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WASTED IN WASTE?
THE BENEFITS OF SWITCHING FROM TAXES TO PAY-AS-YOU-THROW FEES: THE ITALIAN CASE

by Giovanna Messina* and Antonella Tomasi*

Abstract

Solid waste management is one of the most important functions performed by Italian municipalities and is mostly financed through local property taxes. Alternative financing schemes, known as 'pay-as-you throw' (PAYT), are designed to price each additional unit of waste and are becoming increasingly frequent at international level. Their advantages in terms of efficiency and equity, as well as of care for the environment, have been investigated both theoretically and empirically. This paper estimates the impact of PAYT schemes on the amount of waste produced and on the costs of its disposal for Italian municipalities. Results show that PAYT schemes deeply affect user behavior: total waste decreases (unsorted waste almost halves). Overall, the costs incurred by municipalities adopting PAYT fall by roughly 10 to 20 per cent in per capita terms, reflecting a reduction of one third in the cost of managing undifferentiated waste.

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1. Introduction

The success in managing waste services is a testing ground for the quality of local public institutions and is a powerful tool for raise local communities' awareness of environmental issues. A key element for achieving this goal is the way collection and disposal services are financed: both international practices and the economic literature have proven that PAYT fees introduce market incentives for households to limit their waste, on the one hand, and for local governments to use their budget resources more efficiently on the other. Heightened public consciousness about environmental concerns has contributed to making PAYT schemes widespread all over the world. Unit pricing has also been flourishing among European countries as it provides a valuable contribution to the Circular Economy strategy, which sets ambitious targets in terms of recycling rates as well as mandatory limits on landfill disposal.

Despite this fruitful international experience, Italy is still a novice in implementing PAYT schemes. Municipalities are in charge of waste collection and disposal (although within a very complex breakdown of tasks with other layers of government) and devote a significant share of their budgets to such services (nearly a quarter of their current expenditure, i.e. €10 billion). The costs for such services are in most cases covered by a general levy similar to a property tax, which charges households according to the number of their components and the house size. Switching to PAYT fees would bring about remarkable gains, as proved by several studies. The central argument is that waste generation has a negative social impact: under property taxation, households face a zero marginal cost for generating waste, while under a PAYT scheme they would be charged for each additional unit of waste they produce. In the first case, the misalignment between individual and social costs determines/leads to an excessive production of waste and consequently an inefficient allocation of public resources to waste management services; in the second case, unit pricing would act as a Pigouvian tax and enhance the welfare of the community, both from an allocative and a redistributive point of view (richer households, which produce more waste, would pay more than poor ones)

Several years of experience with unit pricing have endowed economists with a toolbox of models and techniques suitable for evaluating the effectiveness of such a policy. Our study aims to apply this toolbox to the Italian case, building on the experience of a narrow group of nearly 600 municipalities that have been implementing unit pricing in recent years. We start with a stylized model of the supply and demand of waste services and then estimate the effect of PAYT fees on waste generation and on the cost of waste services, distinguishing among the main categories of refuse (unsorted, organic, paper and plastic). The evidence drawn on a sample of more than 6, 100 municipalities shows that supply and demand of waste services respond to demographic, social and institutional variables as predicted by the theory. PAYT programs are associated with a lower amount of waste generation, greater propensity to recycle and lower costs of providing waste services for municipalities. We use standard OLS regressions as well as propensity score matching techniques to account for non-linearities. As a further robustness check, we try to tackle the issue of unobservable characteristics by restricting the comparisons to neighbouring municipalities.

The paper is organized as follows. Section 2 outlines the main arguments developed from an extensive amount of both theoretical and empirical literature in favour of unit pricing. Section 3 describes the Italian framework, in which waste management lies at the crossroads of the tasks of different tiers of government. Section 4 describes the data set that we use in our empirical analysis. Section 5 starts by briefly modelling the determinants of the supply and demand of waste services and then focuses on the estimation of the impact of PAYT fees on households' waste-generating behaviour and on the costs incurred by municipalities. Section 6 summarizes the results and discusses future lines of research.

2. The advantages of unit pricing: theory and international evidence

Waste services – by this we mean the full range of collection, hauling and disposal facilities provided to households and businesses – are usually provided by local governments. Such services are often financed through local property taxes, which do not discriminate among economic agents according to the amount and the type of waste they generate. However, in recent years a growing number of municipalities have been adopting a PAYT approach.

The premise of PAYT is that economic agents pay for each unit of waste they send for disposal, in application of the 'polluter pays' principle. Following Kinnaman (2006), three main types of unit pricing systems can be implemented: bag- or tag-based systems, requiring households to purchase specific bags for disposal or stickers that identify refuse containers; weight-based systems, where trucks for collection are provided with scales to weigh a household's waste; and subscription or can systems, where residents subscribe to a given number or size of cans and are billed accordingly.[1]

Some of the more established literature has argued that switching from property taxes to unit pricing brings about significant welfare gains. Starting from the contribution of Wertz (1976), a prolific line of research has put forward an efficiency argument, on the grounds of a theoretical model of household demand for waste services. In this model, waste is a by-product of individual consumption choices: it can be thought of as a normal good, whose demand rises with income levels and reacts negatively to increasing costs for disposal facilities. Waste production entails significant negative externalities for the community as a whole as well as for the environment (landfill congestion, the cost of building new disposal plants, disamenities and a reduction in the real estate values of properties surrounding disposal areas, release of greenhouse emissions and so on). When waste services are financed through general taxation, the individual cost of disposing of an additional unit of waste is equal to zero, in the presence of a sizeable social cost: as a consequence, economic agents deliver an excessive quantity of waste. When waste services are instead financed with PAYT fees, economic agents are charged for each additional unit of waste they produce: individual marginal costs are realigned with social ones, with the benefit of a reduction in the quantity of waste produced and a greater propensity to recycle.[2] Raising awareness of environmental issues emphasizes the role of unit pricing as a Pigouvian tax and at the same time increases popular consent in favour of its implementation.

The efficiency gains of PAYT schemes propagate from the micro level to the aggregate perspective of local public finance. From this point of view, unit pricing is a market signal of the cost of providing public services and gives substance to the benefit principle: on the demand side, it hits the actual recipients of waste services and provides them with the proper incentives to choose the optimal amount of demand for public services; on the supply side, it acts as a yardstick for voters to evaluate local administrators' performance and thus induces them to the best possible use of scarce public resources.[3]

Issues of waste financing also have implications for equity, as pointed out by Wright et al. (2018). In systems based on the collection of tax revenue, the disposal costs for high-income households – producing large quantities of rubbish – are partially subsidized by low-income households, which generate lower amounts of waste. This circumstance was documented for the Italian framework, where waste is financed mostly through

[1] Further details on specific unit pricing programmes can be found in Morlok et. al (2017).
[2] For a detailed model of waste generating processes and recycling decisions, see also Smith (1972), Richardson and Havlicek (1978), Morris and Holthausen (1994).
[3] For a thorough discussion of benefit taxation, see Oates (1999).

property tax revenues, by Messina, Savegnago and Sechi (2018), who showed that households in the lower decile of consumption distribution pay twice as much for waste services as households in the upper decile.

