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Inequality and regressivity in Italian waste taxation. Is there an alternative route?

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ABSTRACT

The Italian financing system for waste collection and disposal services, still far from a price-based system at the national level, is similar to a real property tax system. Among other concerns, this raises equity issues. The aim of this paper is threefold. First, the structure of the waste tax in its components (i.e., fixed and variable) is analysed at the provincial level. This allows to investigate the magnitude of the two tax components in Italian provinces, while showing the differences among macro-areas in the financing system for waste collection and disposal services. Second, the regressivity (progressivity) of the tax system adopted is investigated, so as to highlight the differences among geographical areas. Third, an alternative base for the waste tax is proposed, in order to avoid regressivity and achieve higher equality. For these purposes, official data referring to 2017 are used and a Geographically Weighted Regression is implemented. The results highlight the importance of an alternative base of the waste tax to design an equal and non-regressive tax, more similar to a Pay-As-You-Throw scheme.

1. Introduction

In the field of waste management policies, an important issue involves the types of economic instruments that should be levied by local governments in order to recover the cost of waste collection and disposal services to citizens, while incentivising environmentally friendly behaviours. The use of fiscal levies as a financing system entails concerns over both effectiveness and equity issues. This study focuses on the latter.

Local governments may finance their waste sevices in diffent ways, ranging from taxes to prices-based systems. Traditional financing systems impose a payment on part of users from general taxes or benefit taxes. These systems do not directly link user-payer waste generation to the tax paid. In other words, these taxes are not directly related to the specific services provided to each user.

Conversely, price-based systems (Pay-As-You-Throw schemes, hereafter PAYT) establish a negative incentive approach, requiring a quantity-based payment by users[1] (related to volume, weight, or frequency).

In general, a financing system of waste related services should aim to fulfil various goals. First, the *environmental sustainability goal*: it should discourage citizens (user-payers) from producing waste by introducing a negative incentive ('*polluter user pays*' principle), in order to support the application of the waste hierarchy;

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[1] The latter links the user-payer waste production to the fee (price), forcing the user to internalise the full costs of waste produced. The implementation of this pricing system follows more strictly Pigou's perspective (Pigou, 1929), as well as the polluter pays principle established by Directive 2008/98/EC (Waste Framework Directive). The difference between a user fee and a benefit tax is that the user fee is directly linked to a specific service provided by local governments, which can be observed and used by each citizen (Bird, 1997). In other words, the application of a user fee requires that the beneficiaries of a specific service can be identified, and the amount of benefit can be measured (see Duff, 2004). Examples of priced-based instruments are per-unit fees and variable subscription systems where the payment increases with the number of containers employed.

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second, the *financial sustainability goal*: it should cover all the costs related to the waste management system (e.g. collection, facility, street cleaning, and so on). Indeed, fiscal stress is likely to lead to an inability to deliver waste services (Zafra-Gómez et al., 2016); third, it should account for relevant social aspects, such as equity, incidence among different user-payers groups and political acceptability (Bilitewski et al., 2004; Bilitewski, 2008). Well-designed financing system need to account for all of these goals. In the design of a waste tax or a fee, the rates applied as well as the width of coverage costs are important factors that influence the impact of these instruments, in terms of both effectiveness and incidence (Withana et al., 2014).

The empirical literature suggests that, despite their higher administrative and infrastructural costs, quantity-based schemes, such as PAYT, are more effective in preventing and recycling waste (Acuff and Kaffi, 2013; Bucciol et al., 2015; Fullerton and Kinnaman, 1996). However, most financing systems implemented in Europe levy flat-tax systems (non-PAYT waste charging schemes)[2].

