remains broadly stable. These findings suggest a clear policy trade-off: EU-funded waste investments can improve environmental performance by expanding separate collection, but, when downstream treatment capacity and lifecycle cost planning do not keep pace, they may also increase local fiscal pressure through higher waste taxes. Overall, our findings highlight the importance of integrated investment strategies that support environmental objectives while addressing structural rigidities in downstream waste treatment to ensure fiscal sustainability.

1. Introduction

Municipal waste management represents a crucial sector for both environmental sustainability and local public finance. On the environmental side, the sector is central to the EU circular economy agenda, with binding recycling targets and directives reducing landfill use (European Commission, 2020). On the fiscal side, waste services are one of the largest items of local spending in Italy, with full cost recovery mandated by law and household charges equal to about 20% of municipal revenues (ISPRA, 2022; Messina et al., 2018). This dual relevance explains why scholars have long considered waste management a paradigmatic case for studying efficiency and distributional implications of local services (Bel and Warner, 2008; Abrate et al., 2014). Over the past two decades, EU Cohesion Policy has supported investments in waste management aimed at modernizing facilities, promoting recycling, and fostering the circular economy. In Italy, waste services are locally managed and financed by users, with costs fully reflected in municipal taxation under national rules. While EU-funded projects primarily aim to improve environmental and service outcomes, they can also have unintended fiscal effects. Whether these investments relieve or exacerbate household burdens—by reducing infrastructure costs or triggering higher operational expenses—remains ambiguous and underexplored.

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This paper aims to fill this gap by investigating how EU co-financed waste management investments have affected municipal waste taxes across Italian municipalities. Using panel data from 2007 to 2023, the analysis examines the relationship between EU public funding and local taxation, contributing to the broader debate on the fiscal effects of EU environmental spending.

In Italy, municipalities must set the waste tax to fully cover actual costs of collection, transport, treatment, and disposal, including overheads. The principle is that the waste tax is not a general revenue source but a fee for service, and cannot fund other municipal spending. This framework was established by Law No. 147/2013, Article 1, paragraphs 639–668, which introduced TARI within a broader local tax reform.[1] Changes to the waste tax burden are permitted only when waste service costs vary.

Theoretically, the effect of EU funds in waste management projects on local taxation can go in two opposite directions. On the one hand, EU-funded investments may ease the financial burden on municipalities (and citizens) by covering capital costs for infrastructure improvements—such as composting plants, sorting facilities, or smart collection systems—reducing the need for local borrowing or co-financing and potentially stabilizing or lowering waste taxes (OECD, 2024; Bel and Warner, 2008; Dijkgraaf and Gradus, 2004). On the other hand, several factors may increase costs: many EU-funded projects expand service quality and scope, raising long-term operational expenditures (ISPRA, 2022); co-financing can strain local budgets in the absence of long-term planning; and meeting environmental targets may necessitate costly technological upgrades (Abrate et al., 2014). Inefficiencies in implementation, delays, and mismatches between funded infrastructure and local capacity can further erode savings, leading municipalities to raise tariffs to recover sunk costs or comply with post-project obligations (Bartolacci et al., 2019; Rodríguez-Pose and Garcilazo, 2018; Dijkgraaf and Gradus, 2004). These dynamics highlight that subsidies do not automatically translate into lower taxation: when they lead to higher operating costs, compliance obligations, or fiscal stress—especially under limited administrative capacity—the net effect may be neutral or regressive. Understanding these trade-offs is essential to designing EU funding frameworks that promote both environmental sustainability and fiscal equity.

Using detailed project-level data from the *OpenCoesione* database and municipal waste tax records, we provide new empirical evidence on how EU environmental investments shape local fiscal policy. Our identification strategy compares municipalities that received EU-funded waste management projects to municipalities that did not, leveraging variation in the timing of project start dates.

Italy represents a particularly appropriate setting to investigate the fiscal consequences of EU-funded waste management projects for two main reasons. First, it combines exceptional data availability with distinctive institutional features. The OpenCoesione database provides comprehensive project-level information on all EU Cohesion Policy interventions, while ISPRA[2] reports detailed municipal-level data on waste management costs. In addition, Italian municipalities are legally required to set waste taxes to fully cover actual service costs, ensuring a direct and transparent link between expenditure dynamics and local taxation. Second, Italy is one of the largest beneficiaries of EU funds for environmental infrastructure, with marked regional heterogeneity in administrative capacity and institutional quality. This combination makes the country an informative case study to examine how external transfers affect local fiscal outcomes.

To assess the causal impact of EU funds on municipal waste taxation, we implement a matched Difference-in-Differences (DiD) strategy. Because municipalities receiving EU funding are disproportionately located in the Mezzogiorno[3] and differ systematically from others, we first apply Propensity Score Matching (PSM) to construct a balanced sample of treated and untreated municipalities with comparable observable characteristics. Within this matched framework, we estimate the average treatment effect of EU-funded projects using the staggered difference-in-differences estimator proposed by Sun and Abraham (2021) over 2007–2023, which is specifically designed for settings with staggered treatment adoption and avoids the negative weighting issues associated with traditional two-way fixed effects estimators.

The results consistently indicate that municipalities benefiting from EU-funded waste projects experienced a sizeable increase in per-capita waste taxes, in the order of about 13–15% depending on the specification. Event-study estimates confirm the validity of the parallel trends assumption and reveal that the increase emerges from the second year after project initiation, reflecting implementation lags and co-financing obligations. Additional analyses corroborate these results. A continuous treatment specification shows a positive elasticity between funding intensity and tax levels, while heterogeneity tests highlight stronger effects in Northern municipalities, where administrative capacity and fiscal transparency are higher.

The second part of the empirical analysis concentrates on the transmission mechanism behind the main result that passes through the variation in the costs of waste management service after EU financing. We empirically test this relationship by using data on costs of total, separate and unsorted waste collection provided by ISPRA from 2011 (the first available year) to 2023. The empirical evidence suggests that EU funds on waste management projects have increased the total costs of the waste management service in the treatment group more than in the control group of municipalities. This increase is primarily driven by a statistically significant rise in the costs of unsorted waste collection (+9%), while changes in sorted waste collection costs are not statistically significant.

This evidence prompts a fundamental policy question: do higher waste management costs — particularly those associated with residual waste — reflect improved service quality and long-term efficiency gains, or are they the result of implementation inefficiencies and suboptimal resource allocation? To address this issue, we next examine changes in the composition and volume of collected waste, with the aim of identifying whether cost increases are associated with a shift towards more sustainable practices. The results reveal a substantial rise in separate waste collection and a concurrent decline in residual waste, suggesting behavioral and organizational adjustments in line with policy objectives. At the same time, these compositional changes alone do not fully account for the observed cost dynamics. The next stage therefore decomposes total waste management costs into collection and transportation costs and disposal and recycling costs, for both waste streams. This breakdown enables a more granular assessment of the intervention's effects along the waste management chain and helps identify whether cost increases are concentrated in specific segments of the system.

Finally, to assess whether EU-funded interventions translated into genuine improvements in operational efficiency, we estimate total factor productivity (TFP) changes using a non-parametric Malmquist index approach (Färe et al., 1994). By comparing pre- and post-intervention performance in municipalities that received EU cohesion funds, we are able to disentangle the contribution of technological progress from

[1] The TARI (Tassa sui Rifiuti) is the Italian municipal waste tax introduced by Law No. 147/2013. It is a user charge designed to fully cover the costs of municipal waste management services, including collection, treatment, disposal, and administrative expenses, in accordance with the full cost recovery principle.

[2] ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale) is the Italian public research institute responsible for environmental monitoring and assessment. It provides official, harmonized data on municipal waste generation, collection, and management costs.

[3] The Italian Mezzogiorno refers to the southern macro-area of Italy, including Abruzzo, Molise, Campania, Apulia, Basilicata, Calabria, Sicily, and Sardinia.

changes in relative efficiency. The results point to moderate productivity gains in the management of sorted waste, largely driven by technological advancement and accompanied by slight improvements in operational efficiency. Importantly, these gains do not necessarily translate into immediate cost reductions, but rather reflect improvements in service quality, technological standards, and compliance with environmental objectives. In contrast, the performance of unsorted waste management remains broadly stable, with limited technological progress offset by modest reductions in relative efficiency. This final stage of the analysis provides a comprehensive view of how public investment affects not only service coverage and composition but also the capacity of local systems to use resources effectively.

This paper contributes to the growing literature at the intersection of environmental economics, local public finance, and the economics of the green transition. Within environmental economics, prior research has examined the design and effectiveness of interventions in waste management, energy efficiency, and climate mitigation (Cetrulo et al., 2018; Shooshtarian et al., 2024; Du et al., 2023; Cerqua et al., 2024; Gillingham et al., 2009; Tanaka, 2011; de Coninck and Puig, 2015). Recent studies have also explored the fiscal dimension of environmental policies: unit pricing for unsorted waste reduces waste volumes and municipal expenditures (Valente, 2023), and environmental taxes can foster both economic performance and innovation (Stameski et al., 2024; Wang et al., 2022). This literature has substantially advanced our understanding of environmental outcomes, service quality, and cost drivers. What remains largely unexplored, however, is the fiscal dimension: we know much less about how green investments affect the structure of local taxation. Our paper contributes to this gap by showing how EU-funded waste projects translate into higher municipal waste taxes, thereby linking environmental interventions to their local fiscal consequences.

From the perspective of fiscal federalism, our study adds to a well-established literature on how intergovernmental transfers shape local taxation and spending decisions (Gordon, 2004; Cascio et al., 2013; Baicker and Staiger, 2005; Gennari and Messina, 2014; Dahlberg et al., 2008; Lundqvist, 2015; Knight, 2002). In particular, it relates to the flypaper effect (Gramlich, 1969, 1998; Hines and Thaler, 1995), emphasizing that the impact of transfers depends critically on their design. The effect of earmarked EU environmental funds on user charge-based services such as municipal waste remains largely unaddressed. By analyzing how Cohesion Policy resources in waste management affect the waste tax our paper extends this literature to a new and policy-relevant domain.

In line with recent contributions on the green transition (OECD, 2024; Cerqua et al., 2024), we examine how environmental goals interact with local financial and operational constraints. While separate collection systems require substantial investments (Cerqua et al., 2024), evidence also points to the effectiveness of low-cost interventions such as awareness campaigns (Nepal et al., 2023) and voluntary local initiatives (Meleddu et al., 2024). Yet, these works have predominantly focused on environmental performance and service design, while little is known about the unintended fiscal side-effects of green investments, particularly how they reshape local taxation structures and household burdens. Our paper contributes to this gap by documenting the fiscal fallout of EU-funded waste projects, identifying the transmission channel through increased service costs, and disentangling whether these increases reflect technological improvements or inefficiencies through a productivity analysis (using a Malmquist index, following (lo Storto, 2021; Halkos and Aslanidis, 2024; Färe et al., 1994)).

Finally, while this paper does not address waste prevention or circular economy strategies in a broad sense, it complements the circularity literature by focusing on the fiscal and cost-side implications of investments aimed at increasing recycling and reducing landfill reliance. By examining how green investments translate into local taxation under full cost recovery rules, the paper adds a public finance perspective to the circular economy debate. A broader circular economy agenda, however, places waste prevention and reuse at the top of the waste hierarchy, emphasizing demand-side drivers (consumption patterns, product design, and behavioral change) alongside recycling and treatment capacity. For instance, evidence shows that waste prevention is strongly linked to social preferences and motivations, and cannot be reduced to recycling improvements alone (Cecere et al., 2014). EU institutions and agencies similarly frame prevention — especially for bio-waste and food waste — as a key lever to reduce residual waste and environmental impacts (Cristobal et al., 2016; Brusselaers and Van Der Linden, 2020). Building on this agenda, our paper focuses on a complementary margin by examining how investments aimed at improving waste collection and diversion translate into local fiscal pressure under full cost-recovery rules, thereby providing a municipal-level public finance perspective that complements the broader, innovation- and policy-oriented circular economy framework (Zoboli et al., 2019).

Overall, our evidence suggests that EU cohesion funds have contributed to a structural shift toward more sustainable waste management, primarily by expanding the scope and intensity of separate waste collection. However, the persistence of high disposal costs for residual waste highlights downstream inefficiencies — such as limited treatment capacity or suboptimal waste quality — that constrain the overall effectiveness of the intervention. From a policy perspective, this underscores the need for a more integrated funding strategy that complements investments in collection systems with support for processing infrastructure and quality control. Without such coordination, higher operational costs may be passed on to local taxpayers, potentially generating regressive effects, particularly in economically vulnerable areas.

The key policy implication is that EU-funded waste investments are not fiscally neutral. While they support a transition toward more sustainable waste management by expanding separate collection, they may also increase local waste taxes when the downstream stages of the system — especially residual waste treatment and disposal — remain characterized by rigidities, limited capacity, or weak lifecycle cost planning. In this sense, the fiscal consequences of green investments depend not only on the scale of funding, but also on how well investment in collection systems is coordinated with treatment infrastructure and long-run operational sustainability.

The paper is organized as follows. In Section 2 we provide information on the EU policy funds and on the waste taxes in Italy. In Section 3 we describe the data and variables used in the empirical analysis. In Section 4 we explain the empirical strategy and in Section 5 we provide the estimation results and the robustness. Section 6 assesses the cost-transmission mechanism and Section 7 concludes.