Notwithstanding the undisputable gains in terms of efficiency and of equity, municipalities are frequently held back in their decision to introduce a PAYT scheme by several concerns. First, unit pricing requires waste to be properly differentiated and recycled, hence local communities must be endowed with plants able to compost, select and process materials, as well as with technological devices able to measure the amount of waste disposed of by each user; initial fixed investment costs may be sizeable and only partially compensated in the short term by potential savings in the operating costs of waste management. Secondly, Kinnaman (2006) contends that administrative and enforcement costs may also be significant, in relation for instance to the distribution of bags or stickers, to the making an inventory of waste containers and user assistance. Finally, another perceived barrier is the risk that PAYT fees could be avoided by illegal dumping or waste tourism towards neighbouring municipalities not implementing unit pricing: although with some exceptions, there is prevailing consent among scholars that the scale of such behaviours is small compared with the overall positive impact of PAYT.[4]

The empirical research on PAYT has either estimated arc elasticities starting from individual observations or point elasticities using cross-sections of municipalities, and was pioneered by studies concerning the US. Wertz (1976) compared San Francisco, where a PAYT volume-based system had been adopted (i.e. a fee was charged on the number of bins put out for collection), with other urban areas and estimated a negative price elasticity of -0.15 of rubbish generated by households; the estimate is in line with the value found by Skumatz and Breckinridge (1990) for a similar system implemented some years later in Seattle. According to Kinnaman and Fullerton (1996), the attempt of households to compress rubbish in order to fill fewer bags or bins (an effect known as the 'Seattle stomp') may have reduced the effectiveness of such systems. Elasticities close to -0.30 were estimated by Morris and Byrd (1990) for the bag-based system implemented in Perkasie (Pennsylvania) and Ilion (New York), by Van Houtven and Morris (1999) for the PAYT system implemented in the city of Marietta (Georgia) and by Kinnaman and Fullerton in a cross-section of 114 US municipalities (2000).

The evidence on the European experience is scarce and limited to a few countries. One prominent study is that carried out by Linderhof et al. (2001) on the implementation of a weight-based system in a Dutch municipality (Ostzaan): using a panel data set collected comprising all the inhabitants of the municipality, the authors find significant short-run as well as long-run price effects for the amounts of both compostable and non-recyclable waste, with the elasticity of the former being nearly four times greater than the elasticity of the latter and long-run elasticities about 30 per cent greater than short-run ones. More recently, Allers and Hoeben (2010) applied a difference-in-difference approach to control for unobservable local characteristics on a sample of 458 Dutch municipalities and found a significant effect for unit pricing in reducing waste generation and increasing recycling, even after controlling for endogeneity; the price effect depends on the pricing system: weight-based systems reduce waste quantities more than volume-based systems (for compostable waste they estimate an elasticity of -1.77 with respect to weight-based PAYT). Similar evidence was provided more recently by Morlok et al. (2017) for Germany and by Carattini et al. (2018) for Switzerland.

Overall, the common findings of this very prolific field of empirical research can be traced by following Bel and Gradus (2016), who performed a meta-regression analysis on a database of 25 studies. They found that

[4] Based on the evidence for the Benelux countries, Card and Schweitzer (2016) as well as Linderhof et al. (2001) argue that the risk of illegal dumping is overstated and that its effect would be small compared with the overall positive impact of PAYT; conversely, Kinnaman (2006) maintains that if the costs of deterring and removing illegally dumped waste were included, the net benefits of unit pricing could turn out to be negative.

the elasticity of residential waste production with respect to unit pricing is negative and in the order of 0.3 in magnitude, and this outcome is not influenced by endogeneity issues. There is a slight indication that municipal data provide higher estimates for price elasticities with respect to individual data and that the elasticities found in studies focused on US experiences tend to be higher. As for the design of PAYT schemes, the systems whereby compostable waste is collected and charged separately seem to be more effective; in the same way, the elasticities derived for weight-based systems are considerably greater than those derived for volume-based programmes (whereas it does not make any significant difference if the latter are built upon the collection of bins or bags).

3. The Italian setup

In Italy, waste services are provided under a complex and multidimensional framework, arising from a patchwork of tasks at different levels of government: municipal, supra-municipal, regional, national and supranational.

Collection and disposal services formally fall under the fundamental functions of municipalities: such services are either provided autonomously or in association (through unions or consortia) with surrounding municipalities;[5] services can be managed directly or outsourced to publicly owned companies. At the supra-municipal level, some optimal territorial areas are defined ('ambiti territoriali ottimali', ATOs), within which the entire waste collection and disposal cycle has to be completed: hence the representative bodies provide for the organization of waste services, the definition of managing methods and the awarding of the service; most notably for the purposes of our analysis, the decisions on how to finance waste services are often undertaken at the ATO level. The geographical perimeter of each ATO encompasses several municipalities and is defined by Italy's Regions, which also appoint ATO governing bodies; the Regions are also responsible for outlining regional waste management plans where, among other things, new plants or renovations of the existing ones are envisaged (the areas suitable for locating new disposal and treatment plants must be identified by the Provinces). The national government sets up the general rules and carries out supervisory activities, while an independent authority has had regulatory and enforcement powers since 2018. Finally, the European institutions formulate the guidelines for the environmental policy of the whole area. In June 2018, a "Circular economy package"[6] was approved, setting for member States the goals of collecting separately the organic fraction by 2024, increasing the share of recycled urban waste to 55 per cent by 2025 (and then to 60 per cent by 2030 and 65 per cent by 2035) and reducing the incidence of landfilling disposal to 10 per cent by 2035.

Turning more specifically to the financing side of waste services, most Italian municipalities fully cover the costs of such services with a tax (TARI) which is very similar to a local property tax. The TARI is owed by each family living in a house, either as an owner or a tenant, and is computed based on the house's area and the household size: the first of these two elements can be considered as a rough indicator of real estate wealth, while the second one is only weakly related to the amount of rubbish produced (which also depends on

[5] The starting point for defining the tasks for each level of government is Legislative Decree 152/2006. Waste collection is among the fundamental functions for which the Italian law encourages association among municipalities under a given population threshold (5, 000 inhabitants); for more details on the importance of intermunicipal cooperation, see Manestra et al. (2018).

[6] The package is composed of four directives approved on June 2018: Directive 2018/849 on end-of-life vehicles; Directive 2018/850 on landfills; Directive 2018/851 on municipal waste; and Directive 2018/852 on packaging and packaging waste. The whole package has to be transposed into national legislation within two years.

income, on the age composition of the family, and on households' recycling behaviour, as we will see more thoroughly in Section five). Payments by Italian households for waste services have increased significantly in recent years: in 2019, a representative family paid an amount ranging from €260 in north-eastern regions to €380 in southern regions (Messina, Savegnago and Tomasi, 2018); waste charges have grown by almost a fifth on average since the beginning of the decade (Figure 1).

Over the last few years, some steps have been taken towards a deeper implementation of the 'polluter pays principle' – which is at the heart of the EU's environmental policy[7] – and measures have been adopted in order to make the Italian legislative framework more propitious for municipalities switching to PAYT schemes. The Budget Law for 2014 specified the pricing options for financing waste services and explicitly referred to European regulations in this field, while a decree passed in April 2017 pointed out the different measuring methods available in the implementation of unit charging fees.

As a result of these weak improvements in the institutional setup, only 10 per cent of Italian municipalities currently finance waste services through PAYT fees. This share is very modest compared with the figures reported for other advanced economies: some studies document that unit pricing involves more than a quarter of local communities in the US (Skumatz, 2008), a third in the Netherlands (Dijkgraf and Gradus, 2004) as well as in other continental European countries (Reichenbach, 2008) and 30 per cent in Japan (Sakai et al, 2008).

In Italy, the pricing systems vary across municipalities. Some resort to partial unit pricing, by fixing a flat 'first-tier' fee covering a given number of bags or bins to be collected and a 'second-tier' fee based on the additional amount of waste thrown away; this type of PAYT scheme ensures the coverage of a minimum level of service, at the same time discouraging illegal dumping. Alternatively the price for waste services can be fully associated with refuse production: national law requires the measuring of at least the fraction of unsorted garbage generated by each user, but municipalities frequently also measure organic, differentiated and/or green waste. Assessing the amount of garbage produced is an integral part of waste charges: the dry fraction can be measured either directly according to its weight or indirectly according to its volume. Some types of waste (such as green garbage) can be priced with a flat fee (if the service is activated by the user), according to the number of pieces collected (for bulky materials) or the frequency of collection. Finally, PAYT municipalities employ specific technological devices to measure the amount of waste generated by each user, such as bags endowed with microchips, bins with user recognition systems, and weighing scales located on trucks or installed in waste collection centers.