In many European municipalities, citizens pay a flat fee or a flat tax for waste collection and disposal services (for instance, in the United Kingdom waste management is financed through a council tax, see Messina et al., 2018). Therefore, the economic literature highlights various reasons why the usage of waste taxation and more specifically flat-fee systems should be limited. In particular, even though flat-fee schemes may account for the full social costs of waste generation, the cost of producing an additional unit of waste is zero for a user-payer. This discourages citizens from reducing their waste production. In addition, these systems also raise incidence concerns, that are central for political acceptability and social fairness (EEA, 2011; Serret et al., 2006; OECD, 2006). When policy makers establish a financing system, they should not neglect the potential regressivity (or progressivity) of a tax. In particular, the regressivity of a waste tax plays a key role for an effective and quantitatively substantial implementation. Flat fees however are more regressive than quantity-based pricing systems (Reschovsky and Stone, 1994; Duff, 2004). In particular, flat fees may impose heavier financial burdens on low-income households. In addition, Reschovsky and Stone (1994) highlight that paying only for what you throw away is more equitable, avoiding the subsidisation of high-waste producers by low-waste producers as for any flat-fee system. Leipprand et al. (2007) analysed the distributional effects of environment-related taxes and charges (i.e. energy taxes, charges on water services and waste collection) in Czech Republic, Germany, Spain, Sweden, and the United Kingdom. Their findings pointed to the regressive effect of water charges in Spain, explaining that this effect is a result of a pricing system that is usually unrelated to the actual quantity of water consumed.

Concerning the regressivity and equity of waste-related taxes and charges however, the literature is less developed, to our best knowledge. The purpose of this study is to contribute to this gap. This article focuses on the regressivity and equity concerns related to the financing system employed by Italian municipalities in the delivery of waste collection and disposal services. Italy is a country characterised by a marked regulatory instability and by a certain degree of heterogeneity in the application of urban waste management rules. The financing systems for waste collection and disposal services (i.e. the payment to municipalities by citizens) represent paramount examples of the lack of a clear and stable regulatory framework and constitute an interesting case study.

As already stated above, the study aims to investigate the equity issue related to the Italian waste services financing system in order to help policy-makers to reduce possible distortions in terms of tax regressivity/progressivity (tax social dimension). The latter risk is linked to the methods of establishing a waste tax (a no-PAYT), which involves the use of presumptive criteria that should approximate the tax-payers waste production. These tax bases, set by law as a 'temporary solution', may result in a taxation too far away from a negative incentive system (related to the 'polluter pays' principle as a Pigouvian tax) ending up to be more similar to a property tax, as suggested also by Messina et al. (2018). This eventuality might raise difficulties in the achievement of the environmental sustainability goal (i.e., not trying to discourage the production of waste), while implying that the disposal costs of high-income households (producing high amount of waste) could be partially covered by low-income households (that generate a lower amounts of waste). Messina et al. (2018), find that Italian households in the lower decile of consumption distribution pay twice as much for waste services as compared to households in the upper decile.

To this end, we, firstly, show how the magnitude of tax components (fixed and variable) vary across the Italian provinces, starting from the waste tax structure set by Italian law (accounting identity). This is an interesting feature to explore because the tax structure depends on its tax base, tax rate and tax rate variation. The tax bases of the waste tax (the amount to which a tax rates are applied) are the same for the whole Italian territory (housing surface and household size). The tax rates (of the fixed and variable components), instead, are established by local authorities (municipalities) and differ according to the geographical areas. The analysis of the tax components magnitudes, thus, allows to highlight the features and differences of the financing systems across macro-areas, as well as their spatial heterogeneity. Secondly, the social dimension of taxation in term of tax regressivity (progressivity) is investigated, showing the differences among geographical areas. Finally, a hypothetical scenario where one tax base is replaced in order to avoid regressivity and to achieve a more equitable taxation is analysed. In this scenario, per capita income hypothetical tax base is introduced to replace the household size-base.