2. Italian institutional framework

This section outlines the institutional framework governing the relevant EU policy regulations and the waste taxation in Italy.

2.1. EU policy funds in waste management services

Cohesion Policy is the EU's main tool for promoting sustainable development, reducing regional disparities, and improving quality of life. It operates through seven-year programming cycles with specific goals, instruments, and priorities, subject to the "n+2" rule to ensure timely fund absorption.[4]

[4] Under the EU cohesion policy framework, fund disbursement is subject to the so-called "n+2" rule, according to which resources committed in year n must be spent and certified by the end of year n+2. Any funds not used within this deadline are automatically decommitted and lost. This rule creates strong incentives for timely project implementation and often leads to a concentration of spending toward the end of the eligibility window.

Our analysis covers 2007–2023, spanning three cycles (2007–2013, 2014–2020, 2021–2027). We start in 2007 because this marks the introduction of harmonized monitoring procedures and the effective intensification of environmental infrastructure funding. Investments during these periods were largely concentrated in less developed regions.[5]

Data on funded projects come from *OpenCoesione*.[6] The thematic area Waste includes landfill remediation and closure, expansion of separate collection systems, and upgrading of treatment and recycling facilities, in line with EU circular economy goals. The dataset spans all three programming periods and reports number of projects, spending, payments, geographic coverage, and intervention types.

Waste management projects are grouped into three categories: (1) separate collection, (2) remediation, and (3) infrastructure, further subdivided into public works, goods and services, grants, incentives, and equity participation. Table C.1 in Appendix C provides descriptive evidence on the composition of EU-funded waste management projects. Projects related to separate waste collection represent the most frequent category, accounting on average for about 1.2 percent of municipality–year observations, followed by remediation activities (0.3 percent) and infrastructure projects (0.8 percent). While these shares may appear small, they reflect the fact that waste-related investments constitute a specific subset of cohesion policy interventions and are highly concentrated in time and space. Separate collection projects typically include investments in door-to-door systems, collection equipment, and organizational upgrades, whereas remediation projects mainly involve landfill closures, site clean-ups, and environmental restoration. Infrastructure projects encompass facilities such as treatment plants, transfer stations, and recycling centers, which are less frequent but often involve larger-scale investments. Overall, the distribution of project types highlights a stronger policy emphasis on improving collection systems rather than on large infrastructure expansion during the period considered (2007–2023).

This project-based perspective is consistent with the view of the circular economy as a systemic and innovation-intensive transition, emphasizing the joint role of technological change, institutional frameworks, and policy coordination, as articulated in Zoboli et al. (2019, 2020).

This perspective is also consistent with policy frameworks developed by European institutions, which emphasize separate collection — particularly for bio-waste — as a key lever for circular economy objectives, while acknowledging the presence of short- to medium-term cost pressures at the local level (Brusselaers and Van Der Linden, 2020).

Table C.2 further illustrates the degree of separation in household waste collection by reporting the main waste fractions collected separately at the municipal level. On average, Italian municipalities collect multiple fractions per household, including organic waste (biowaste), paper and cardboard, glass, plastics, metals, and — less frequently — wood, WEEE (waste electrical and electronic equipment), and textiles. The most widespread fractions in terms of collected volumes per household are paper and cardboard, organic waste, glass, and plastics, consistent with standard door-to-door collection schemes. The presence of additional fractions such as WEEE and textiles indicates a relatively granular system of separate collection compared to many other countries. Overall, these data suggest that a typical Italian household is exposed to a multi-bin collection system rather than a simple recyclable–non-recyclable split.

In Italy, multi-bin systems are implemented through different collection modalities. The most widespread approach in recent years has been door-to-door collection, whereby households are provided with dedicated bins or bags for each waste fraction and collection occurs at the household level on scheduled days. The main alternative is a system based on communal roadside containers ("bring banks"), where households dispose of waste in shared street bins. While door-to-door schemes have expanded markedly over time — especially in small and medium-sized municipalities — communal containers remain common in large and densely populated urban areas. International evidence suggests that collection modality and convenience constraints are important determinants of household recycling outcomes, highlighting the role of access costs and organizational features of waste collection systems (Dijkgraaf and Gradus, 2003; Abbott et al., 2011).

In addition to household collection systems, Italian municipalities typically operate municipal recycling centers (often referred to as civic amenity sites or household waste recycling centers). These facilities allow households to dispose of bulky items, WEEE, textiles, wood, metals, and other special household waste that cannot be easily collected at home. Recycling centers thus complement door-to-door and bring-bank systems and ensure access to separate collection even for households facing space or logistical constraints.

Fig. 1 shows the geographical (by regions) distribution of the municipalities receiving the EU funds for waste management projects (in green) and of municipalities not affected by EU policy intervention (in white) between 2007–2023. The map highlights two features. Firstly, the greatest part of the financed municipalities belong to the *Mezzogiorno* regions, namely Abruzzo, Apulia, Basilicata, Calabria, Campania, Molise, Sicily and Sardinia. Second, not all Italian regions had municipalities involved in EU-funded waste management projects. In particular, no municipalities in Emilia Romagna, Friuli Venezia Giulia and Valle d'Aosta received funding of this kind.

This geographical pattern, with most funded municipalities located in the South and untreated ones concentrated in the North, underscores the need for a matching procedure to construct a suitable control group. Accordingly, our empirical strategy relies on propensity score matching to ensure comparability between treated and untreated municipalities before applying the treatment model.

2.2. Waste taxes in Italy

In Italy, municipal waste services are managed locally and financed through specific waste taxes that have evolved over time. Initially introduced in 1993, the TARSU (Tax for the Disposal of Solid Urban Waste) was based on property size and use, but lacked alignment with actual waste generation. It was gradually replaced by the TIA in 1998, which introduced variables such as household size and business type, aiming for a closer link to service costs. In 2013, the short-lived TARES combined waste and general public services in a single tax but proved administratively complex.

Since 2014, the national standard has been the TARI, introduced by Law No. 147/2013. It is composed of a fixed and a variable component, calculated respectively on property size and occupancy characteristics, and is designed to fully cover the cost of the waste management service — including collection, treatment, overheads, and administration. Importantly, municipalities are legally required to adjust the TARI annually to reflect actual service costs. This results in a time-lagged pass-through: increases in costs in year t are reflected in tariffs in the following years. TARI represents a significant share of local revenues (about 20%, see Messina et al. (2018)) and averaged €312 per household in 2021 (ISPRA, 2022).

[5] Although all EU regions are eligible for cohesion support, the regulatory framework classifies them into three categories based on per-capita GDP, which determines the extent and type of financial assistance. Notably, Objective 1 (also known as the Convergence Objective) targets NUTS II regions with a per-capita GDP below 75% of the EU average, representing the cornerstone of regional policy. These less developed regions benefit most from the European Regional Development Fund (ERDF) and the European Social Fund (ESF), followed by transition regions, while the more developed regions receive comparatively limited support (Crucitti et al., 2024).

[6] Source: OpenCoesione. OpenCoesione is the national open government initiative on cohesion policies, coordinated by the Department for Cohesion Policies and for the South of the Presidency of the Council of Ministers. It provides data and information on projects funded with national and European resources, which are published on the portal.

Fig. 1. Geographical distribution of the EU funds for waste management projects.
Note. The map illustrates the geographical (by regions) distribution of the municipalities receiving the EU funds for waste management projects (in green) and of municipalities not affected by EU policy intervention (in white). Period: 2007–2023. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Alongside the TARI, municipalities with appropriate measurement technologies can adopt the alternative pay-as-you-throw system (TARIP), introduced by Article 1, paragraph 668 of Law No. 147/2013. TARIP directly links the variable component of the tax to the actual quantity of unsorted waste produced by each user and has been increasingly adopted in Northern regions, particularly in Veneto (Bucciol et al., 2025). This system creates an additional source of heterogeneity in observed tax levels, as municipalities applying TARIP may follow different dynamics in response to changes in service costs. Moreover, TARIP often goes hand in hand with the diffusion of door-to-door collection schemes, which also affect both service costs and the resulting tariffs. While our empirical strategy mitigates confounding by matching municipalities on observable characteristics, it is important to acknowledge that part of the North–South divide in treatment exposure reflects differences in local tariff policies such as TARIP and in the organization of collection systems.

For some municipality-year observations, recorded waste-tax revenues are equal to zero (see Table C.4, Appendix C). These are not missing observations: in the source dataset, unavailable values are coded as missing and are excluded from the analysis. Rather, zeros are observed entries in municipal accounts and may reflect institutional and accounting features of the Italian system, including delays in assessment or collection, differences in booking practices across municipalities, transitional phases across charging regimes, or cases in which waste services are managed supra-municipally and revenues are not directly recorded in municipal budgets.

3. Data and variables

3.1. Dependent variable

AIDA (“Analisi Informatizzata Delle Aziende”) PA (“Pubblica Amministrazione”)[7] provides yearly data on the amount of resources collected through the waste taxes (as described above) in each Italian municipality from 2007 to 2023. The dependent variable of the main analysis is this per-capita waste tax amount (i.e., the waste tax amount divided by the resident population) in real Euros (€). We express the variable in natural log to have the interpretation of the coefficients in terms of elasticity (*Waste tax*).[8] Importantly, in our analysis, we do not use AIDA PA data at the waste-management company level, but rather a municipality-level dataset that directly reports waste tax revenues for each municipality and year. Thus, our outcome, that reflects the actual tax revenues of each municipality, is not affected by aggregation issues arising when multiple municipalities are served by the same company.

[7] AIDA PA is a database by Bureau van Dijk (a Moody’s group company) that contains economic and financial information on Italian public administrations.

[8] The dependent variable is per-capita municipal waste taxation. Since the per-capita municipal waste taxation can take zero values for some observations, we add one before applying the logarithmic transformation.

3.2. Main regressor

The regressor of interest is based on EU funding for waste management projects received by Italian municipalities, as reported in the OpenCoesione database (1997–2023). For consistency, we restrict the sample to 2007–2023, excluding municipalities that received funds in 2000–2006.[9] The measure includes EU transfers, national co-financing reimbursements, and regional or provincial allocations of cohesion funds.

As Fig. 1 shows, we can identify a group of municipalities that received funding (the treatment group), and a group composed of municipalities that were not affected by waste management financing projects (the control group). Furthermore, since the funds were disbursed at different times between 2007 and 2023, we exploit the staggered rollout of the EU policy. This allows us to compare the outcome of interest over time between municipalities that have already received funding and those that have not yet received it in a given year, and those that never received it. Therefore the treatment status of a municipality begins in the starting year of the project. The years prior to this date are to be considered pre-treatment periods.

3.3. Control variables

In the empirical analysis, we control for time-varying municipal characteristics. First, population size (*Pop*) and average household size (*Family members*, computed as residents divided by families), which account for waste generation. We also include per-capita municipal income (log, real € – *Per-capita income*).[10] These variables capture demographic and socioeconomic conditions that may influence both the demand for waste services and the cost structure of their provision, as well as municipalities' ability to finance service-related expenditures through local taxation. Controlling for these factors helps isolate the effect of EU funding from pre-existing differences in fiscal capacity and service needs across municipalities. Since the waste tax partly depends on property size and use, income is an important determinant. We further control for council composition: average education and age (*Councilors education*, *Councilors age*), share of female councilors (*Female councilors*), and mayor's gender (*Mayor's gender*).[11] These controls aim to proxy for differences in local governance, administrative capacity, and political decision-making, which may affect both the implementation of EU-funded projects and the way service costs are translated into local tax levels. Including political characteristics reduces concerns that estimated effects reflect heterogeneous local responses to funding rather than the funding itself. Finally, we include the Municipal Administrative Quality Index (*MAQI*) (Cerqua et al., 2025), which captures efficiency, transparency, and fiscal performance of local governments, and is particularly relevant in contexts of weak institutions (Charron et al., 2014; Cerqua and Pellegrini, 2018).[12]

Overall, the inclusion of demographic, socioeconomic, political, and institutional controls mitigates concerns that the estimated treatment effects capture pre-existing structural differences across municipalities rather than the causal impact of EU-funded waste management investments. Table C.4 in Appendix C shows the descriptive statistics of variables.

4. Research design

In this section, we discuss the matched Did design we use to examine the effects of the EU funds in waste management services on municipal waste taxation.

4.1. Matched DiD

In this study, we employ a matched DiD analysis (Goodman-Bacon, 2021; Borusyak and Jaravel, 2017) to support the identification of the empirical research design. In evaluating the impact of EU funds allocated to waste management projects in Italian municipalities, Propensity Score Matching (PSM) offers a robust method to address potential selection bias inherent in observational data. Municipalities that receive EU funding for waste management initiatives often differ from those that do not, in terms of demographic, economic, and infrastructural characteristics. Indeed, they are mostly located in the Mezzogiorno of Italy (as said above, the Italian Mezzogiorno includes Abruzzo, Molise, Campania, Apulia, Basilicata, Calabria, Sicily, and Sardinia), which has historically had very different characteristics compared to the rest of the country. These differences can confound the estimation of the treatment effect, making it challenging to attribute observed outcomes solely to the intervention.