The limited diffusion of unit pricing in Italy goes hand in hand with the poor performance of waste services, especially in the most populated towns and in some areas of the country. Although the figures for waste production (500 kg per capita) as well as the rates of differentiation, recycling and landfilling rates (respectively 58, 27 and 22 per cent) are similar overall to the EU average, they are still far behind the achievements of some major EU countries, such as Germany (where half of the waste generated is recycled and landfilling has substantially disappeared).[8] Furthermore, there is a huge variability across regions and municipalities. Although southern regions produce a lower amount of waste (450 kg per capita, against 550 in central regions and 517 in northern regions), they differentiate much less than the rest of the country (46 per cent, against 54 and 68 in central and northern regions) and consequently dispose of significant shares of rubbish in landfills (36 per cent, against 24 in central regions and 11 per cent in northern regions); these figures reflect a general lack of infrastructural waste facilities in this part of the country. The

[7] See the Waste Framework Directive (Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008).
[8] The data for Italy are taken from ISPRA (2019), while for the comparison they are taken from Arera (2019).

underperformance of municipal waste services is even more evident in some of the most populated urban areas, where the share of differentiation remains at 40 per cent and emergencies in the management of waste collection services, with great attention from the media, occur rather frequently.

In the next sections we will present evidence that a wider implementation of PAYT schemes could significantly improve the conditions under which waste services are provided, both on the demand and on the supply side, to the benefit of the efficiency of local budgets and of faster progress towards European environmental targets.

4. Dataset and descriptive statistics

The starting point of our analysis is the construction of a multifaceted dataset at the municipal level, gathering the information needed to answer the following questions. How are waste services financed? What are the features of the service provided? How are municipalities characterized structurally and from an institutional or political point of view?

As for the first item, Italian law requires each municipality to issue a regulation on waste charges, usually by the end of May, and to publish it on the website of the Ministry of Economy and Finance. Neither the timing nor the format of such a regulation is uniform across municipalities, and collecting information was therefore extremely burdensome. After carefully examining almost 6,100 regulations we were able to distinguish two groups of municipalities: those financing waste services with the TARI tax and those adopting a PAYT scheme (we will refer to these groups as TARI and PAYT municipalities respectively). The reference year is 2018.

The second subset of information is related to the features of the waste disposal services provided by municipalities. In particular, we collected from ISPRA (higher institute for environmental protection and research) details on waste production (kg per inhabitant), type of waste disposed of (i.e. paper, glass, metal, plastic and so on), costs (made up of unsorted waste costs, recycling costs, administrative and use of capital costs), location of waste treatment facilities (organic and unsorted), and management of the service (individually or shared with other municipalities).[9]

As a third subset of information, we have considered some fixed characteristics representing municipal peculiarities in the demand for or in the cost of waste disposal services. More specifically, this subset includes geomorphologic and demographic data taken from the National Institute of Statistics (i.e. latitude, longitude, x and y centroid coordinates, area, altitude, dummies for coastal municipalities, population, age, density, sleeping accommodations for tourists) as well as economic data (personal income tax base, number of contributors, cadastral rent) taken from the Ministry of Economy and Finance.

Finally, we included a fourth subset of institutional, political and balance sheet variables. The former identify municipalities located in special statute Regions or that are subject to extraordinary management procedures; the latter concern the mayor (sex, date of birth, education, place of birth, election date) and mayor'sparty, and are derived from the electoral archives of the Ministry of interior.

After merging all this information, we ended up with a dataset of almost 6, 100 observations and 180 variables. Some descriptive evidence on the distinctive features of municipalities adopting taxing versus PAYT schemes is reported in Table 1. Taxing schemes (TARI) are preponderant: as already noted, PAYT schemes

[9] Data were collected from the higher institute for environmental protection and research and refer to 2017, given that municipalities establish waste charges in year *t* based on disposal costs in year *t-1*. Unsorted waste management includes street sweeping and cleaning, and the collection, transport, treatment and disposal of refuse.

have only been adopted in 10 per cent of the municipalities included in our sample. PAYT municipalities are almost exclusively located in the north-eastern part of the country (

Figure 2) and are on average 16.4 km away from a disposal plant (roughly one km less than TARI municipalities). They do not differ strikingly from TARI municipalities with respect to waste generation but they are significantly dissimilar in recycling behaviour: almost 80 per cent of waste is differentiated in PAYT municipalities, against 60 per cent in the TARI group. There appear to be sizeable differences in waste management costs in the two subsamples of municipalities: PAYT municipalities record lower costs (overall roughly €130 per capita, against €150 in the TARI group), especially in managing unsorted waste (which costs 40 per cent less in per capita terms with respect to TARI municipalities). As for demographic variables, the municipalities in the PAYT group appear to be smaller in size and slightly less densely populated than TARI municipalities. Concerning their economic conditions, they are characterized by larger tax bases for the main local taxes (the municipal share over personal income and the property tax) and larger tourist inflows. Household size is quite similar among the two groups. Finally, PAYT municipalities are run by mayors which are on average younger (47 against 53 in the TARI group); the share of female mayors is slightly higher, while that of graduated majors is sensibly lower than in the TARI group (respectively 18 against 15 per cent and 41 against 47 per cent in the two subgroups).

5. The impact of unit pricing on the supply and demand of waste services

Fuelled by the seminal contribution of Wertz (1976), several models have investigated the determinants of the supply and demand of waste services. These models usually derive a waste-generating function from standard consumer choice theory, in particular from households seeking to maximize the utility of consuming a composite commodity good, which generates waste according to a specific fraction, subject to a given budget constraint. Under the usual first order conditions, individuals set their optimal choice for waste so as to equalize the marginal benefit of acquiring an additional unit of the consumption good with the purchase price of the good itself plus the price of waste. If waste services are financed through general taxes the price that households pay for disposing of additional waste is zero and households have no economic incentive to limit the quantity of garbage they produce; conversely, if user fees are applied, the unit price of waste disposal enters into households' optimal decision-making process and the production of waste is limited. Some authors, such as Kinnaman and Fullerton (1999) and Morris and Holthausen (1994), explicitly model recycling activities as a function of time and individual effort and express the opportunity cost of such activities in terms of time subtracted from work or leisure; Wertz (1976) also augments the utility function so as to explicitly take into account the disutility generated by the accumulation of refuse on households' premises. In all these cases, the optimality condition requires that the marginal cost of discarding rubbish on the pavement equals the marginal cost of recycling, thus user fees influence not only the quantity of waste produced but also its composition.

A waste demand function W can be derived from the model of household disposal decisions:

$$W = W(c, \alpha, y, p_c, p_w, \delta) \tag{1}$$

(where *c* is the consumption good, α denotes the fraction of *c* that gets wasted, *y* is income, p_c is the price of the consumption good, p_w is the unitary charge for waste, and δ is the effort for recycling). Comparative staticson household's disposal decisions describe how the equilibrium values of the demand for waste services change in response to variations in the arguments of W. Increases in the user fee should reduce the total amount of waste and increase recycling, as a result of an income and a substitution effect; a rise in income should increase consumption and have a positive impact on the amount of waste; less effort in recycling should limit waste generation and increase recycling.

The amount of waste generated by each household enters into the supply side of waste services provision. In particular the cost for waste services provision C can be expressed as a growing function of W

$$C = C(W, A, k) \tag{2}$$

where A denotes technology and k capital endowment. As a consequence, all the variables that increase household disposal decisions exert a positive effect on C. The composition of W can also be relevant, since disposal is usually more costly for unsorted waste than for recycled materials (which can also deliver some returns, as in the case of plastic).

In the following subsections we will use aggregate data at the municipal level to test the empirical specifications of W and C. It must be noted that (1) and (2) do not form a simultaneous equations system, since in the Italian institutional framework, the municipal costs for waste services provision are set with a one year lag (i.e. on the basis of the refuse collected in the previous period).