The results show the presence of an equity issue due to a regressivity of the Italian waste tax. This is, in particular, linked to the type of variables choice concerning the tax bases that end up likening the tax more to a property tax than to a PAYT system. The tax is indeed based on elements that transcend actual service usage and tends to ignore the taxpayer's ability to pay. However, if Ta.ri. is applied incorrectly, the system not only endanger the ability to fully recover local financial outgoings, as in the case of a flat-rate system (see Bilitewski, 2008), but it also endanger the ability to achieve the environmental sustainability goal (e.g., the reduction of total waste) and to avoid inequity risk. The study also provides further basis for the argumentation that the PAYT system represents the best solution not only to improve environmental protection (i.e., achieving an allocative efficiency in term of waste production) but also avoid inequity risk (i.e., richer households, which produce more waste, may pay more than poor ones).

The paper is organised as follows. Section 2 contains a historical reconstruction of the waste tax systems adopted during the past decades in Italy. Section 3 deals with the empirical strategy adopted, presenting the methodological aspects of Geographically Weighted Regression. Section 4 introduces the data used in the analysis and presents some stylised facts. Section 5 elaborates the main empirical findings and provides policy implications. Section 6 presents the limitation of the analysis, as well as some robustness check. Section 7 concludes.

[2] In particular, PAYT schemes are often established at the municipal level, e.g. in the Netherlands, Luxembourg, Spain, the United Kingdom, and Italy. Only a few countries have PAYT schemes at the national level (e.g. Austria, Finland, and Ireland) (Withana et al., 2014; Messina et al., 2018). In addition, the current PAYT and waste charging schemes adopted in European countries as well as across municipalities of the same country are very heterogeneous in their design (Bilitewski, 2008). For instance, PAYT schemes vary in the base employed as a proxy for waste generation, i.e., weight, volume, or frequency.

2. The puzzle of waste taxation in Italy. A historical perspective

Over the years, the national regulatory framework of financing systems for waste collection and disposal services (i.e., the payment to municipalities by citizens) has undergone various transitions: first, from a *tax* (TARSU) to a charge system labelled "*Tariffa di igiene ambitale*" (TIA1) and then "*Tariffa integrata ambientale*" (TIA2); second, from a charge to a tax system labelled "*Tributo sui rifiuti e sui servizi indivisibili*" (TARES); finally, to another type of tax system labelled "*Tassa sui rifiuti*" (Ta.ri.), which is currently in force. This has led Italian municipalities to use heterogeneous financing systems over the years. In general, those changes aimed to 1) guarantee full-cost coverage, in order to avoid resorting to general taxation (*cost recovery principle*) and 2) introduce a quantity-based charge system, more closely related to the '*polluter pays*' principle.

In the 1940 s indeed the first waste tax – TARSU, established by Law 366/41 – consisted in a compulsory payment to municipalities, levied on a certain tax-base regardless of the level of services provided to taxpayers (i.e., to their level of the waste generation), which did not imply full-cost coverage. Thereby municipalities might be forced to resort to general taxation in order to reimburse full cost. In particular, TARSU was formed by several components: 1) a tax computed on disposal costs per unit of house surface multiplied by one or more quantitative and qualitative waste productivity coefficients; 2) an additional tax (up to a maximum of 10 percent of the tax) to cover the cost of the landfill disposal; 3) an additional provincial tax (between 1 and 5 percent of the tax) for environmental protection services. This financing system was modified both in the 1980 s and in 1993 (see Legislative Decree 507/93).

In 1997, Legislative Decree 22/97 (*Decreto Ronchi*) set a transition from a tax[3] to a charge system (TIA1). TIA1 identifies environmental sustainability as its long-term objective, following the *polluter pays* principle and the financial principle, aiming at both full cost coverage and management efficiency. TIA1 is indeed computed in three steps. In the first step, a quantification of the total revenues that fully cover the management and investment costs is provided. In the second step, the necessary revenues estimated are divided into two parts: a *fixed part,* related to the cost of the service for street splitting and washing, administrative costs, common costs for investments and depreciation; and a *variable part,* related to the quantity of waste delivered, to the service provided and to management costs (e.g. for collection, transport and disposal). Finally, the third phase is related to the division of costs between user-payer groups (domestic and non-domestic).