PSM, introduced by Rosenbaum and Rubin (1983), estimates the probability (propensity score) of a municipality receiving treatment based on observed covariates. By matching treated municipalities with untreated ones that have similar propensity scores, PSM creates a counterfactual group that approximates a randomized control group, thereby isolating the effect of the intervention.

The propensity score is estimated with a logit model predicting the likelihood of a municipality receiving EU funds for waste management projects (treatment) in the 2007–2023 period. Treated municipalities are then matched to controls with similar scores, ensuring comparable pre-treatment trends.[13]

The logit model includes covariates capturing regional/provincial, demographic, political, and economic characteristics: regional and provincial dummies; resident population and female population (log); share of residents with a university degree (log); average household size; per-capita municipal waste; standardized municipal income; average age of residents (log); average education of councilors; and share of female councilors.

To assess matching quality, we conduct two-sample t-tests on covariate means between treated and matched controls. Results (Table C.3, Appendix C) show no significant mean differences, indicating good balance. Overall diagnostics also support this: pseudo R^2 = 0.003, LR chi^2 test p = 0.590, Rubin's B = 12.0, and Rubin's R = 0.85.

Fig. D.1, Appendix D, illustrates propensity score distributions before and after matching. In particular, Graph D.1(b) shows strong overlap between treated and controls, confirming improved comparability. Finally, Section A in Appendix A shows the relevant statistics in the matched sample of municipalities.

[9] Although the OpenCoesione database nominally spans the period 1997–2023, the coverage and thematic scope of project monitoring vary substantially over time. In particular, projects implemented between 1997 and 1999 are not systematically monitored. During the subsequent programming period (2000–2006), OpenCoesione records only projects financed under the Fondo per lo Sviluppo e la Coesione (FSC), while EU structural funds are not comprehensively covered. As a consequence, projects related to waste management implemented in this period are not systematically observed in the database, preventing a consistent and comparable identification of treatment status across municipalities. To avoid measurement error in treatment assignment and ensure a homogeneous definition of exposure to EU-funded waste management projects, we restrict the empirical analysis to the period 2007–2023, when project-level information becomes comprehensive and thematically complete.

[10] Source: Italian Ministry of Finance (MEF), yearly declared income by municipality, including dependent and self-employment income, entrepreneurial income (ordinary and simplified accounting), and pensions.

[11] Source: Italian Ministry of Interior.

[12] *MAQI* is a composite index of three dimensions: bureaucratic capacity, quality of politicians, and economic/fiscal performance.

[13] Matching implemented via Stata command *psmatch2* (Leuven and Sianesi, 2003).

4.2. Empirical strategy

To examine whether — and through which mechanisms — the allocation of EU Cohesion Funds for waste management projects has affected municipal waste taxation in Italy, we apply a matched difference-in-differences (DiD) approach over the period 2007–2023. The analysis exploits the staggered timing of fund disbursements across municipalities as a source of temporal variation. We define the receipt of payments as the treatment. Given that payments are disbursed at different times, the DiD framework enables us to compare the per-capita waste tax over time between municipalities that have already received funding (treated units) and a control group composed of municipalities that have not yet received funding in a given year as well as municipalities that never receive funding over the sample period, within the matched sample. Municipalities are considered treated from the starting year of the funded project onward.

The equation that estimates the treatment effect of fund disbursement on citizens' taxation between treated and control groups is as follows:

$$Y_{it} = \beta_1 Treatment_{it} + \alpha_i + \delta_t + X_{it} + \epsilon_{it} \quad (1)$$

where Y_{it} represents the per-capita waste taxation (expressed in log) at year t in municipality i. The dummy $Treatment_{it}$ takes the value of 1 from the year of the beginning of the project onward and 0 otherwise. α_i represents the set of municipality fixed effects that control for heterogeneity in the cross-sectional dimension, allowing us to account for unobservable time-invariant factors that could bias the estimates. δ_t represents the set of year fixed effects that control for unobservable events specific to each year, which may affect all municipalities in the same way. X_{it} is the vector of control variables listed above. ϵ_{it} is the error term. Under the parallel trend assumption, the coefficient β_1 measures the average effect of the disbursement of cohesion funds on the outcome.

The parallel trends assumption is fundamental to the validity of the DiD approach. It implies that, in the absence of treatment, the difference in outcomes between treated and control groups would have remained stable over time. To assess this assumption, we adopt a dynamic matched DiD specification by estimating an event-study model. This framework enables us to trace the trajectory of the outcome variable for both treated and control municipalities in each year before and after the fund disbursement (Mora and Reggio, 2019). This approach not only tests the parallel trends assumption, but also reveals the dynamic evolution of waste taxation in the years following the treatment.

The dynamic specification is the following:

$$Y_{it} = \sum_{k=-n}^{+n} \nu_k \cdot D_{it-k} + \alpha_i + \delta_t + X_{it} + \epsilon_{it} \quad (2)$$

where, as before, Y_{it} represent the (log o) per-capita taxation in municipality i at time t. D_{t-k} is the set of event-time dummies, which take the value of 1 for treated municipalities if the year t is the k period (from $-n$ to $+n$) before /after the beginning of the project. The event-time window is defined within the overall sample period, which spans from 2007 to 2023. Accordingly, the number of pre- and post-treatment periods varies across municipalities depending on the year in which the project begins and is bounded by the start and end of the sample. We identify as t_0 the year of the beginning of the project. We consider as omitted category the year of the first payment, D_{t0}; the remaining coefficients ν_t measure the difference in the citizens' waste taxation before and after the payments in the treatment group of municipalities with respect to the control group. n represent the number of estimated lags/leads. In all the specifications we control for municipality (α_i) and year (δ_t) fixed effects (FE); then, we include all the control variables listed above. ϵ_{it} is the error term.

In our analysis, the treatment — namely, the EU intervention in waste management projects — is implemented in a staggered fashion over time, meaning that different units receive the treatment at different points. Recent contributions in the literature (Goodman-Bacon, 2021; De Chaisemartin and d'Haultfoeuille, 2020) have shown that the conventional DiD estimator may be inadequate in such settings and can yield misleading results. Specifically, the estimated treatment effect under the traditional DiD framework is a weighted average of group-time-specific treatment effects. Critically, some of these weights can be negative, even when the true treatment effects are positive, which can distort the overall estimate. As a result, the average treatment effect may appear negative despite the intervention having a genuinely positive impact. This issue arises when treatment effects are heterogeneous across groups and over time, leading to situations where already-treated units are incorrectly used as controls for newly treated ones. Such contamination in the comparison group due to timing differences can introduce bias into the final estimate of the treatment effect.

To address the problem of negative weights in the staggered treatment setting, we apply the estimator proposed by Sun and Abraham (2021), on the matched sample of municipalities, which is designed for linear models and remains robust in the presence of heterogeneous treatment effects. In practice, the approach proposed by Sun and Abraham (2021) builds on the event-study specification in Eq. (2) and estimates group-time-specific treatment effects by comparing each treated cohort only to units that have not yet been treated at the same point in time. These cohort-specific effects are then aggregated into an overall average treatment effect that is free from contamination by already-treated units. When applied to the static specification in Eq. (1), this procedure yields an average post-treatment effect that is robust to treatment effect heterogeneity and avoids the negative weighting problem inherent in conventional two-way fixed effects estimators.

While the matched DiD design and the (Sun and Abraham, 2021) estimator are well suited to our staggered-treatment setting, they should be interpreted as tools that strengthen identification under specific assumptions, rather than as self-sufficient guarantees of causal validity. In particular, the credibility of the design depends not only on the plausibility of parallel trends, the quality of the matched comparison group, and the institutional interpretation of treatment timing and exposure, but also on the specification of the empirical model and on the consistency of the evidence across complementary analyses. In this sense, our matched DiD approach should be seen as one empirical tool among others, whose credibility is reinforced by the convergence of descriptive evidence, robustness checks, and the analysis of the cost-transmission mechanism, in line with a broader model-based econometric perspective (Hendry, 2000). More generally, the credibility of the empirical design depends not only on treatment timing and identification assumptions, but also on model specification and functional-form choices, which recent contributions have emphasized in panel settings with complex dependence structures (Musolesi et al., 2025; Gioldasis et al., 2023; Soberon et al., 2024; Escobar-Lemmon and Taylor-Robinson, 2009).

5. Results

5.1. Average effect

Table 1 presents the estimation results based on Eq. (1). The dependent variable is the (Log of) municipal per-capita waste tax (in real €), and standard errors are clustered at the municipal level to account for intra-municipality correlation over time. The key regressor, *Treatment*, is a binary indicator equal to 1 for municipalities that received EU funding for waste management projects from the year of project initiation onward, and 0 otherwise. Across all specifications, the coefficient on *Treatment* is positive and statistically significant at conventional level, suggesting that municipalities benefiting from EU-funded waste management projects experienced a systematic increase in local waste taxation compared to those not receiving such funding. In the most parsimonious specification (Column 1), which includes municipality

Table 1
Sun and Abraham (2021)'s estimates.

Dep. Var.:	(1) (Log)Waste taxes	(2) (Log)Waste taxes	(3) (Log)Waste taxes
Treatment	0.147**	0.133**	0.128**
	(0.065)	(0.065)	(0.065)
Pop	2.49e−06***	2.43e−06***	2.42e−06***
	(4.48e−07)	(4.44e−07)	(4.38e−07)
Family members	711.6***	732.5***	746.8***
	(196.3)	(196.0)	(200.1)
(Log) Per-capita income	−0.683	−0.602	−0.552
	(0.551)	(0.552)	(0.559)
Councilor's education		−0.0283	−0.0294
		(0.0249)	(0.0249)
Councilor's age		−0.00906	−0.00885
		(0.00702)	(0.00705)
Female councilors		0.409*	0.340
		(0.228)	(0.232)
Mayor's gender		0.0431	0.0429
		(0.0874)	(0.0882)
MAQI			0.00867
			(0.00674)
Observations	57,134	57,134	56,686
No. Municipalities	3891	3891	3841
Municipality FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes

Note. Matched DiD estimates of Eq. (1) based the Sun and Abraham (2021)'s procedure. The dependent variable is the (Log of) municipal per-capita waste tax (in real €). The variable *Treatment* is a dummy that takes the value 1 starting from the year of the beginning of the financed waste management project onward, and 0 otherwise. The analysis period spans from 2007 to 2023. The control variables include: the resident population in thousands, the average household size, the per-capita income (in real €) (in natural log), the average level of education and the average age and the share of female and the gender of the mayor of municipal council, the MAQI. All specifications include fixed effects for year and municipality, though the coefficients for these effects are not reported. Standard errors are clustered at the municipality level and are presented in parentheses. Coefficient significance levels are indicated by * (10% significance), ** (5% significance), and *** (1% significance).

and year fixed effects and time-varying municipal characteristics — including the resident population, average household size, and log of per-capita income —, the estimated impact is an increase of approximately 14.7% in the per-capita waste tax for treated municipalities relative to the control group. Given the mean value of the waste tax is approximately 95€ (as shown in Table C.4), this implies an average increase of around 14€ per person per year in treated municipalities. Using the exact transformation $100 \cdot (e^{\beta} - 1)$, the estimated effect corresponds to an increase of approximately 15.9% in per-capita waste taxes. This magnitude is economically meaningful, suggesting that the fiscal impact of EU-funded waste projects on local taxpayers is not only statistically significant but also quantitatively relevant. Notably, larger municipalities (as captured by population) and those with bigger average households tend to levy higher waste taxes, while per-capita income does not have a statistically significant effect on waste taxes.

Column 2 adds political variables, including the average education level and age of municipal council members, the share of women in the council, and the gender of the mayor. Despite the additional controls, the estimated treatment coefficient is 0.133, corresponding to a 14.2% increase in per-capita waste taxes. The result remains very close to the baseline estimate, indicating that the effect is robust to the inclusion of political controls

In the final specification (Column 3), we further include the Municipal Administrative Quality Index (MAQI) (Cerqua et al., 2025), an index measuring institutional quality, transparency, and governance performance. Although the MAQI itself is not statistically significant, its inclusion helps rule out confounding effects due to variation in local institutional capacity. The estimated treatment coefficient is 0.128, corresponding to a 13.7% increase in per-capita waste taxes. This estimate is again very close to the baseline result, reinforcing the robustness of the main finding.

The relative stability of the treatment effect across all model specifications is a strong indication of its robustness and supports the assumption that the treatment is exogenous with respect to unobserved factors that could otherwise bias the estimates. The inclusion of detailed control variables and fixed effects rules out several alternative explanations, such as omitted variable bias due to structural differences in local governance or socioeconomic context.

Taken together, the results suggest that EU funding for waste management projects, while intended to support service improvements, is associated with a significant increase in local waste taxation. This finding is consistent with the hypothesis that the operational and financial obligations linked to these projects — such as co-financing requirements, maintenance costs, and expanded service scope — may offset any short-run fiscal relief from the capital investment itself.

As an additional robustness check, we re-estimate the matching procedure using only pre-treatment covariates so that the matching is based exclusively on pre-treatment information. The resulting estimates are very similar to the baseline ones and confirm the positive and statistically significant effect of EU-funded waste management projects on per-capita waste taxes. The corresponding results are reported in Table C.8 in Appendix C.