5.1 Standard linear regression analysis

Estimating the impact of PAYT fees on waste generation by households and on the costs of waste services entails a preliminary discussion on the issue of the endogeneity of the policy variable. Adopting a PAYT program could in fact be dependent on municipal characteristics. It may be the case, for example, that environmentally aware municipalities, generating lower amounts of garbage regardless of the policy adopted, are more prone to introducing a variable pricing system, or conversely that communities with structurally higher levels of refuse per capita and lower recycling rates expect sizeable gains from PAYT policies and hence are more likely to adopt them. Because of this bias, simple cross-sectional comparisons would tend to overestimate or underestimate policy effectiveness.[10]

Due to the complex allocation of tasks among different levels of government, the decision to adopt PAYT fees is not under the control of the single municipality, which may attenuate the abovementioned identification concerns. As already mentioned, when the 'environmental code' entered into force in 2006, the management of waste services was mostly reorganized by assigning each municipality to an ATO, a supramunicipal administrative unit better able to exploit economies of scale and carry out the different phases of the waste cycle (collection, treatment and disposal) in an integrated way.[11] While it is very unlikely that a single municipality can influence the financing of waste services, simple OLS estimates can reflect unobservable differences between groups of municipalities. To address this concern, we will also provide estimates based on matching and spatial discontinuity techniques.

As a first step we estimate the impact of PAYT fees on the demand for waste services assuming a linear specification of (1) and in particular:

[10] Some works have attempted to identify which source of bias dominates, with contrasting results: Kinnaman and Fullerton (2000) adopt a 2SLS approach and estimate the likelihood of implementing user fees, finding stronger evidence of policy effectiveness after controlling for endogeneity; on the other hand, Dijkgraaf and Gradus (2004) correct for municipal environmental activism and find a lower reactivity of waste to unitary prices with respect to a baseline cross section comparison.

[11] There are Currently 76 ATOs operating in Italy: their geographic boundaries and governing bodies are established at the regional level and only a few of them that are in densely populated areas (Turin, Verona, Naples 1 and Naples 2) have a municipal dimension (Figure 3). The Region of Lombardy did not designate any ATOs.

$$W_{i,j} = \beta_{0,j} + \beta_{1,j}PW_i + \beta_{2,j}RENT_i + \beta_{3,j}RENT_i^2 + \beta_{4,j}CLASS_i + \beta_{5,j}SLEEP_i \quad (1')$$

where the dependent variable $W_{i,j}$ is the yearly per capita weight in kilos of solid waste produced in the *i*-th municipality relative to j categories (total, unsorted, organic, paper, plastic) and PW_i is a dummy representing the charging system for waste services (equal to 1 if the *i*-th municipality applies PAYT fees and to 0 if waste services are financed through the TARI property tax). As further regressors, we consider a set of socio-demographic and economic variables that play the role of consumption, income and recycling effort in (1) in determining the demand for waste services. In particular:

- $RENT_i$ is the average cadastral value of residential property in per capita terms. This variable describes the variation in local economic conditions among municipalities more reliably than recorded income tax?, which is more severely affected by under reporting (a similar choice was made by Richardson and Havlicek, 1978). The fact that waste is a by-product of consumption and that individuals usually consume normal goods generates the presumption that the demand for waste services is increasing in income and therefore the coefficient for $RENT_i$ should be positive[12].
- $CLASS_i$ measures the population class to which the *i*-th municipality belongs (with values ranging from 1 to 5 according to growing population size). We expect that more populated municipalities produce higher waste streams.
- $SLEEP_i$ is the ratio of sleeping accommodations in tourism facilities to the population. Larger tourist inflows should positively affect urban waste generation.

The application of OLS to the 5 equations generated by (1') (one for each type of waste) yields results that substantially confirm our expectations and the evidence of previous studies (see Table 2). As we can see, our variable of interest PW_i has a negative and significant impact on municipal waste: municipalities applying PAYT schemes reduce total waste by almost 28 kg per capita per year (roughly 6 per cent of the average value), as a composite effect of a sharp reduction in unsorted waste (108 kg per capita, which is nearly 61 per cent of the average sample value) and a large and statistically significant increase in organic, paper and plastic refuse. This evidence is consistent with the design of PAYT fees, which charge households exceeding a given threshold of unsorted waste disposal and boost recycling behaviour.

Waste generation responds to the other control variables included in the regression as expected. The coefficient for $RENT_i$ is highly significant and positive for all waste categories, denoting that waste is itself a normal good. The implied demand elasticity with respect to income is 0.27 for total waste, a value which is in line with the average elasticity arising from the empirical analysis reviewed by Bel and Gradus (2016). Unsorted waste is more responsive to income (the elasticity grows to 0.41), as opposed to paper and plastic (their elasticity with respect to income decreases to 0.20); organic waste is substantially inelastic to income. The magnitude of the effect of income on waste reduces as income grows, as denoted by the negative sign of β_3. Finally, the coefficients of $CLASS_i$, and $SLEEP_i$ have the expected sign. Waste generation is increasing with the population, presumably as a consequence of higher standards of living and higher commuting flows to and from the most densely populated towns. Tourism inflows involve increasing demand for waste services, especially in the collection of unsorted waste (which includes street sweeping).

To estimate the impact of adopting PAYT fees on the costs of delivering municipal waste services, we run j linear regressions of the following form:

[12] The magnitude of the income coefficient could be mitigated by a composition effect, since a large fraction of residential waste is made up of food, newspapers and magazines, whose consumption is rather income-inelastic (as argued by Wertz, 1976).

$$C_{i,j} = \gamma_{0.j} + \gamma_{1,j}PW_i + \gamma_{2,j}RENT_i + \gamma_{3,j}RENT_i^2 + \gamma_{4,j}CLASS_i + \gamma_{5,j}SLEEP_i + \gamma_{6,j}COOP_i + \gamma_{7j}DIST_{i,j} \quad (2')$$

where the dependent variable $C_{i,j}$ is the yearly per capita cost in euros for the *i*-th municipality by j types of refuse (total, unsorted, differentiated), while the explanatory variables are the same set of socio-demographic regressors in (1') plus some variables capturing the organization of the production process or its fixed inputs. In particular:

- $COOP_i$ describes the number of associated jurisdictions sharing the provision of waste services with the *i*-th municipality. Italian law encourages interjurisdictional cooperation among neighbours (in the form of unions, consortia or municipal agreements). The sign of $COOP_i$ is expected to be negative since there is evidence of economies of scale in the provision of waste services (up to a given threshold in terms of population size, see Manestra *et al.*, 2018).
- $DIST_{i,j}$ (with *j*=1 for undifferentiated waste treatment plants and *j*=2 for composting plants) is the distance in km of the *i*-th municipality to the nearest disposal plant and can be considered as a proxy for fixed capital endowment.

The results of the 3 OLS regressions over the full sample of municipalities are shown in Table 3. Municipalities adopting PAYT fees record a reduction of €25.60 per capita (nearly 18 per cent of the average value) in total waste management costs, as a result of a fall of €23 (45 per cent) in unsorted waste management and of €5 (11 per cent) in the cost of disposing of differentiated waste. As expected, the variables $RENT_i, CLASS_i, and\ SLEEP_i$ influence costs in the same direction since they impact on waste generation; in particular, the positive coefficient for population class confirms previous evidence of diseconomies of congestion based on municipal budget data (see Manestra *et al.*, 2018). Turning to the variables more related to the supply side, larger forms of cooperation among municipalities exert a reducing impact over each type of cost. Finally, the more distant the municipality from a disposal plant the higher the cost of providing waste services: each additional km apart from a disposal plant for unsorted waste is worth roughly €0.5 in terms of increased total per capita costs. This evidence stresses the importance of a proper endowment of fixed capital for managing municipal waste services efficiently.