However, the implementation of TIA1 involved only a few municipalities. TIA1′s enforcement was postponed in the municipalities that had reached a cost coverage ratio ranging between 55% and 85% under the previous financial system. In addition, TIA1 was to be replaced by TIA2 (introduced by the so-called Environmental Code, see Legislative Decree 152/2006), but its implementing regulation was never issued. Both TIA1 and TIA2 consisted in a two-component waste charge, which included a *fixed fee* (determined on the basis of both user house surface and number of household members) to cover the fixed costs of the service; and a *variable fee* component (determined on the basis of the number of household members, the quantity of waste produced, the type of service provided and the amount of management costs), to recovery variable costs.

Until 2013 therefore, the financing systems for waste collection and disposal services applied by municipalities were extremely heterogeneous in Italy: some municipalities applied a charge system (i.e., TIA1) while others applied a waste tax system (i.e., TARSU).

As mentioned above, the idea underlying the transition to a charge system was to reach a full cost recovery of the waste services, while linking the payment to the amount of waste generated by user-payers, in order to incentivise a reduction in waste generation. This last goal seems to have been missed, since measuring the level of waste generated by each user-payers proved unfeasible. A proxy was used instead as a base of the charge (i.e. number of household members, which is labelled 'presumptive base'), thus failing to reward virtuous behaviours. This happened because the charge is flat with respect to the waste generated by user-payers. Owing to this latter aspect indeed, Bucciol et al. (2011) defined this financing system as a flat-fee system. Moreover, given the nature of tax, it may produce distorted effects in terms of equity and social justice (Bird and Tsiopoulos, 1997; Duff, 2004). In setting waste-related taxes and charges, local policymakers cannot neglect these aspects. A financial system is intended to fulfil a number of needs and criteria such as, fairness of charge, social fairness, reliability, adaptation to local structure, and cost recovery (Bilitewski et al., 2004; Bilitewski, 2008). If applied incorrectly, the system will not only endanger the ability to fully recover local financial outgoings, as in the case of a flat fee (see Bilitewski, 2008), but it will also endanger the ability to achieve the environmental sustainability goal (e.g. the reduction of total waste).

Only in few municipalities of North-Eastern Italy (particularly in Veneto, and Emilia Romagna), kerbside collection system has allowed for an application of the polluter pays principle, linking the fee paid to waste generation, while encouraging separate collection (Chiades and Torrini, 2008). Chiades and Torrini (2008) indeed find a positive correlation (0.22) between the variation in separate collection rates (from 2000 to 2005) and the variation in the degree of TIA coverage across Municipalities (from 2000 to 2004), calculated at the provincial level, only in North-Eastern Italy. In the regions of Central Italy, the correlation is almost zero, while in Southern Italy a negative correlation is reported.

Law 147/2013, starting from January 1st 2014, legally replaced a financial system labelled 'Tassa sui Rifiuti' (Ta.ri.), which follows the computation criteria of the TIA1 system. Despite the continuous legislative changes indeed, the financing of municipal waste collection and disposal services is still based on a system where the variable part of the waste tax is rarely based on frequency, volume or weight (like the PAYT scheme). Regarding the presumptive criteria, it is useful to remember that D.P.R. April 27th 1999n. 158 established a presumptive methodology as a 'temporary solution', owing to the inability of local governments to operate an accurate measurement of the waste produced by each user-payer. However, this 'temporary solution' is still the most widely used practice. In 2015, 94% of the municipalities applied Ta.ri. and 5.7% of the municipalities applied the PAYT Scheme (ISPRA, 2017).

In summary, today the national legal framework allows for a wide degree of discretion on part of municipalities, which can apply a tax system or a PAYT Scheme to finance waste collection and disposal services. These choices are in most cases also driven by municipal financial needs (such as consolidated budget deficits and debts). In practice, since 2016, Ta.ri. is a very important form of financing for municipalities (Messina et al., 2018). However, if applied incorrectly, the system will not only endanger the ability to fully recover local financial outgoings, as in the case of a flat-rate system (see Bilitewski, 2008), but it will also endanger the ability to achieve the environmental sustainability goal (e.g. the reduction of total waste).