5.2. Dynamic

In this section we estimate an event-study model as in Eq. (2) according the Sun and Abraham (2021)'s procedure in order to assess for (1) the validity of the parallel trend assumption and (2) the dynamic of the municipal per-capita waste tax during the post-treatment period. We estimate 6 pre-treatment coefficients and up to 9 post-treatment coefficients.

This choice reflects a balance between the need to test the parallel trends assumption and to capture the long-run dynamics of EU-funded waste investments. A 6-year pre-treatment window provides a sufficiently long horizon to verify the absence of differential trends before the intervention without fragmenting the sample and reducing statistical power. At the same time, extending the horizon up to 9 years after the treatment allows us to trace the medium- and long-run consequences of EU funding. This is particularly relevant in the context of waste management projects, whose fiscal effects often materialize with a delay due to construction times, procurement processes, and the gradual rise of operating and maintenance costs once new facilities become fully operational. Moreover, limiting the window to 9 years prevents estimates at the tails from being driven by few observations, ensuring more reliable inference. Overall, this specification provides both credibility to the identification strategy and a meaningful characterization of the temporal dynamics of investments in local waste services.

Fig. 2 shows the estimation results of Eq. (2). In all Graphs we control for year and municipality FE; Graphs 2(a), 2(b) and 2(c) refer to estimations in Column (1), (2) and (3) in Table 1, respectively, that is, adds all the control variables specified above, such as *Pop*, *Family members*, *(Log) Per-capita income*, *Councilor's education*, *Councilor's age*, *Female councilors*, *Mayor's gender*, *MAQI*.

First, all the graphs indicate that the parallel trend assumption is likely satisfied, as the confidence intervals from $t_0 - 6$ to $t_0 - 1$ are centered around zero. To formally assess this, we conduct an F-test to determine whether all pre-treatment coefficients are jointly equal to zero. The results support the null hypothesis at conventional significance levels, with p-values of 0.43, 0.39 and 0.40 for estimations shown in Graphs 2(a), 2(b) and 2(c), respectively. These findings suggest that, prior to the disbursement of EU funds for waste management projects, there were no statistically significant differences in the trend of municipal per-capita income growth between the two groups of municipalities.

The analysis of the post-treatment dynamic presents an increasing trend of the waste tax in treatment group than in the control group starting from the second year after the beginning of the waste management project ($t_0 + 2$).

The significant increase in waste tax from $t_0 + 2$ likely reflects the time lag between project approval and implementation: construction, procurement, and administrative procedures often delay operational and financial effects. Thus, higher tariffs coincide with infrastructure becoming operational rather than with the funding year. Short-run increases may also stem from co-financing requirements or non-eligible expenses borne by municipalities, which explains the temporary rise at $t_0 + 2$ and the insignificant effect at $t_0 + 3$, when such expenditures end. Year $t_0 + 3$ can therefore be seen as a "transition year", marked by administrative adjustments, temporary efficiency gains, or delays in activating new facilities.

From $t_0 + 4$ onward, higher tax burdens may result from several factors. New infrastructure and services (e.g., recycling systems, treatment plants) increase operating and maintenance costs, which become visible once EU funding ends. Tariffs may also rise due to the internalization of environmental costs or broader waste-management reforms. Effectiveness depends on scale and complementarity: if upstream investments are not matched by downstream capacity (e.g., disposal or recycling markets), costs may grow faster than efficiency. Moreover, EU funding may have encouraged municipalities to expand services beyond what was fiscally feasible, creating rigidities and lock-ins that require higher tariffs, reinforced by the legal obligation (Law 147/2013) to fully cover costs via TARI.[14] Finally, inefficiencies in project and resource management may also play a role, an issue further discussed in Section 6.

[14] We also assess the robustness of the dynamic results to the construction of the matched sample. Specifically, we repeat the matching procedure using only pre-treatment covariates, i.e. municipal characteristics observed before treatment exposure. The event-study estimates obtained on this alternatively matched sample closely mirror the baseline dynamic pattern: pre-treatment coefficients remain jointly insignificant, while the increase in per-capita waste taxes emerges only in the post-treatment period. The corresponding event-study coefficients are shown in Fig. D.5 in Appendix D.

5.3. Further results

In addition to the baseline specification, we conducted two complementary exercises whose detailed results are reported in Appendix B. First, we estimated a continuous treatment specification, where the intensity of EU funding is measured as the logarithm of transfers received. The results uncover a clear dose–response relationship: a 10% increase in funding is associated with roughly a 0.10% rise in per-capita waste taxes in the subsequent year. Second, we explored heterogeneity across macro-areas by allowing for differential effects between Northern/Central and Southern municipalities. The evidence indicates that the increase in taxation is concentrated in the North and Center, while it is much weaker in the South, a pattern consistent with differences in administrative capacity and in the ability to translate service costs into local tariffs.

6. The cost transmission mechanism: from public funding to waste taxation

Our analysis shows that EU-funded waste projects raise per-capita waste taxes in treated municipalities. This section investigates the mechanism underlying this result, namely whether the increase in local taxation operates through higher waste management service costs and, if so, through which components of the waste management chain. To this end, we examine how EU-funded projects affect total waste management costs, the composition of waste flows, the different operational phases of the service, and, finally, productivity dynamics. This mechanism is consistent with evidence that such investments often increase short-term service costs, especially when they expand separate collection systems with high fixed and operating expenses (Dijkgraaf and Gradus, 2004; Bel and Warner, 2008). Other studies, however, highlight possible medium- to long-run savings from economies of scale and efficiency gains (Bel and Fageda, 2010; Bartolacci et al., 2019). These mixed outcomes stress the role of implementation capacity, service design, and complementary infrastructure.

The main transmission channel is higher operating and maintenance costs from system upgrades — new recycling facilities, smart collection, or expanded waste streams — which, while improving service quality, entail recurring expenses not covered by one-off EU grants (ISPRA, 2022; Ichinose, 2024; Dijkgraaf and Vollebergh, 2004). While previous studies suggest that waste management costs may weigh more heavily on small or fiscally constrained municipalities (Dijkgraaf and Vollebergh, 2004), our empirical results do not confirm this pattern in terms of per-capita waste taxation. In our setting, larger municipalities are associated with higher per-capita waste taxes (Table 1), suggesting that differences in service intensity, organizational complexity, and the pass-through of costs into tariffs may dominate scale-related cost considerations. In Italy, Article 1, paragraph 654, of Law No. 147/2013 requires full cost recovery through the TARI, so any cost increase — maintenance, staff, or compliance — is passed on to taxpayers (Carattini et al., 2018). Co-financing and pre-financing add further pressure, while inefficiencies or poor alignment with local needs may produce overinvestment or underused assets.

Overall, these mechanisms suggest that the fiscal impact of EU funds depends on administrative capacity and institutional quality (Rodríguez-Pose and Garcilazo, 2018; Cerqua and Pellegrini, 2018), and that weak lifecycle planning can increase the burden on local taxpayers.

6.1. Empirical evidence

We use municipal-level data on urban hygiene expenditures from ISPRA, available for 2011–2023 (the first year of reporting). The dataset provides aggregate figures and a breakdown of per-capita spending (real €) on differentiated and unsorted waste. Throughout the paper, we use the terms "separate collection", "sorted waste", and "differentiated

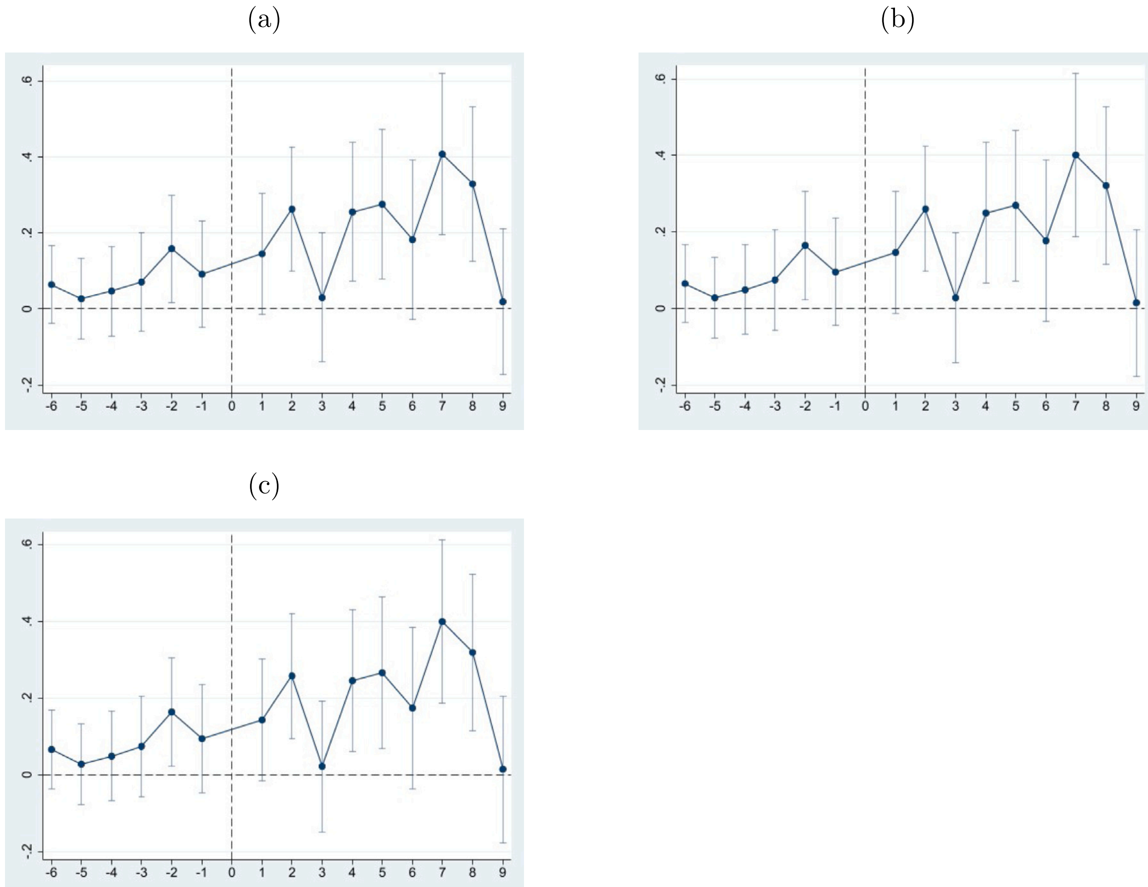


Fig. 2. Sun and Abraham (2021)'s estimates.
Note. The graphs report coefficients and confidence intervals estimated according to the Sun and Abraham (2021)'s procedure. The dependent variable is the (Log of) municipal per-capita waste tax (in real €). Estimation in Graph 2(a) controls only for time and municipality FE. Estimation in Graph 2(b) includes also for the resident population in thousands, the average household size, the per-capita income (in real € and in natural log), the average level of education and the average age and the share of female and the gender of the mayor of municipal council. Estimation in Graph 2(c) includes also the MAQI. Event time 0 denotes the year of the beginning of the project and it takes as omitted category. Positive (negative) values indicate subsequent (previous) year relative to the event. Standard errors are clustered at municipal level. Standard errors are clustered at the municipal level. The points represent the estimated coefficients; the confidence intervals are at 95%. The *p*-value of the F-test that all pre-treatment coefficients are jointly equal to 0 is 0.43, 0.39 and 0.40 for the estimates in Graph 2(a), 2(b) and 2(c), respectively. Time period: 2007–2023.

waste" interchangeably to refer to waste fractions collected separately at source for recycling or treatment, following the terminology adopted in ISPRA statistics. By contrast, "unsorted waste" refers to residual mixed waste.

Table C.7 (Appendix C) reports descriptive statistics. The *Total waste cost* covers collection and transportation (sorted and unsorted), treatment and recycling, street cleaning, overhead (administration, utilities, insurance), capital outlays (equipment, infrastructure), and ancillary services (e.g., awareness campaigns). Sorted and unsorted waste account for most expenditures: on average, 35% for sorted waste and 37% for unsorted, with the rest reflecting shared or ancillary services. We define *Total costs for separate waste* as the expenditure for collection, transport, and processing of sorted waste, and *Total costs for unsorted waste* as all expenses linked to residual waste, including logistics and downstream treatment.

Fig. D.4 (Appendix D) shows annual trends in per-capita spending: Panel D.4(a) reports overall expenditures, while Panel D.4(b) disaggregates sorted and unsorted waste.

To analyze cost pass-through, we estimate Eq. (1) by the Sun and Abraham (2021)'s procedure, regressing treatment on the log of total municipal waste costs (real €), using the matched sample. Controls include resident population, per-capita income (log), total per-capita waste, and household size, plus municipality and year fixed effects. The latter capture structural cost drivers such as the presence or distance of disposal/recycling facilities. Results (Column 1, Table 2) show that the estimated treatment coefficient is 0.030, corresponding to about a 3.0% increase in per-capita total waste costs in treated municipalities relative to controls.

Accordingly, we estimate Eq. (1) by regressing the treatment variable on the (Log of) total cost for separate and unsorted waste collection, whose results are respectively in columns 2 and 3 of Table 2.