5.2 Propensity score matching

Estimates derived from regression models could be biased since there may be significant differences in the distribution of explanatory variables among the two groups of PAYT and TARI municipalities. In this case, Imbens and Woolridge (2009) show that a linear approximation of the policy effect may not be globally accurate and regression may lead to severe biases. This issue is analogous to multicollinearity: if the averages of the covariates in the two groups are very different, then the correlation between the explanatory variables and the policy variable tends to be relatively high; least squares standard errors take multicollinearity into account but are conditional on the linear specification of the regression function. We can use the normalized difference in explanatory variables as a statistic to assess the reliability of linear regression methods.[13] If this statistic exceeds 0.25, indicated as a rule of thumb by Imbens and Woolridge (2009), then the estimators could be sensitive to the specification of a linear functional form. Table 4 reports the normalized differences of the explanatory variables used in our analysis: three of them exceed the 0.25 and two are not very far from this threshold.

[13] The normalized difference is the difference in the sample means of the two groups weighted by the squared root of the sum of the sample variances.

A more sophisticated method for adjusting for the differences in explanatory variables, with respect to linear regression, is the propensity score method (PSM). This method aims at replacing the many explanatory variables in a regression with a function (the propensity score), describing the likelihood of a municipality adopting PAYT based on the observed covariates. The probabilities calculated using the PSM are used to adjust covariate distributions between the two policy groups (i.e. PAYT and TARI). The method is largely non parametric and hence PSM is less sensitive than OLS to the violation of model assumptions. The advantages of PSM have been neatly described by Li (2013): 'overall, when one is interested in investigating the effectiveness of a certain management practice but is unable to collect experimental data, the PSM should be used, at least as a robust test to justify the findings estimated by parametric models' (p. 193).

The objective of PSM is to build a counterfactual for each observation in the sample in order to properly evaluate the effect of the PAYT pricing scheme.[14] The assumption is that the policy choice ($PW_i = 1$ or $PW_i = 0$) is random once we have controlled for a set of observable municipal characteristics X_i (acting as confounding factors) which simultaneously influence the decision to adopt user fees and the outcome variables (W_i and C_i). In other words, matching is a method for determining a control group ($PW_i = 0$) in which the distribution of the covariates X_i is similar to the distribution in the treated group ($PW_i = 1$) By this we mean that – without the treatment – the outcomes would not differ systematically in the two subgroups (Rosenbaum and Rubin, 1983).

An illuminating example of the application of PSM to the evaluation of unit pricing in waste management is the study by Wright *et al.* (2018) on a sample of 108 New Hampshire towns. The authors estimated that the adoption of PAYT resulted in a reduction from 54 to 42 per cent in the level of household solid waste disposed of each year. In what follows, we apply the same procedure of Wright *et al.* (2018) to estimate the impact of PAYT fees in the Italian case.

To select the proper control group for our PAYT municipalities, we run a logistic regression and compute the propensity score S_i of each municipality i, i.e. the conditional probability of adopting PAYT given the following observable characteristics:

$$S_i = \mathrm{P}\left(PW_i = 1 \middle| CLASS_i, RENT_i,\ RENT_i^2, SLEEP_i, COOP_i, DIST_i\right) \tag{3}$$

The confounding factors make the waste demand (or the cost of waste services) structurally different among municipalities and may simultaneously affect the choice of the pricing schedule. The logit results are reported in Table 5 and show that municipalities with higher populations, better economic conditions and a growing number of relationships with surrounding municipalities may find it easier to adopt PAYT schemes.

The next step after computing propensity scores is to divide them into different blocks so that the conditional distribution of the covariates, given the balancing score, is the same for the treated observations (PAYT municipalities, i.e. with $PW_i = 1$) and the control group (TARI municipalities, i.e. with $PW_i = 0$).This means that the explanatory variables are not confounded with the policy effect attributed to PAYT fees. Stratifying the propensity score into five blocks can generally remove much of the difference due to the non-overlap of all observed covariates between the treated and the untreated (Li, 2013). Covariates balancing can be tested by means of t-tests for mean differences of explanatory variables by block. Such statistics are reported in Table 6 and show that the mean differences among groups are statistically significant for each explanatory

[14] A proper evaluation of the impact of PAYT fees on waste demand would require two observations for each municipality, relative to the quantity of waste produced, with and without the application of the user fee. But in real data, only one of such outcomes can be observed, since we cannot observe the waste produced by PAYT (TARI) municipalities should they apply a TARI (PAYT) scheme; this generates a missing data problem. The same line of reasoning holds for waste management costs.

variable prior to matching and are not statistically significant for the propensity score after matching. This outcome emulates a treatment assignment in which mean characteristics of participants and non-participants are similar (balanced) after a random assignment to the treatment or control group.

We then use matching techniques to compare the outcome in the treated observations with the outcome of their most similar counterparts in the non-treated group, selected according to their respective propensity scores. We follow the nearest-neighbour method, select the control observations with the closest propensity scores to the treated municipalities and obtain estimates of the average treatment effect on both the treated ($ATET$) and on the untreated units ($ATEUT$). The $ATET$ compares the effective outcomes of PAYT municipalities with the outcomes they would have experienced in the absence of the treatment. The $ATEUT$ compares the effective outcomes of TARI municipalities with the outcomes they would have experienced had they adopted PAYT fees.[15]

The propensity score estimators of the impact of adopting PAYT fees for Italian municipalities are reported in Table 7 and confirm the significant effect of unit pricing on waste generating behaviour as well as on management costs. Total waste is reduced by 22 kg per capita (approximately 5 per cent of the mean value), reflecting a substantial decrease in unsorted waste (minus 94 kg, corresponding to a 53 per cent decrease) only partially offset by an increase in differentiated waste (organic, plastic and paper garbage increase respectively by 42, 12 and 7 kg); this result can be explained by an improvement in recycling behaviour. Managing costs also record a remarkable improvement: total costs are reduced by €26 per capita (18 per cent of the mean), reflecting a decrease in both the components of unsorted and sorted waste (which decrease respectively by €22 and €5 per capita, corresponding to a reduction of 44 and 11 per cent).

5.3 A further robustness check

By adjusting the covariates between treated and control groups, the PSM reconstructs a counterfactual in absence of experimental data. However, in order to obtain unbiased estimates, all the variables that need to be adjusted must be observed: in other words, this requires that there are no unobserved characteristics associated with both the treatment assignment and with the potential output.[16] A violation of this assumption may arise if circumstances that cannot explicitly be modelled, such as environmental awareness, social norms and habits, may push some municipalities to adopt PAYT fees or not and simultaneously influence the outcomes in terms of the amount (and the composition) of garbage generated locally and of the resulting management costs.

One possible way to tackle this source of bias could be to narrow the scope of the analysis to neighbouring municipalities. There is a strong presumption that contiguous municipalities are very similar to each other not only in terms of population size, area and distance from disposal plants but also in their underlying characteristics. Hence, as a further robustness check, the third and final step of our analysis is to restrain the control group only to the TARI municipalities which lie on the boundaries of PAYT municipalities.

The differences between the outcomes of PAYT municipalities and their neighbouring TARI counterparts are reported in the last column of Table 8; such results are also compared with the ones previously obtained over the full sample by applying the standard OLS approach and with propensity score matching estimates. The

[15] Wright *et al.* (2018) show analytically that a simple comparison of the average outcomes in the treated and non-treated groups, as in standard OLS, would distort the evaluation of policy effectiveness by the sample selection bias, i.e. the different outcomes of the two subgroups in the absence of the treatment.