For unsorted waste collection, the estimated treatment coefficient is 0.090, corresponding to about a 9.4

The estimated treatment coefficient is positive in both cases, although it is statistically significant only for unsorted waste collection. For unsorted waste collection, the estimated treatment coefficient is 0.090, corresponding to about a 9.4% increase in costs in treated municipalities relative to the control group.[15]

[15] A noteworthy aspect of the cost analysis is that the estimated impact on total expenditure (approximately 3%) is smaller than the effect on unsorted waste collection costs (about 9%), which is statistically significant. By contrast, the estimated effect on the cost of separate waste collection, although positive, is not statistically significant and should therefore be interpreted with caution. This pattern reflects measurement and compositional factors

Table 2
Sun and Abraham (2021)'s estimates — Costs of waste management service.

Dep. Var.:	(1) (Log)Total waste cost	(2) (Log)Total cost for separate waste	(3) (Log)Total cost for unsorted waste
Treatment	0.030**	0.059	0.090***
	(0.013)	(0.045)	(0.032)
Observations	14,855	14,763	14,822
No. Municipalities	1210	1210	1210
Municipality FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Controls	Yes	Yes	Yes

Note. Matched DiD estimates of Eq. (1) based the Sun and Abraham (2021)'s procedure. The dependent variable is 1) the (Log of) municipal per-inhabitant total cost of waste management service (in real €) in Column 1; 2) the (Log of) municipal per-inhabitant total cost of separate waste collection (in real €) in Column 2; 3) the (Log of) municipal per-inhabitant total cost of unsorted waste collection (in real €) in Column 3. The variable *Treatment* is a dummy that takes the value 1 starting from the year of the beginning of the financed waste management project onward, and 0 otherwise. The analysis period spans from 2011 to 2023. All specifications include fixed effects for year and municipality, though the coefficients for these effects are not reported. The control variables include, in all the specifications: the resident population, the average household members and the (Log of) per-capita municipal income. Moreover, in regression in column 1 we also control for the municipal per-capita tonnes in total waste collection; in column 2 we also control for the municipal per-capita tonnes in separate waste collection; in column 3 we also control for the municipal per-capita tonnes in unsorted waste collection. Coefficient significance levels are indicated by * (10% significance), ** (5% significance), and *** (1% significance).

Fig. 3 illustrates the dynamic effects of EU-funded waste management projects on per-capita waste management costs. Across all panels, pre-treatment coefficients are close to zero and display no systematic trend, suggesting that treated and control municipalities followed similar cost dynamics prior to the intervention. This visual evidence is corroborated by formal F-tests reported in the note to the figure, which fail to reject the null hypothesis that all pre-treatment coefficients are jointly equal to zero (p-values of 0.87, 0.14, and 0.37 for total, separate, and unsorted waste costs, respectively). These results support the validity of the parallel trends assumption in the matched DiD framework. Post-treatment dynamics reveal a gradual increase in costs following project initiation. For unsorted waste collection, coefficients become positive and grow over time, consistent with the emergence of higher operating and disposal costs once new infrastructure becomes fully operational. By contrast, the dynamic effects for separate waste collection are more imprecisely estimated, in line with the weaker and statistically insignificant average effect documented in Table 2.

6.2. Further empirical evidence on the cost transmission mechanism

Preliminary findings indicate that Italian municipalities receiving EU cohesion funds for waste management projects experienced an increase in per-capita expenditures on municipal solid waste services. This is consistent with findings in the literature that investments in advanced waste management technologies, such as waste-to-energy facilities, are typically associated with higher unit operating costs compared to traditional options (Dijkgraaf and Vollebergh, 2004). This rise in costs pertains to both the sorted (recyclable) and unsorted (residual) waste collection components.

However, cost increases alone do not provide a sufficient basis for assessing the actual impact of the intervention.[16] Such increases may stem from two fundamentally different scenarios: on one hand, they may reflect investments in system improvements and the adoption of more advanced infrastructure and services — such as smart bins, door-to-door collection, and public awareness campaigns; on the other hand, they may result from inefficient or poorly targeted spending.

6.2.1. Waste management system improvement or inefficiencies?

To assess whether the observed increase in costs corresponds to genuine improvements in service quality or rather signals inefficiency, it is crucial to examine whether the intervention led to meaningful changes in the volume and composition of waste collected — particularly an increase in per-capita sorted waste and a reduction in unsorted waste. This analysis is key to distinguishing between a virtuous transition towards more sustainable waste practices and a scenario of resource misallocation.

Therefore, we investigate the impact of the intervention on per-capita sorted and unsorted waste collection. If higher costs are accompanied by a significant rise in differentiated waste and a simultaneous decline in undifferentiated waste, the cost increase may be interpreted as indicative of a shift towards a more sustainable, though initially more expensive, waste management system (Dijkgraaf and Gradus, 2003). In this case, public intervention appears to have successfully influenced both user behavior and service design in a more environmentally sound direction, thus at least partially justifying the higher expenditures.

Table 3 shows that the estimated treatment coefficient for per-capita sorted waste (Column 1) is 0.190, corresponding to a 20.9% increase in treated municipalities relative to the control group. For per-capita unsorted waste (Column 2), the estimated treatment coefficient is −0.095, corresponding to a 9.1% reduction. These results suggest that EU interventions primarily operate by shifting waste flows from unsorted to sorted collection, in line with recycling and landfill diversion objectives.

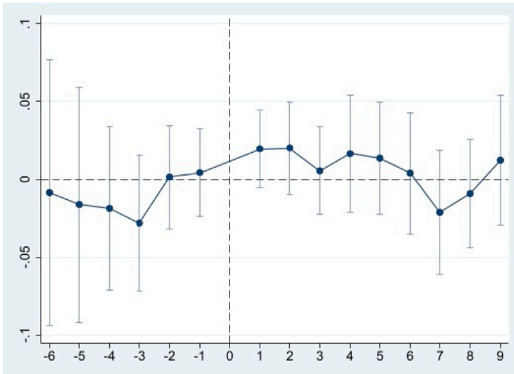
The marked increase in sorted waste collection documented in Table 3 is consistent with the policy objective of promoting recycling and landfill diversion, in line with Bel and Warner (2008). These results indicate that EU-funded investments successfully shift waste flows toward more sustainable collection practices. Behavioral responses may also play a role in this transition: Bonan et al. (2025) show that norm-based feedback reduces unsorted waste, while tariff salience can weaken intrinsic motivations.

By contrast, the decline in unsorted waste is accompanied by a significant increase in the associated collection costs (Table 2), suggesting heterogeneous effects across stages of the waste management cycle. While the expansion of separate collection does not translate into a

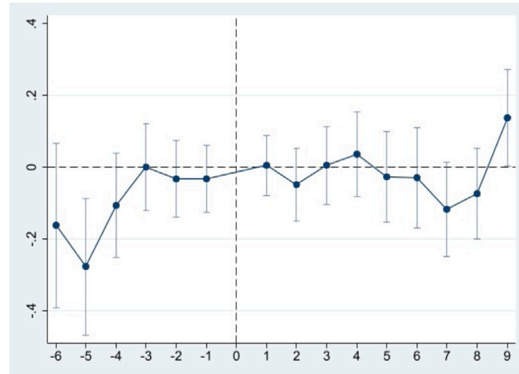
rather than inconsistency. First, total waste costs include components beyond collection activities — such as street cleaning, administrative overheads, capital expenditures, and information campaigns — that are only weakly affected by EU-funded investments and therefore dilute the aggregate effect. Second, total and stream-specific costs are estimated in separate regressions with different controls (e.g., per-capita tonnes of total versus stream-specific waste), so coefficients are not directly additive. Finally, within each stream, different cost components may move in opposite directions — for instance, reductions in collection and transport costs may coexist with higher treatment or disposal costs — attenuating the net impact at the aggregate level.

[16] Moreover, research indicates that increased waste tariffs may be more readily accepted by citizens if clearly linked to improved environmental outcomes and transparent pricing schemes (Carattini et al., 2018).

(a) Total costs of waste collection



(b) Total costs for separate waste collection



(c) Total costs for unsorted waste collection

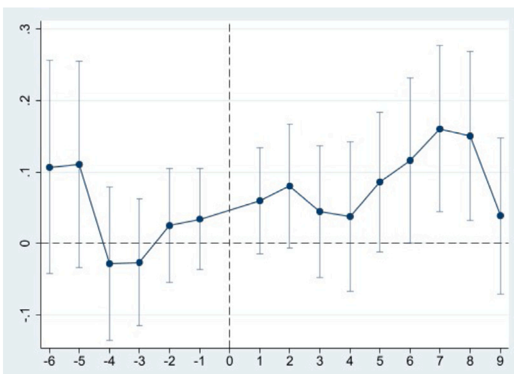


Fig. 3. Sun and Abraham (2021)'s estimates — Dynamic of costs of waste .
Note. The graphs report coefficients and confidence intervals estimated according to the Sun and Abraham (2021)'s procedure. The dependent variable is: the (Log of) municipal total cost of waste collection (in real €) per inhabitant in Graph 3(a), the (Log of) municipal total cost of separate waste collection (in real €) per inhabitant in Graph 3(b), the (Log of) municipal total cost of unsorted waste collection (in real €) per inhabitant in Graph 3(c). Estimations include municipality and year FE, Estimations also include the municipal resident population and the per-capita municipal income (in log), the (log of) total amount of waste collected (Panel 3(a))/the (log of) total amount of separate waste collected (Panel 3(b))/the (log of) total amount of unsorted waste collected (Panel 3(c)) per-capita in the municipality, the average household size. Event time 0 denotes the year of the beginning of the project and it takes as omitted category. Positive (negative) values indicate subsequent (previous) year relative to the event. Standard errors are clustered at municipal level. Standard errors are clustered at the municipal level. The points represent the estimated coefficients; the confidence intervals are at 95%. The *p*-value of the F-test that all pre-treatment coefficients are jointly equal to 0 is 0.87, 0.14 and 0.37 for the estimates in Graph 2(a), 2(b) and 2(c), respectively. Time period: 2007–2023.

Table 3
Sun and Abraham (2021)'s procedure — Separate/unsorted waste collection.

Dep. Var.:	(1) (Log)Per-capita sorted waste	(2) (Log)Per-capita unsorted waste
Treatment	0.190***	−0.095***
	(0.028)	(0.016)
Observations	32,542	32,545
No. Municipalities	3384	3384
Municipality FE	Yes	Yes
Year FE	Yes	Yes
Controls	Yes	Yes

Note. Matched DiD estimates of Eq. (1) based the Sun and Abraham (2021)'s procedure. The dependent variable is: in Columns 1 and 2, the (Log of) municipal per-capita tonnes of separate and unsorted waste collection, respectively. The variable *Treatment* is a dummy that takes the value 1 starting from the year of the beginning of the financed waste management project onward, and 0 otherwise. All specifications include fixed effects for year and municipality, though the coefficients for these effects are not reported. We control for the resident population. The analysis period spans from 2011 to 2023.

statistically significant increase in its specific costs, higher costs emerge for unsorted waste management, likely reflecting changes in treatment and disposal technologies rather than volume effects alone. This pattern points to the importance of cost structures and operational adjustments in shaping the fiscal consequences of green investments.

Importantly, the increase in costs documented in treated municipalities is accompanied by clear environmental benefits. EU-funded projects lead to a substantial expansion of separate waste collection and a reduction in residual waste, consistent with recycling and landfill diversion objectives. These outcomes align with the core principles of circular economy strategies, even if waste prevention is not directly addressed in this analysis. From the perspective of the waste hierarchy, shifts from unsorted (residual) to separately collected waste are central to landfill diversion and higher recycling rates. Prior work on Italy documents that the transition away from landfilling and toward recycling is shaped by policy, geography, and institutional conditions, and can be interpreted as a structural adjustment process rather than a purely mechanical response in volumes (Mazzanti et al., 2009; Nicolli et al., 2010). In the broader European context, policy reports highlight that expanding separate collection — especially for bio-waste — is a key channel to reduce landfill disposal and associated methane emissions, and to advance circular economy objectives (Brusselaers and Van Der Linden, 2020). Consistent with this framework, our estimates show that EU-funded projects generate tangible environmental gains (higher separately collected waste and lower residual waste), which provide the benefits-side counterpart to the fiscal costs documented in the paper. A large applied literature in environmental and engineering-oriented journals also documents how waste collection systems, pricing schemes, and separation requirements affect recycling outcomes and landfill diversion (e.g. Dijkgraaf and Gradus (2003); Guerrero et al. (2013)).

Taken together, these results point to a clear improvement in environmental performance, while at the same time raising questions about the fiscal implications of the transition for local governments. This trade-off between environmental gains and fiscal pressures is consistent with evidence from European policy reports, which stress that circular economy transitions often entail uneven cost dynamics across governance levels, particularly for municipalities responsible for service provision (Brüggemann et al., 2025).

6.2.2. Disentangling cost dynamics across operational phases of waste management

We next decompose total waste management costs into two phases: (1) collection and transportation, mainly driven by logistics (e.g., frequency, coverage, equipment, labor), and (2) disposal and recycling, which depend on treatment facilities, pricing, and waste quality.

In treated municipalities, the expansion of separate waste collection does not translate into a statistically significant increase in its specific per-capita costs. This suggests that EU-funded investments may have facilitated the scaling up of more intensive collection systems — such as door-to-door schemes or improved sorting infrastructure — without proportionally increasing operating costs. By contrast, per-capita costs for unsorted waste rise despite declining volumes, pointing to structural rigidities and fixed costs in treatment and disposal activities that limit cost reductions when residual waste decreases.

Disposal and recycling trends may also contribute to the observed cost dynamics. Residual waste can become more expensive to process when advanced facilities are adopted or when its quality deteriorates, requiring more complex treatment technologies (Ichinose, 2024). By contrast, improvements in the quality of separately collected waste could, in principle, reduce recycling costs, but only if collected fractions are sufficiently pure to allow for efficient processing and valorization. In practice, this potential cost-saving effect may be offset by operational constraints or may fail to materialize within the time horizon considered.

In order to check how the receipt of EU funds in waste management projects affects the costs of the two main operational phases of the waste management cycle, we regress the treatment variable on the (Log of) per-capita collection and transportation costs (in real €) for separate and unsorted waste collection (*C/T costs of sorted waste* and *C/T costs of unsorted waste*, respectively) and on the (Log of) per-capita disposal and recycling costs (in real €) for separate and unsorted waste collection (*D/R costs of sorted waste* and *D/R costs of unsorted waste*, respectively). Results are presented in Columns 1–4 Table 4.

The results reveal a nuanced pattern. In treated municipalities, the estimated treatment coefficient for collection and transport costs of sorted waste is 0.178, corresponding to a 19.5% increase, consistent with the adoption of more service-intensive systems (e.g., door-to-door schemes, higher frequency), which promote sustainability but increase logistics costs. Conversely, the estimated coefficient for collection and transport costs of unsorted waste is −0.138, corresponding to a 12.9% reduction, reflecting lower residual volumes and greater efficiency. However, this efficiency gain is partially offset by the fact that the estimated coefficient for disposal and recycling costs of unsorted waste is 0.109, corresponding to an 11.5% increase. This suggests that although residual quantities decline, the remaining waste is of poorer quality and more expensive to process (Guerrero et al., 2013). Two complementary mechanisms likely explain this: (i) EU-funded projects accelerate the shift toward higher separate collection rates, so residuals quickly reach a composition dominated by harder-to-treat fractions, raising processing costs; (ii) investments create rigidities in treatment capacity and long-term contracts, so shrinking residual volumes increase unit costs by spreading fixed costs over fewer tons. Since the dataset lacks direct indicators of waste quality, this interpretation should be seen as a plausible mechanism, consistent with the evidence and literature (Guerrero et al., 2013; Ichinose, 2024), rather than as a causal estimate.

Interestingly, disposal and recycling costs for sorted waste show no statistically significant differences between treated and control municipalities. This suggests that EU-funded investments did not translate into measurable changes in downstream treatment costs for recyclables within the period considered. One possible explanation is that improvements in collection systems and sorting quality, while effective in increasing separate collection volumes, were not sufficient to generate substantial processing efficiencies or higher market value for recycled materials. Alternatively, potential cost savings in recycling may be offset by fixed costs or contractual rigidities in treatment infrastructure.

6.2.3. Assessing efficiency and technological change through productivity analysis

While the econometric evidence above details how the intervention influenced waste volumes and cost components, it does not clarify whether the observed changes reflect genuine productivity-enhancing improvements or implementation inefficiencies. In particular, the evidence points to sizeable compositional shifts in waste streams (higher sorted and lower unsorted waste) together with heterogeneous cost dynamics across operational phases, rather than a uniform increase in all cost items. To address this ambiguity, we estimate a non-parametric productivity frontier using the Malmquist index framework (a tool to measure changes in total factor productivity, TFP, over time) (Färe et al., 1994; Halkos and Aslanidis, 2024), comparing municipalities before and after EU-funded waste management projects (lo Storto, 2021).[17]

Methodologically, the Malmquist productivity index is appropriate for several reasons. First, it requires only input and output quantities rather than detailed price data, typically unavailable in municipal waste management. Second, unlike static DEA measures, it traces productivity changes over time and decomposes them into efficiency change (catch-up to the frontier) and technological progress (frontier shifts). This decomposition directly addresses our research question by distinguishing transitional inefficiencies from genuine technological improvements. Third, compared to parametric approaches such as stochastic frontier analysis, the Malmquist index avoids strong assumptions on functional form and error distributions, which are difficult to validate given the heterogeneity of Italian municipalities. For these reasons, the Malmquist approach represents a robust tool to assess the impact of EU-funded waste projects on service efficiency.

We estimate two separate efficiency frontiers: one for sorted (differentiated) waste and one for unsorted (residual) waste. In each case, the per-inhabitant total cost of the service is treated as the output,

[17] We use the *malmq2* Stata routine.

Table 4
Sun and Abraham (2021)'s procedure — Types of waste costs.

Dep. Var.:	(1) (Log)C/T costs of sorted waste	(2) (Log)C/T costs of unsorted waste	(3) (Log)D/R costs of sorted waste	(4) (Log)D/R costs of unsorted waste
Treatment	0.178***	−0.138***	−0.034	0.109***
	(0.051)	(0.039)	(0.058)	(0.042)
Observations	14,434	14,448	12,083	13,708
No. Municipalities	1211	1211	1179	1209
Municipality FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes

Note. Matched DiD estimates of Eq. (1) based the Sun and Abraham (2021)'s procedure. The dependent variable is: in Columns 1 and 2, the (Log of) municipal per-capita collection and transportation costs for separate and unsorted waste collection (in real €), respectively; in Columns 3 and 4 the (Log of) per-capita disposal and recycling costs for separate and unsorted waste collection (in real €), respectively. The variable *Treatment* is a dummy that takes the value 1 starting from the year of the beginning of the financed waste management project onward, and 0 otherwise. All specifications include fixed effects for year and municipality, though the coefficients for these effects are not reported. We control for the resident population. The analysis period spans from 2011 to 2023.

Table 5
Productivity analysis.

Types of waste	TFPCH	TECH	BPC
Selected	1.079151	1.076859	1.003547
Unsorted	0.99358	1.014699	0.986942

Note. Estimation of non-parametric productivity frontier using the Malmquist index framework (Färe et al., 1994). We estimate two separate frontiers, one for selective waste collection (first row) and one for unsorted waste collection (second row). We use the (Log of) the per-inhabitant cost and the per-capita volume of sorted waste respectively as output and input of the estimation of the frontier for selective waste collection. We use the (Log of) the per-inhabitant cost and the (monotonic transformation of the) per-capita volume of unsorted waste respectively as output and input of the estimation of the frontier for unsorted waste collection. TFPCH refers to the total factor productivity; TECH refers to technological change; BPC refers to best-practice catch-up. Period 2011–2023.

and the corresponding per-capita waste volume as the input. Since unsorted waste represents an undesirable input environmentally, we apply a monotonic transformation to reframe it as desirable, consistent with Malmquist requirements. This enables efficiency measurement over time while accounting for both desirable and undesirable inputs.

The analysis compares municipal efficiency before and after receipt of EU cohesion funds. The Malmquist index captures productivity changes by measuring the distance of each observation from a best-practice frontier estimated for each period. Specifically, total factor productivity change (TFPCH) is decomposed into technological change (TECH, frontier shifts) and efficiency change (BPC, best-practice catch-up). This allows us to assess whether public investment is associated with gains in efficiency, technological progress, or both.

Results are reported in Table 5 for differentiated (recyclable) and undifferentiated (residual) waste. For differentiated waste, the estimated TFPCH is 1.079, indicating a 7.9% productivity increase after EU funding. This improvement is mainly driven by technological progress (TECH = 1.077), while the BPC index is slightly above unity (1.004), suggesting that municipalities not only adopted more advanced methods and infrastructure but also marginally improved their relative efficiency.

By contrast, results for undifferentiated waste show essentially no productivity gain: TFPCH = 0.994, very close to unity. Although modest technological progress is observed (TECH = 1.015), the decline in relative efficiency (BPC = 0.987) points to a slight deterioration in best-practice catch-up.

These findings help clarify the cost dynamics observed earlier. Contrary to what might be expected, the expansion of separate waste collection does not translate into a statistically significant increase in the costs associated with recyclable waste. This pattern is consistent with the presence of moderate productivity gains in the management of sorted waste, driven mainly by technological progress and accompanied by slight improvements in operational efficiency. In this segment of the system, investments appear to translate into organizational and technological upgrades rather than higher unit costs.

By contrast, cost increases are concentrated in the management of residual waste. Even though residual volumes decline following the intervention, limited technological progress combined with modest efficiency losses implies that the remaining fraction becomes more complex and costly to treat. In this case, post-intervention cost increases are not indicative of productivity improvements but rather reflect the worsening composition of residual waste and the greater treatment intensity required for disposal.

Overall, these results resolve the apparent tension between declining residual volumes and rising disposal costs. While reductions in quantities would mechanically suggest lower costs, this effect is offset by quality deterioration: as recyclable materials are increasingly diverted, the residual stream concentrates less recoverable and more problematic components, requiring advanced and more expensive treatment. Consistent with the productivity analysis, recyclable waste exhibits modest technological progress with slight efficiency gains, whereas residual waste shows no comparable productivity improvements and a mild decline in best-practice catch-up. Rising disposal costs therefore reflect structural rigidities and transitional inefficiencies in residual waste management, rather than inefficiencies in the expansion of separate collection.

7. Conclusions

This paper provides novel empirical evidence on the fiscal effects of EU-funded waste management investments on local taxation in Italy. Overall, the results indicate that municipalities receiving cohesion funds experienced a significant increase in per-capita waste taxes compared to untreated ones. This effect emerges gradually in the years following the intervention and appears robust across specifications. It suggests that while European funding aims to modernize infrastructure and promote sustainability, it may also entail financial burdens for local governments and households, particularly when operational costs rise or when co-financing obligations are substantial (Bel and Fageda, 2010).

To unpack these dynamics, we analyzed the evolution of waste volumes and service costs. Our findings reveal that the intervention led to a notable expansion of separate waste collection and a simultaneous reduction in residual waste, consistent with the environmental objectives of EU policy. Importantly, this transition did not result in a statistically significant increase in the costs associated with separate waste collection. Instead, cost increases are concentrated in the management of residual waste.

A more detailed decomposition of costs along the waste management chain shows that collection and transport costs rise modestly for recyclable waste, while they decline for residual waste. At the same time, disposal costs for residual waste increase significantly, reflecting the worsening quality of the remaining fraction and structural rigidities in treatment processes. As recyclable materials are progressively diverted, the residual stream concentrates less recoverable components, requiring more complex and expensive disposal technologies (Dijkgraaf and Vollebergh, 2004).

These findings point to a clear policy lesson: green investments in waste management can deliver environmental gains without being fiscally neutral. When separate collection expands faster than downstream treatment capacity and cost planning, the resulting increase in operating costs may be passed on to households through higher waste taxes. The effectiveness of EU funding therefore depends not only on whether it improves collection performance, but also on whether it is embedded in an integrated strategy that addresses the residual waste stream, treatment infrastructure, and long-run financial sustainability.

In the final stage of the analysis, we estimated changes in total factor productivity (TFP) to assess whether cost increases reflected genuine efficiency gains or implementation frictions. Results from the Malmquist decomposition indicate moderate technological progress in the management of recyclable waste, accompanied by slight efficiency gains. In the case of residual waste, modest technological improvements were offset by efficiency losses, resulting in essentially stable productivity. These findings suggest that while EU funding contributed to modernization and service innovation, its effectiveness in improving cost efficiency remains uneven — especially downstream.

Beyond its empirical findings, this paper offers new insights into how environmentally motivated public investments shape local fiscal outcomes. By linking EU-funded improvements in waste management to changes in cost structures, tax levels, and service productivity, it highlights the complex interplay between environmental ambitions and local budgetary constraints. In doing so, it sheds light on an often-overlooked dimension of the green transition — its implications for municipal finance and governance — complementing recent work on the fiscal effects of environmental taxation and policy interventions (Valente, 2023; Stameski et al., 2024; Meleddu et al., 2024) and extending the debate on how intergovernmental transfers affect local decision-making (Baicker and Staiger, 2005; Gramlich, 1998).

While our results emphasize the fiscal costs associated with green investments in waste management — particularly those emerging in the downstream treatment of residual waste — it is important to recognize that inaction also entails substantial economic and environmental costs. Delaying investments in waste infrastructure may lead to higher long-term expenditures, environmental degradation, regulatory non-compliance, and increased health and social costs. From this perspective, the short- to medium-term increase in local taxation documented in this paper should be interpreted as part of a broader trade-off between fiscal sustainability and the long-run benefits of environmental improvement and regulatory compliance.

From a policy perspective, this underlines the need to complement infrastructure funding with targeted support for institutional capacity and lifecycle cost planning, in order to maximize the return on investment and minimize regressive fiscal effects. Indeed, strategic infrastructure planning becomes crucial in scenarios where traditional disposal options, such as landfills, become scarce or unsustainable, thus raising the financial burden of alternative waste management solutions (Ichinose, 2024). At the same time, recent evidence suggests that pairing infrastructure investments with behavioral interventions — such as norm-based feedback or clearer communication of tariff structures — may enhance the effectiveness of environmental spending while mitigating public resistance to tax increases (Bonan et al., 2025). These softer tools may be especially valuable in economically vulnerable municipalities, where tariff hikes risk generating regressive effects and undermining support for the green transition.