[16] This is the unconfoundedness assumption pointed out by Rosenbaum and Rubin (1983). It is equivalent to the independence of the error terms and the treatment variable in the linear regression model.

evidence of a decline in waste generation and in waste management costs is substantially confirmed. In the restricted sample, the application of PAYT fees is associated with a reduction in the production of total and particularly unsorted garbage, which both decrease by 60 kg per capita (respectively roughly 13 and 52 per cent of the corresponding average). This clearly reflects the design of most of PAYT schemes put in place, which explicitly price each additional bin of unsorted waste that exceeds an agreed limit. The effect on differentiating behaviour is confirmed positive in its sign (except for organic waste) but becomes statistically insignificant in the restricted sample of neighbouring municipalities. Total costs still appear to be reduced by PAYT although the coefficient is lower (€14 per capita, equivalent to a decline of 11 per cent on a yearly basis). The negative impact of PAYT fees on the cost components of unsorted and differentiated garbage is confirmed (€13 and €7 per capita respectively, roughly corresponding to a 35 and a 16 per cent decrease in their yearly amount).

The interpretation of the results should be complemented by two additional considerations. First, the decrease in costs associated with the adoption of PAYT could strengthen over time as long as the increase in the fixed costs due to setting plants necessary to the new policy is reabsorbed; similarly, the component of general costs could also exhibit a declining path to the extent that experience and reorganization of administrative procedures take hold. A further consideration is that, due to the geographical concentration of PAYT municipalities, restricting to neighbouring jurisdictions is equivalent to selecting observations among northeastern regions, that start from more favorable conditions and hencestand out as being particularly environmentally active (as witnessed by the higher percentages of differentiation and the lower shares of landfilling reported in Section 3). Households in those areas are more prone to recycling even in the absence of unit pricing and therefore they could respond less to the implementation of the new policy. It is therefore possible that the application of PAYT schemes to less environmentally aware municipalities could produce a more sizeable impact on the cost of providing waste services.[17]

Overall, our results seem to substantially confirm that PAYT is very effective in improving waste services, both on the demand (waste generation) and on the supply side (managing costs); its impact is sizeable in containing unsorted waste. This is in line with the findings of Bel and Gradus (2016), who claim that endogeneity issues are not a major problem and do not seem to significantly influence the price-elasticities estimated by empirical studies.

6. Concluding remarks

PAYT has been broadly implemented as a method for charging households for the waste services they receive from local communities. Economic theory strongly supports unit pricing, on the grounds of the fundamental assumption that individuals respond to economic incentives: if they are explicitly priced for each additional unit of garbage they send for disposal, they would limit their solid urban waste generation. This would lead to a more efficient allocation of resources in local public budgets and a more careful attitude towards the environment, in the wake of the Pigouvian polluter pays principle. A great deal of empirical literature has provided evidence that corroborates such conclusions.

In the Italian framework, the adoption of PAYT schemes is still at an early stage and, within the limits of our knowledge, no attempt has been made so far to evaluate what the impact of a wider diffusion of unit pricing in the management of waste services would be. Our analysis has tried to fill this gap, by building up and

[17] In other words, if environmental awareness can affect the external validity of our results, it would be in the direction of underestimating the real impact of PAYT policies.

exploiting a huge set of information on a sample of more than 6,100 municipalities – of which roughly 10 per cent adopt pricing schemes in line with PAYT principles. We have estimated the reactiveness to the adoption of PAYT fees of households' waste generating behaviour, on the one hand, and on waste management costs, on the other, also distinguishing between unsorted and differentiated garbage.

Our results seem robust to different estimation strategies and are summarized in Table 8. PAYT fees seem to have a remarkable impact on household behaviour: unsorted waste would substantially halve (with an aggregate reduction of 4 to 5 million tons). On the supply side, the implementation of PAYT fees would lead to costs savings in the range of at least 10 to almost 20 per cent on a yearly basis (on aggregate corresponding to almost €1.3 billion in absolute values). The decrease would be particularly significant for the unsorted component (which would fall by one third in the most prudent estimates); the differentiated component would decrease as well (by 10 to 15 per cent).

Through unit pricing, local public finance could achieve two goals: improving the efficiency of public goods provision and contributing to a more sustainable environment. Yet the transition to PAYT fees does not occur with a simple snap of fingers. It is only the final step of a broader strategy that requires a profound renovation of fixed capital endowment, adaptation to new technologies, the rescaling of waste services on a wider territorial perimeter in order to benefit from possible economies of dimension, and the implementation of strong enforcement mechanisms. Municipalities would need sufficient financial resources and adequate organization skills to take up this challenge. The current governance system, with several layers of governments overlapping with each other and interacting in a very complex way, is not helping Italy to speed up this transition.

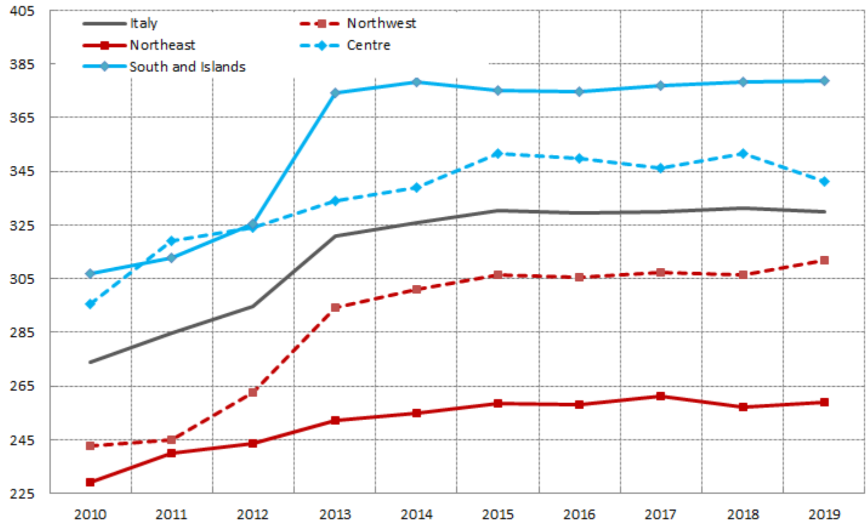
The results of this study are founded on the assumption that reductions in household waste disposal are not offset by an increase in illegal dumping. Although the literature is quite unanimous that such an assumption effectively holds, further developments of our analysis will be directed at exploring this issue in depth. Our idea is that the risk of waste tourism acts as a trigger for strategic interactions among neighbouring municipalities, leading to a strong spatial correlation in policy choices. Furthermore, the development of a panel dimension in our dataset, on which we are already working, will allow us to estimate long-run elasticities to PAYT policies (presumably cost savings could increase over time) as well as to explore the determinants of waste financing policy decisions by each municipality more deeply.

Tables and figures

Figure 1

Household payments for waste services in Italy

(euros)



Source: Federconsumatori and, for the years 2017 and 2018, municipal resolutions. Figures are computed for a three-member household resident in a provincial capital and living in a 100 square metre house.