By focusing on municipal cost structures and taxation, our analysis complements the multidimensional approach to circular economy measurement advocated by the European Topic Centre on Circular Economy and Resource Use, which calls for greater attention to investments, governance, and economic sustainability alongside material flows (Vercalsteren et al., 2025).

CRediT authorship contribution statement

Anna Laura Baraldi: Writing – original draft, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Claudia Cantabene:** Writing – original draft, Validation, Investigation, Formal analysis, Conceptualization. **Alessandro De Iudicibus:** Validation, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Giovanni Fosco:** Validation, Methodology, Investigation, Data curation, Conceptualization. **Iacopo Grassi:** Writing – original draft, Validation, Supervision, Project administration, Investigation, Conceptualization.

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process

During the preparation of this work the authors used ChatGPT o1 in order to improve the readability and language of the manuscript. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Statistics

After the PSM procedure, the final sample consists of 3891 municipalities (2581 controls and 1310 treated). By matching treated municipalities with observationally similar untreated ones, the procedure avoids comparisons merely reflecting the North–South divide in Fig. 1, and instead balances demographic, economic, and institutional characteristics. This mitigates concerns that estimated effects capture pre-existing regional disparities rather than EU-funded interventions.

Table C.4 (Appendix C) reports descriptive statistics for the matched sample. Fig. D.2 (Appendix D) shows the yearly distribution of EU funding by project start date, with peaks in 2008, 2014, and 2017, and lows between 2019–2023.

Table C.5 (Appendix C) highlights heterogeneity in treatment. On average, treated municipalities received €24 million (2007–2023), but amounts range from $< €100,000$ to $> €2.4$ billion. The number of projects per municipality varies between 0 (i.e., municipalities received funds but none in the five macro-typologies: public works, services, goods/equipment, grants, incentives) and 25, with an average of 1.6. This indicates strong variation in both intensity and composition of interventions. Typology data are qualitative (presence of at least one project per type) but, combined with funding aggregates, help contextualize results: some municipalities host large infrastructure projects, others only small-scale interventions.

The same table shows project distribution by typology. Most are public works (0.32 projects per municipality on average, max 16). Services (0.08 on average, max 21) and goods/equipment (0.13, max 6) are less common, while grants and incentives are rare, and equity participation is absent. This aligns with the policy focus on infrastructure and operational investments in waste management.

Fig. D.3 (Appendix D) plots per-capita waste taxes (2007–2023). Taxes increased gradually until 2011, then rose sharply during the TARES–TARI transition (2012–2015), and temporarily declined in 2020–2021 due to COVID-19 relief. Before causal analysis, it is crucial to check baseline comparability: a two-sample t-test shows no significant difference between North (€96,406) and South (€94,811), with a mean gap of €1594 ($p = 0.22$). Thus, despite the concentration of EU funds in the South, treated and untreated municipalities in the matched sample do not differ systematically in waste taxes at baseline, supporting the validity of the matched DiD strategy.

Finally, Table C.6 (Appendix C) presents the mean covariates for treatment and control municipalities (2007–2023).

Table B.1
Sun and Abraham (2021)'s estimates — Matched Continuous DiD.

Dep. Var.:	(1) (Log)Waste taxes	(2) (Log)Waste taxes
(Log) Treatment intensity	0.001044***	0.000919**
	(0.000406)	(0.000408)
Observations	57,133	56,685
No. Municipalities	3891	3841
Municipality FE	Yes	Yes
Year FE	Yes	Yes
Controls	No	Yes

Note. Matched DiD estimates of Eq. (1) based the Sun and Abraham (2021)'s procedure. The dependent variable is the (Log of) municipal per-capita waste tax (in real €). The variable *Treatment intensity* is the (Log of) EU funds received for waste management investments, and 0 otherwise. The analysis period spans from 2007 to 2023. The control variables include: the resident population in thousands , the average household size, the per-capita income (in real €) (in natural log); estimation in Column 2 we add the average level of education and the average age and the share of female and the gender of the mayor of municipal council, the MAQI. All specifications include fixed effects for year and municipality, though the coefficients for these effects are not reported. Standard errors are clustered at the municipality level and are presented in parentheses. Coefficient significance levels are indicated by * (10% significance), ** (5% significance), and *** (1% significance).

Table B.2
Sun and Abraham (2021)'s estimates — North vs South.

Dep. Var.:	(1) (Log)Waste taxes	(2) (Log)Waste taxes
Treatment	0.815***	0.806***
	(0.257)	(0.257)
South*Treatment	−0.704***	−0.714***
	(0.265)	(0.266)
Observations	57,133	56,685
No. Municipalities	3891	3841
Municipality FE	Yes	Yes
Year FE	Yes	Yes
Controls	Yes	Yes

Note. Matched DiD estimates of Eq. (1) based the Sun and Abraham (2021)'s procedure. The dependent variable is the (Log of) municipal per-capita waste tax (in real €). The variable *Treatment* is a dummy that takes the value 1 starting from the year of the beginning of the financed waste management project onward, and 0 otherwise. The variable *South*Treatment* is the interaction term between the dummy variable *South* that takes the value of 1 in the regions of Mezzogiorno, namely Abruzzo, Molise, Campania, Apulia, Basilicata, Calabria, Sicily, Sardinia and 0 otherwise, and the *Treatment* variable. In the estimated equation we also add the dummy *South* that is dropped because of collinearity. The analysis period spans from 2007 to 2023. The control variables include: the resident population in thousands , the average household size, the per-capita income (in real €) (in natural log); estimation in Column 2 we add the average level of education and the average age and the share of female and the gender of the mayor of municipal council, the MAQI. All specifications include fixed effects for year and municipality, though the coefficients for these effects are not reported. Standard errors are clustered at the municipality level and are presented in parentheses. Coefficient significance levels are indicated by * (10% significance), ** (5% significance), and *** (1% significance).

Appendix B. Further results

B.1. Continuous treatment and dose–response effects

While the baseline analysis considered treatment as a binary condition, municipalities differ substantially in the intensity of EU funding they receive. To capture this heterogeneity, we re-estimate the model using a continuous treatment variable defined as the (Log of) EU funds received for waste management investments, which is set to zero until the first year of disbursement (hereafter *Treatment intensity*). This specification enables us to assess whether the relationship between EU funding and waste taxation scales with the amount of resources transferred. Results are in Table B.1.

The estimates indicate a positive and significant elasticity of 0.01 (Column 1). In practical terms, a 10% increase in funding intensity leads, on average, to a 0.10% increase in per-capita waste taxes in the following year.

These results highlight a dose–response relationship: municipalities receiving larger transfers exhibit stronger increases in local waste taxation, whereas smaller projects are associated with more modest changes. The elasticity is quantitatively limited, implying that even substantial variations in funding translate into relatively contained adjustments in taxation. This pattern suggests that local tariff dynamics reflect not only the inflow of external resources but also structural and institutional factors — such as pre-existing infrastructure, cost recovery mechanisms, and administrative capacity — that mediate the extent to which EU funding affects municipal tax levels.

B.2. Regional heterogeneity of treatment effects

A possible concern is that the relationship between Cohesion Policy funds and local waste taxation may not be homogeneous across Italian regions. In particular, previous literature has highlighted persistent problems of waste misreporting and illegal dumping in Southern Italy (e.g., Savona et al. (2018)), which may lead to biased cost calculations and weaker links between actual service costs and local taxation. If such mechanisms are indeed present, the way in which EU funds translate into per-capita tax levels may vary between Northern and Southern regions.

To test this hypothesis, we extend our baseline specification by allowing the effect of EU funds to differ between Northern and Southern municipalities. Concretely, we interact the treatment variable with a dummy for Southern regions (the regions of Mezzogiorno, namely Abruzzo, Molise, Campania, Apulia, Basilicata, Calabria, Sicily, and Sardinia), so that the estimated coefficient for the treatment captures the impact in the North and Center, while the sum of the treatment and interaction coefficients represents the corresponding effect in the South. In this way, we can directly assess whether the relationship between EU funds and local waste taxation is homogeneous across the country or whether it differs between macro-areas.

Table B.2 reports the results. The coefficient on $Treatment_{it}$ is positive and significant, indicating that in Northern municipalities EU funds are associated with a sizable increase in per-capita waste tax, consistent with our baseline findings. By contrast, the interaction term is negative and significant, implying that the effect in Southern municipalities is reduced to roughly 0.092 (=0.806 – 0.714).

This result has two important implications. First, the results indicate that the relationship between EU funds and per-capita taxation is not the same across Italian regions: the impact of EU funds on waste taxation differs sharply between North and South. Second, the weaker effect in the South suggests that EU funding does not translate into higher local taxation with the same intensity as in the North. One plausible interpretation is that, in the presence of widespread underreporting of waste flows and reliance on illegal disposal channels, additional resources may not be fully reflected in service costs, and hence in municipal tariffs. In other words, while in the North EU funds are more transparently incorporated into the cost structure of waste management (and ultimately passed on to households through taxation), in the South institutional weaknesses and data inconsistencies tend to attenuate this transmission channel.

Taken together, these findings reinforce our main result by showing that the effect of EU funds on local taxation is not only positive on average, but also heterogeneous across space: it is stronger in the more institutionally capable regions of the North, and weaker where misreporting and inefficiencies are more prevalent. This pattern is consistent with the broader literature on the role of administrative capacity and institutional quality in shaping the local impact of Cohesion Policy (Becker et al., 2013; Crescenzi and Giua, 2020).

Table C.1
Descriptive statistics of waste projects.

	Obs	Mean	Std. Dev.	Min	Max
Remediation	142 414	0.003	0.063	0	9
Separate collection	142 414	0.012	0.153	0	18
Infrastructures	25 143	0.008	0.101	0	4

Note. Descriptive statistics of the types of waste management projects. Period: 2007–2023.

Table C.2
Descriptive statistics of types of separate collection.

	Obs	Mean	Std. Dev.	Min	Max
Organic waste	56 236	0.11	0.198	0	20.867
Paper and cardboard	79 244	0.111	0.195	0	23.551
Glass	78 400	0.091	0.145	0	17.69
Wood	57 121	0.041	0.092	0	8.766
Metals	72 085	0.017	0.027	0	1.711
Plastics	78 075	0.055	0.103	0	10.036
WEEE (waste electrical and electronic equipment)	71 186	0.012	0.019	0	1.68
Textiles	56 527	0.007	0.012	0	0.932

Note. The table reports descriptive statistics for the main separately collected waste fractions at the municipal level. For each fraction, the collected amount is divided by the number of households in the municipality, thus expressing waste volumes per household. Period: 2007–2023.

Table C.3
Mean difference tests.

Variable	Mean		t-test	
	Treated	Control	t	p>t
Region dummies	6.908	6.830	0.410	0.680
Province dummies	49.173	48.203	0.810	0.416
(Log) Population	1.278	1.202	1.490	0.137
(Log) Female population	7.520	7.442	1.510	0.131
(Log) Population holding a university-level qualification	5.815	5.733	1.430	0.154
Average household size	0.002	0.002	−0.350	0.726
Per-capita municipal total waste	383.320	385.980	−0.490	0.626
Standardized municipal income	0.084	0.072	0.160	0.874
(Log) Municipal average age of resident population	3.798	3.798	0.000	0.998
Average education council level	14.140	14.135	0.110	0.910
Share of female councilors	0.217	0.214	1.090	0.274

Note. The Table shows the value of the t and the *p*-value of the covariates used for the logit estimation of the treatment status. The variables are: regional and provincial dummies, the resident population and resident female population size (log-transformed), population holding a university-level qualification (log-transformed), the average household size residing in the municipality, the per-capita municipal total waste, the standardized municipal income, the municipal average age of resident population (log-transformed), the average education level and the share of female councilors among city council members. We use the Stata command *pstest*.

Table C.4
Descriptive statistics.

	Obs	Mean	Std. Dev.	Min	Max
Waste tax	61 130	95.019	77.483	0	1638.986
Pop	66 147	7584.872	51 261.878	0.036	2873494
Family members	62 037	.002	0	0.001	0.004
Per-capita income	61 806	46 427.39	11 693.721	13 940.785	147 724.11
Councilor'e education	66 128	13.869	1.578	5	21
Councilor's age	66 128	44.437	4.254	19.934	76.447
Female councilors	66 128	0.237	0.132	0	0.727
Mayor's gender	66 128	0.104	0.305	0	1
MAQI	65 297	102.495	3.838	81.719	117.703

Note. Descriptive statistics of the variables. *waste tax* is the municipal waste tax amount divided by the resident population. *Pop* is the municipal resident population. *Family members* is calculated dividing the resident municipal population by the number of families in that municipality. *Per-capita income* is the municipal income divided by the resident population. *Councilor's education* is the average councilors education. To construct this variable we converted the qualitative data on the degrees held by councilors and mayors into years of education. Where data are not available, we exploit information about politicians' previous occupations to infer, where possible, the level of education required for such occupations. Therefore, we tab the measure of the city councilor's education as the follow: no education = 0 years; primary education = 5 years; lower secondary = 8 years; upper secondary = 13 years; university = 18 year and higher level = 21 years. *Councilor's age* is the average age of city council members. *Female councilors* is the share of female councilors in city council. *Mayor's gender* is a dummy that takes the value of 1 if the mayor is female and 0 otherwise. *MAQI* is the MAQI index. Period: 2007–2023.

Appendix C. Tables

See Tables C.1–C.8.

Table C.5
Variation in EU waste management funds across treated municipalities.

	Obs	Mean	Std. Dev.	Min	Max
Total funding received (real €)	1310	24,000,000	121,000,000	83,811	2,450,000,000
N. projects per municipality	1310	1.59	1.37	0	25
N. projects in Public works	3891	0.325	0.748	0	16
N. projects in Services	3891	0.082	0.475	0	21
N. projects in Goods and equipment	3891	0.128	0.381	0	6
N. projects in Grants	3891	0.001	0.032	0	1
N. projects in Incentives	3891	0.001	0.023	0	1
N. projects in Equity participation	3891	0.000	0.000	0	0

Note. The table reports summary statistics for municipalities that received at least one EU-funded waste management project. Funding amounts (*Total funding received (€)*) are expressed in current € and aggregated over the period 2007–2023. *N. projects per municipality* counts the number of projects per municipality across all typologies (works, services, goods, grants, incentives, equity) over the period 2007–2023.

Table C.6
Mean of covariate in treatment and control group.

Covariates	Treatment group	Control group
Pop	10 214.508	6250.187
Family members	0.002	0.002
Per-capita income	38 763.308	50 333.846
Councilor's education	14.138	13.732
Councilor's age	43.704	44.809
Female councilors	0.217	0.247
Mayor's gender	0.075	0.118
MAQI	102.372	102.559

Note. The table shows the mean of the covariates in the treatment and control group of municipalities in the matched sample. *Pop* is the municipal resident population. *Family members* is calculated dividing the resident municipal population by the number of families in that municipality. *Per-capita income* is the municipal income divided by the resident population. *Councilor's education* is the average councilors education. To construct this variable we converted the qualitative data on the degrees held by councilors and mayors into years of education. Where data are not available, we exploit information about politicians' previous occupations to infer, where possible, the level of education required for such occupations. Therefore, we tab the measure of the city councilor's education as the follow: no education = 0 years; primary education = 5 years; lower secondary = 8 years; upper secondary = 13 years; university = 18 year and higher level = 21 years. *Councilor's age* is the average age of city council members. *Female councilors* is the share of female councilors in city council. *Mayor's gender* is a dummy that takes the value of 1 if the mayor is female and 0 otherwise. *MAQI* is the MAQI index. Period: 2007–2023.

Table C.7
Descriptive statistics of costs.

	Obs	Mean	Std. Dev.	Min	Max
Total waste cost	25 616	148.647	72.993	14.555	1340.236
Total cost for separate waste	25 409	50.802	34.324	0	609.224
Total cost for unsorted waste	25 483	53.684	42.116	0	565.317

Note. Descriptive statistics of the waste cost variables. Period: 2011–2023.

Table C.8
Sun and Abraham (2021)'s estimates — Restricted matched sample.

Dep. Var.:	(1) (Log)Waste taxes	(2) (Log)Waste taxes	(3) (Log)Waste taxes
Treatment	0.311**	0.297**	0.280**
	(0.095)	(0.096)	(0.096)
Observations	35,657	35,657	35,440
No. Municipalities	2417	2417	2394
Municipality FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes

Note. Matched DiD estimates of Eq. (1) based the Sun and Abraham (2021)'s procedure. For the matching procedure we use only pre-treatment covariates. The dependent variable is the (Log of) municipal per-capita waste tax (in real €). The variable *Treatment* is a dummy that takes the value 1 starting from the year of the beginning of the financed waste management project onward, and 0 otherwise. The analysis period spans from 2007 to 2023. The control variables include: the resident population in thousands, the average household size, the per-capita income (in real €) (in natural log), the average level of education and the average age and the share of female and the gender of the mayor of municipal council, the MAQI. All specifications include fixed effects for year and municipality, though the coefficients for these effects are not reported. Standard errors are clustered at the municipality level and are presented in parentheses. Coefficient significance levels are indicated by * (10% significance), ** (5% significance), and *** (1% significance).

(a) Propensity score *before* matching (b) Propensity score *after* matching

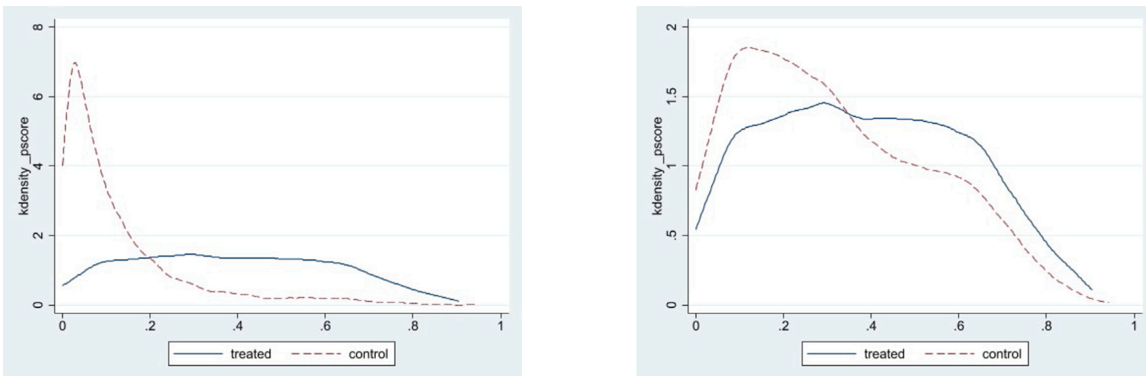


Fig. D.1. Propensity score graphs.
Note. Overlap in propensity scores in treated and matched samples of municipalities before and after the propensity score matching.

Appendix D. Figures

See Figs. D.1 and D.5.

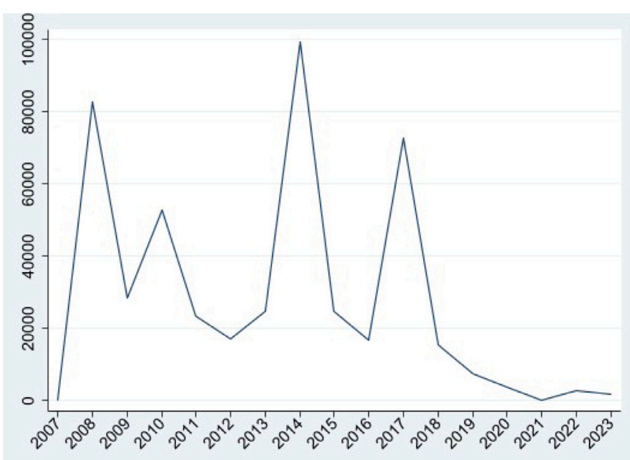


Fig. D.2. EU funding in waste management project per year of the beginning of the project.
Note. The Graph shows the yearly distribution of the EU funding in waste management projects per year of the beginning of the project. Period: 2007–2023.

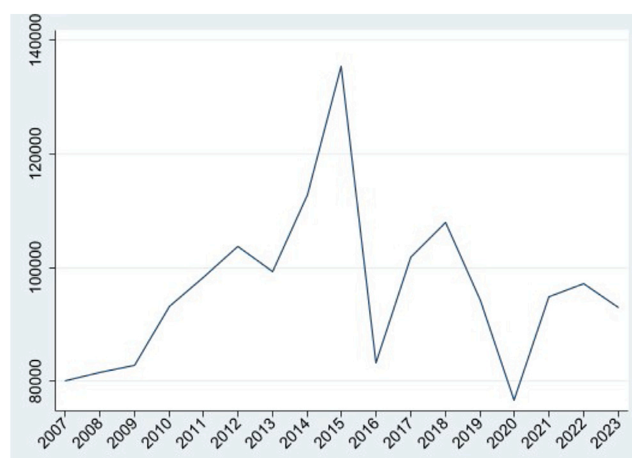
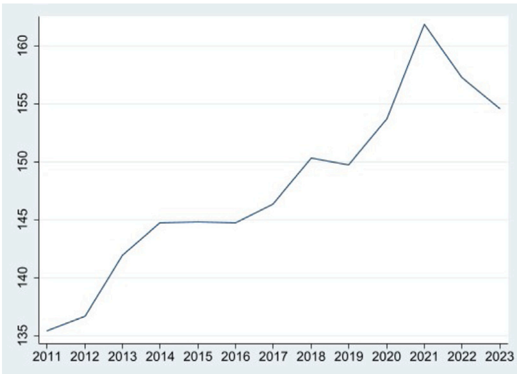


Fig. D.3. Waste tax over years.
Note. The Graph shows the mean, over years, of the municipal per-capita waste tax. Time period: 2007–2023.

(a) Per-capita total costs of waste collection



(b) Per-capita total costs of separate/unsorted waste collection

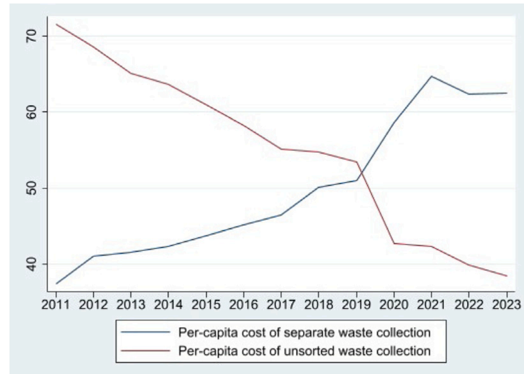
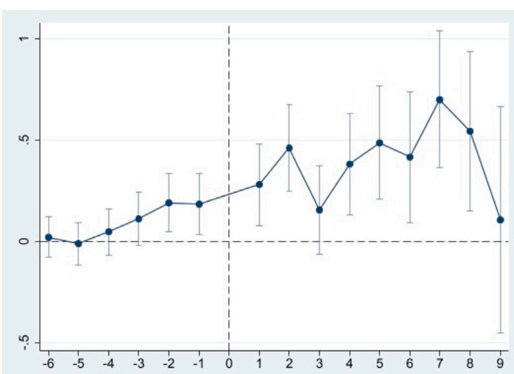
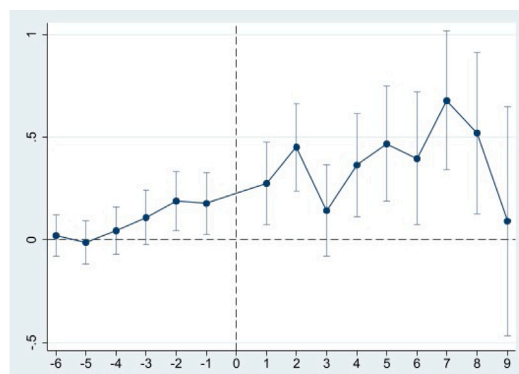


Fig. D.4. Per-capita total costs of waste collection.
Note. The Graph D.4(a) shows the mean, over years, of the per-capita total cost of the municipal waste collection. It comprises the costs for separate and unsorted waste collection and other costs as street sweeping and washing costs and common costs. The Graph D.4(b) shows the mean, over years, of the per-capita total costs of separate and unsorted waste collection. Period: 2011–2023.

(a)



(b)



(c)

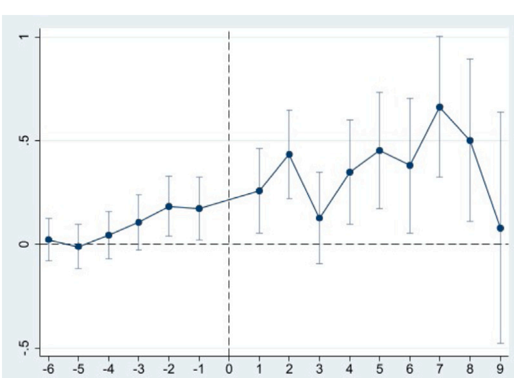


Fig. D.5. Sun and Abraham (2021)'s estimates — Restricted matched sample.
Note. The graphs report coefficients and confidence intervals estimated according to the Sun and Abraham (2021)'s procedure. For the matching procedure we use only pre-treatment covariate. The dependent variable is the (Log of) municipal per-capita waste tax (in real €). Estimation in Graph D.5(a) controls only for time and municipality FE. Estimation in Graph D.5(b) includes also for the resident population in thousands, the average household size, the per-capita income (in real € and in natural log), the average level of education and the average age and the share of female and the gender of the mayor of municipal council. Estimation in Graph D.5(c) includes also the MAQI. Event time 0 denotes the year of the beginning of the project and it takes as omitted category. Positive (negative) values indicate subsequent (previous) year relative to the event. Standard errors are clustered at municipal level. Standard errors are clustered at the municipal level. The points represent the estimated coefficients; the confidence intervals are at 95%. The *p*-value of the F-test that all pre-treatment coefficients are jointly equal to 0 is 0.11, 0.12 and 0.15 for the estimates in Graph 2(a), 2(b) and 2(c), respectively. Time period: 2007–2023.

Data availability

Data will be made available on request.

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