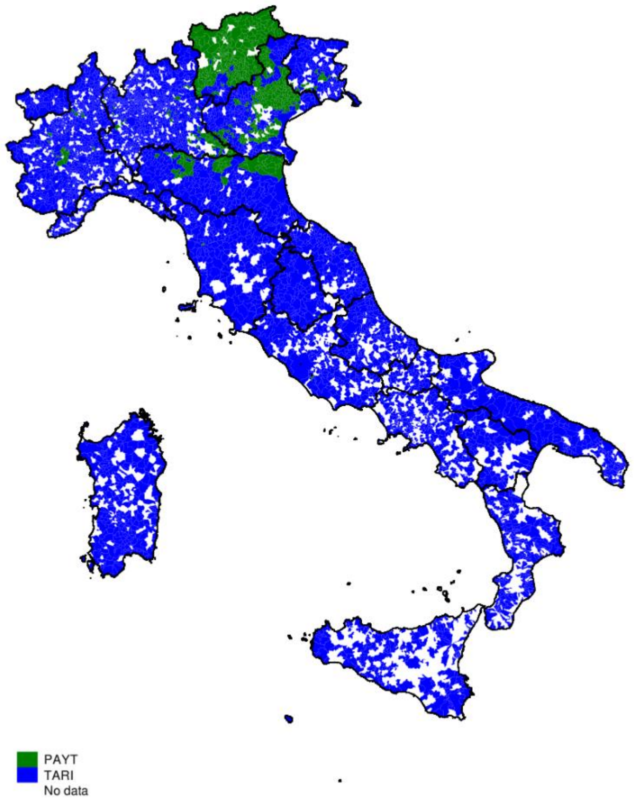
Table 1

Summary statistics

Variables	Definition	MEAN AND STDEV			
		overall	PAYT	TARI	n.obs
W_i	waste per capita (kg)	450.62 (167.72)	456.41 (163.59)	450.00 (168.16)	6092
$W_{i,diff}$	differentiated waste (kg)	272.91 (128.13)	359.47 (124.15)	263.60 (125.05)	6077
$W_{i,uns}$	unsorted waste (kg)	178.39 (125.26)	96.95 (67.83)	187.12 (126.86)	6092
$W_{i,org}$	organic waste (kg)	111.86 (65.98)	147.87 (69.97)	107.70 (64.22)	5678
$W_{i,pap}$	paper waste (kg)	48.03 (27.75)	63.53 (36.71)	46.34 (26.05)	6025
$W_{i,pla}$	plastic waste (kg)	24.50 (16.09)	31.07 (19.18)	23.78 (15.56)	6004
C_i	waste management costs (euro pc)	143.42 (67.42)	126.64 (45.17)	145.57 (69.47)	5109
$C_{i,uns}$	unsorted waste costs (euro pc)	51.29 (35.94)	32.56 (20.23)	53.69 (36.8)	5109
$C_{i,diff}$	differentiated waste costs (euro pc)	47.54 (30.82)	44.17 (19.63)	47.98 (31.95)	5109
RD_i	% of differentiated waste	59.91 (21.4)	79.01 (9.65)	57.86 (21.33)	6092
$COOP_i$	number of associated municipalities	13.91 (25.49)	15.52 (18.68)	13.71 (26.23)	5109
$DIST_{i,1}$	km from nearest unsorted plant	17.44 (11.31)	16.38 (7.98)	17.56 (11.6)	6097
$DIST_{i,2}$	km from nearest differentiated plant	17.54 (12.87)	13.43 (8.62)	17.98 (13.17)	6097
PW_i	dummy for PAYT municipalities	0.09 (0.29)	1 (0)	0 (0)	6097
$AREA_i$	municipal area (km2)	39.05 (53.11)	38.65 (42.35)	39.10 (54.11)	6077
POP_i	inhabitants	8588.15 (48579.13)	6510.88 (12969.39)	8810.70 (50934.33)	6097
$CLASS_i$	population class (1 to 6)				
$CLASS_i = 1$	% of municipalities with pop ≤2000	39.81	31.02	40.75	2427
$CLASS_i = 2$	% of municip. with 2000<pop≤5000	27.34	31.02	26.95	1667
$CLASS_i = 3$	% of municip. with 5000<pop≤15000	22.27	31.02	21.34	1358
$CLASS_i = 4$	% of municip. with 15000<pop≤60000	8.96	6.10	9.26	546
$CLASS_i = 5$	% of municip. with 60000<pop≤100000	0.92	0.34	0.98	56
$CLASS_i = 6$	% of municip. with pop>100000	0.71	0.51	0.73	43
$DENS_i$	population density	328.36 (683.93)	237.77 (294.55)	337.22 (710.08)	6077
$HSIZE_i$	household size	2.36 (0.25)	2.47 (0.21)	2.35 (0.25)	6097
$RENT_i$	real estate cadastral rent (euro pc)	268.04 (207.4)	288.13 (139.51)	265.95 (213.13)	6033
$PERS_i$	personal taxable income (euro)	12543.19 (3053.31)	14573.65 (1974.61)	12325.65 (3068.47)	6097
$SLEEP_i$	sleeping accommodation for tourists (pc)	0.15 (0.51)	0.29 (0.67)	0.14 (0.49)	5955
$MAGE_i$	mayor's age (years)	52.83 (10.74)	49.41 (10.13)	53.05 (10.74)	5692
$MFEM_i$	% of female mayors	15.09 (35.79)	17.80 (38)	14.80 (36)	6096
$GRAD_i$	% of graduated mayors	46.31 (49.87)	41.00 (49)	47.00 (50)	5727

Figure 2

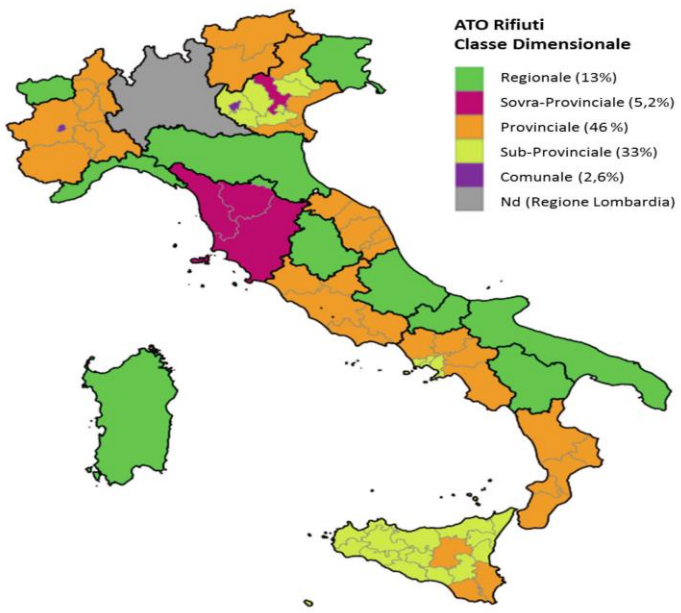
Municipalities with TARI and PAYT waste management systems



Source: municipal regulations, 2018

Figure 3

Geographical boundaries of optimal territorial areas (ATO)



Source: Invitalia (2019)

Table 2

OLS estimates of the determinants of the demand for municipal waste services

	Total waste	Unsorted	Organic	Paper	Plastic
Constant	258.537***	100.689***	69.106***	26.482***	19.175***
	(5.11)	(4.4)	(2.63)	(1.05)	(0.62)
PW_i	-27.607***	-108.044***	36.157***	13.888***	5.626***
	(5.55)	(4.78)	(2.74)	(1.13)	(0.67)
$RENT_i$	0.466***	0.275***	0.024**	0.034***	0.018***
	(0.02)	(0.01)	(0.01)	(0)	(0)
$RENT_i^2$	-0.000076***	-0.00005***	-0.000001	-0.000005***	-0.000003***
	(0.000006)	(0.000005)	(0.000003)	(0.000001)	(0.000001)
$CLASS_i$	29.499***	5.991***	13.265***	4.802***	-0.402*
	(1.51)	(1.3)	(0.76)	(0.31)	(0.18)
$SLEEP_i$	116.100***	57.632***	24.893***	11.073***	6.117***
	(3.77)	(3.25)	(1.9)	(0.77)	(0.46)
R_2	0.442	0.264	0.132	0.165	0.117
n.obs	5937	5937	5527	5870	5851

* Significant at the 0.5 level; ** significant at the 0.01 level; *** significant at the 0.001 level. Standard errors are in parentheses. $CLASS_i$ equals 1 if the population < 2000; 2 if the population is between 2001 and 5,000; 3 if the population is between 5,001 and 15,000; 4 if the population falls between 15,001 and 60,000; 5 if the population is > 60,000.

Table 3

OLS estimates of the determinants of the cost of municipal waste services

	Total waste	Unsorted	Differentiated
Constant	81.467***	36.488***	33.181***
	(3.15)	(1.77)	(1.59)
PW_i	-25.642***	-23.069***	-5.219***
	(2.63)	(1.48)	(1.32)
$RENT_i$	0.167***	0.054***	0.032***
	(0.01)	(0)	(0)
$RENT_i^2$	-0.000016***	-0.000002*	-0.000004*
	(0.000003)	(0.000001)	(0.000002)
$CLASS_i$	6.843***	-1.258**	2.542***
	(0.8)	(0.45)	(0.4)
$SLEEP_i$	12.288***	6.363***	4.059***
	(1.82)	(1.02)	(0.92)
$COOP_i$	-0.186***	-0.075***	-0.032
	(0.03)	(0.02)	(0.02)
$DIST1_i$	0.459***	0.365***	0.019
	(0.08)	(0.05)	(0.04)
R_2	0.259	0.174	0.092
n.obs	4977	4977	4977

* significant at the 0.5 level, ** significant at the 0.01 level; *** significant at the 0.001 level. Standard errors are in parenthesis. $CLASS_i$ equals 1 if the population < 2000; 2 if the population is between 2001 and 5.000; 3 if the population is between 5.001 and 15.000; 4 if the population falls between 15.001 and 60.000; and 5 if the population is > 60.000. The results are substantially confirmed if we restrict the sample to the regions where PAYT schemes are applied.

Table 4

Normalized differences for explanatory variables

	Sample	Mean	SD	Normalized Difference
$CLASS_i$	Control	2.05	1.09	-0.099360
	Treatment	2.15	0.98	
$RENT_i$	Control	265.90	213.13	-0.123160
	Treatment	288.10	139.51	
$RENT_i^2$	Control	116,145	544,270	0.033980
	Treatment	102,449	169,217	
$SLEEP_i$	Control	0.14	0.49	-0.254910
	Treatment	0.29	0.67	
$COOP_i$	Control	13.71	26.23	-0.079500
	Treatment	15.52	18.68	
$DIST1_i$	Control	17.56	11.60	0.118750
	Treatment	16.38	7.98	

Table 5

Propensity score of adopting PAYT fees

	Estimated coefficient	Standard error	z	p-value
$CLASS_i$	0.1048449	0.0422635	2.48	0.013
$RENT_i$	0.0080914	0.0012103	6.69	0
$RENT_i^2$	-0.0000071	0.0000013	-5.44	0
$SLEEP_i$	-0.0268237	0.1016672	-0.26	0.792
$COOP_i$	0.0039356	0.0017545	2.24	0.025
$DIST1_i$	0.0062147	0.0169154	0.37	0.713
Constant	-3.871339	0.2651134	-14.6	0

Coefficients are derived from a logit estimation of the binary variable PW=1 for municipalities applying PAYT fees, 0 otherwise. The SLEEP and DIST variables are expressed in quantiles in order to allow/enable a balanced matching.

Table 6

Balancing of Sample Means before and after Matching

	Unmatched Matched	**Mean**			**%reduction**	**t-test**	
variable	Sample	Treated	Control	%bias	|Bias|	t	p>|t|
$CLASS_i$	Unmatched	2.153	2.050	9.9		2.2	0.028
	Matched	2.172	2.278	-10.2	-2.7	-1.63	0.103
$RENT_i$	Unmatched	288.130	265.950	12.3		2.43	0.015
	Matched	289.140	297.240	-4.5	63.5	-0.91	0.362
$RENT_i^2$	Unmatched	1.00E+05	1.20E+05	-3.4		-0.6	0.55
	Matched	1.00E+05	1.10E+05	-2.4	29.6	-0.91	0.361
$SLEEP_i$	Unmatched	1.548	1.495	10.7		2.43	0.015
	Matched	1.548	1.545	0.7	93.3	0.12	0.904
$COOP_i$	Unmatched	15.519	13.709	8		1.61	0.107
	Matched	15.489	13.835	7.3	8.6	1.22	0.223
$DIST1_i$	Unmatched	5.476	5.500	-0.9		-0.19	0.849
	Matched	5.391	5.127	9.6	-1014.5	1.64	0.101

Table 7

Propensity matching estimation of the treatment effect of adopting PAYT fees

	Treated	Controls	Difference	t-stat
$\boldsymbol{W_i}$ **(kg per capita)**				
Unmatched	457.357	459.979	-2.62193783	-0.35
$ATET$	457.357	479.7492	-22.3921914	-2.18
$ATEUT$	459.979	446.3425	-13.6364661	.
ATE			-14.6790813	.
$\boldsymbol{W_{i,uns}}$ **(kg per capita)**				
Unmatched	96.44324	174.319	-77.8757994	-15.05
$ATET$	96.44324	190.7156	-94.2723532	-14.1
$ATEUT$	174.319	88.56832	-85.7507199	.
ATE			-86.7654599	.
$\boldsymbol{W_{i,org}}$ **(kg per capita)**				
Unmatched	148.8872	109.0809	39.8063329	13.89
$ATET$	148.8872	106.5453	42.3419134	10.4
$ATEUT$	109.0809	153.2147	44.1338185	.
ATE			43.9204418	.
$\boldsymbol{W_{i,pap}}$ **(kg per capita)**				
Unmatched	63.3129	49.33656	13.9763393	11.09
$ATET$	63.3129	50.618	12.6949033	6.06
$ATEUT$	49.33656	60.14874	10.8121742	.
ATE			11.036366	.
$\boldsymbol{W_{i,pla}}$ **(kg per capita)**				
Unmatched	30.88289	24.85199	6.03089627	8.73
$ATET$	30.88289	24.17741	6.70548123	5.93
$ATEUT$	24.85199	31.21339	6.36139824	.
ATE			6.40237099	.
$\boldsymbol{C_i}$ **(euro per capita)**				
Unmatched	125.5696	144.4689	-18.8993652	-6.59
$ATET$	125.5696	151.0951	-25.5255914	-6.39
$ATEUT$	144.4689	121.617	-22.8519453	.
ATE			-23.170318	.
$\boldsymbol{C_{i,diff}}$ **(euro per capita)**				
Unmatched	43.92321	48.63721	-4.71400142	-3.45
$ATET$	43.92321	49.02887	-5.10566308	-3.39
$ATEUT$	48.63721	44.99307	-3.64414002	.
ATE			-3.81817542	.
$\boldsymbol{C_{i,uns}}$ **(euro per capita)**				
Unmatched	32.36075	52.08069	-19.7199377	-13.2
$ATET$	32.36075	54.80801	-22.4472581	-10.28
$ATEUT$	52.08069	31.43148	-20.6492078	.
ATE			-20.8633163	.

The table shows the results given by the nearest neighbour (NN) matching estimator

Table 8

Estimated impact of PAYT: full and restricted sample

(kg and euros per capita; percentage variations in square brackets)

Variables	Full sample (OLS)	Full sample (matching)	Restricted sample (OLS)
W_i	-27.607***	-22.3922***	-59.995***
	[-6.13]	[-4.97]	[-12.75]
$W_{i,uns}$	-108.044***	-94.2724***	-60.152***
	[-60.57]	[-52.85]	[-51.52]
$W_{i,org}$	36.157***	42.3419***	-0.127
	[32.32]	[37.85]	[-0.09]
$W_{i,pap}$	13.888***	12.6949***	0.535
	[28.92]	[26.43]	[0.87]
$W_{i,pla}$	5.626***	6.7055***	0.543
	[22.96]	[27.37]	[1.82]
C_i	-25.642***	-25.5256***	-13.598***
	[-17.88]	[-17.80]	[-10.53]
$C_{i,diff}$	-5.219***	-5.1057***	-7.368***
	[-10.98]	[-10.74]	[-15.66]
$C_{i,uns}$	-23.069***	-22.4473***	-12.844***
	[-44.98]	[-43.77]	[-34.83]

Column 1: coefficients of PW_i estimated over the full sample and the linear models specified in equations (9) and (10); column 2: average treatment effects estimated by propensity score matching over the full sample; column 3: coefficients of PW_i estimated over the restricted sample and the linear models specified in equations (9) and (10).

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