The analysis on the budgets of the Italian municipalities carried out by CRIF Ratings indeed shows that Ta.ri. represents on average about 30% of the total tax revenues of Italian municipalities.

[3] A type that Duff (2004) defined as a *crude proxy* for a user fee, more similar to a *property tax* or *council tax*, since it is based on house surface.

Among municipal taxes, Ta.ri exhibits the highest non-payment risk, due to the *quasi-universalistic* nature of the service it is related to. The tax is indeed based on elements that transcend actual service usage and it tends to neglect the taxpayer's ability to pay. This feature tends to amplify the negative externalities of non-virtuous behaviours. In 2016, many regions in the South displayed a high non-collection rate for the waste tax (measured in per capita terms), including: Lazio, with €121, Sicily, Campania (€63), and Calabria (about €45). Northern regions instead (as Friuli Venezia Giulia, Trentino Alto Adige, Val d'Aosta, Lombardy, and Veneto) stood out as virtuous (CRIF Ratings, 2020)[4].

3. Empirical strategy

The empirical strategy used in this work is developed as a two-step procedure. First, we aim to estimate the fixed, and variable components of Ta.ri. for each Italian province. Since the classic methods (such as OLS) just allow to obtain the average level of the parameters considering all the provinces of analysis, they are not well-suited for our research objectives. To overcome this limitation, we resort to Geographically Weighted Regression (GWR). This method associates each province to the corresponding set of coefficients (which represents the estimated values of the fixed, and variable component). Second, on the basis of the results of GWR, we propose an alternative income-based waste tax, aiming to improve equity.

In order to exaplain the first step of the analysis – i.e., the estimation of the fixed, and variable component of Ta.ri – the GWR method must be outlined, due to its pivotal role in our empirical strategy. Proposed by Brunsdon et al. (1996), GWR has grown increasingly more popular in studies where to control for spatial heterogeneity among regression parameters was relevant (see, for example, Fotheringham et al., 1998; Farrow et al., 2005; Shi et al., 2006; Yu, 2007). Formally, the model can be expressed as follows:

$$y_j = \beta_0(u_j, v_j) + \sum_{k=1}^{q} \beta_k(u_j, v_j)x_{kj} + \varepsilon_j \quad j = 1, \cdots., n \tag{1}$$

that represents the following measures at location j (in this work, the j units are the provinces of Italy): y_j is the dependent variable, x_{kj} is the *k-th* explanatory variable, ε_j is the random error. Hence, the regression parameters estimated at each location are spatially explicit, implying that each coefficient in the model is a function of province *j*. As a result, GWR gives rise to a distribution of local estimated parameters. In particular, $\beta_0(u_j, v_j)$ is the intercept, $\beta_k(u_j, v_j)$ is the coefficient of *k-th* explanatory variable while u_j and v_j represent the coordinates of the *j-th* province. The estimation of the local parameters requires to define a weight for each observation in order to use the Weighted Least Square (WLS, see Fotheringham et al. (2003a,b)). Formally, the estimator of local parameters is the following:

$$\widehat{\beta}(u_j, v_j) = \left(X^T W(u_j, v_j) X\right)^{-1} X^T W(u_j, v_j) y \tag{2}$$

where $W(u_j, v_j)$ is the matrix of geographical weights, which plays a central role in the estimation procedure. The underlying principle is that in the estimation of the local parameter of unit *j*, closer neighbours have a higher impact with respect to farther neighbours. As a result, the geographical weights assume increasing values as units are nearer. According to Fotheringham et al. (1998; 2003), the geographical weighting scheme follows the continuous Gaussian function and it is defined as:

$$w_{ij} = e^{-\left(d_{ij}/b\right)^2} \tag{3}$$

The weights are a function of the Euclidean distance between units i and j (i.e., d_{ij}), and of kernel bandwidth b. The latter is the smoothing parameter, whose selection plays a critical role in the GWR estimation procedure, because it controls for data density, assigning greater weights to observations closer to location *j*. That is, an oversmoothed model leads to coincidence between GWR and OLS estimates, returning a global average relationship. On contrary, the parameters estimated through an undersmoothed model are too local and the determination of geographical pattern becomes a complex task. Obviously, these are two extreme scenarios and the optimal solution is to use a medium bandwidth, allowing to obtain informative local estimates. Some methods can be used for bandwidth selection, such as user-supplied bandwidth, the cross-validation function, the Bayesian Information Criterion (BIC), and the corrected Akaike Information Criterion (AIC_c). We use the minimisation of AIC_c (for furthermore details on other methods, see Fotheringham et al., 1998; Nakaya, 2002; Nakaya et al.; 2016), which is computed as follows (Fotheringham et al. (2003a,b)):

$$AIC_c = 2nln(\widehat{\sigma}) + nln(2\pi) + n\left\{\frac{n + tr(S)}{n - 2 - tr(S)}\right\} \tag{4}$$

where n is the number of observations and *tr(S)* is the trace of hat matrix (Hoaglin and Welsch, 1978) *S*, which is a function of the bandwidth, defined as follows: $\widehat{y} = Sy$ (details on matrix S can be found in Fotheringham et al., 2003a,b, Chapters: 2, 4, and 9). The underlying principle is to compare models with different bandwidths and then to select the one with the lowest AIC_c. This iterative procedure can be carried out through the golden section search, to determine optimal bandwidth size (see Nakaya, 2015). In this work, we use Gaussian adaptative kernel, which allows to control for the variation in the geographical density of the observed data (it sets smaller bandwidths when the data are denser and larger bandwidths when they are more sporadic, see Fotheringham et al., 2003a,b).

GWR also controls for spatial variability in the coefficients. According to Warsito et al. (2018), the following hypotheses are to be tested: $H_0 : \beta_k(u_j, v_j) = \beta_k$; H_1 :at least one $\beta_k(u_j v_j) \neq \beta_k$, with $k = 0, 1, \cdots, q$ and $j = 1, 2, \cdots, n$. The test follows the Fisher–Snedecor F distribution and under the null hypothesis there is no significant difference between GWR and OLS coefficients. When the null hypothesis is rejected, it is not always obvious which (and how many) coefficients should be assumed as local. Thus, the spatial variability of each coefficient is controlled for through an AIC_c-based comparison across models (known as 'Diff on Criterion'). To assess the variability of the *k-th* coefficient, we compare a full GWR model, where all coefficients vary over the space, with a fixed GWR, where the *k-th* coefficient is spatially constant, while the others are allowed to vary (Nakaya, 2015). We do not reject the hypothesis of spatial variability in the coefficient if the full model produces a statistically better fit with respect to the fixed model (see Nakaya et al., 2005; 2016, for furthermore details). That is, if the full model minimises the AIC_c we consider the *k-th* coefficient as a local parameter. The comparison is structured as follows: $\Delta AIC_{c_k} = AIC_{c_{k;full}} - AIC_{c_{k;fixed}}$. If this quantity is positive, the full model yields a worse fit with respect to the fixed model and the *k-th* coefficient should be considered as a global parameter (i.e., OLS is preferred to GWR). On contrary, if spatial a pattern exists, the ΔAIC_{c_k} assumes values lower than -2 (Burnham and Anderson, 2002; Nakaya, 2015) and the GWR should be preferred to OLS.

On this basis, through GWR we can estimate coefficients α_j (the fixed component) and β_j (the variable component) for each of the *j* provinces according to following expression:

[4] Retrieved from https://www.crifratings.com/lista-ricerche/ (Accessed on 21/03/2020)

$$\overline{Ta.ri}_{.j} = \alpha_j \overline{hs}_j + \beta_j \overline{fs}_j \quad (5)$$

where $\overline{Ta.ri}_{.j}$ represents the average amount of tax. Regarding the covariates, $\overline{hs}_j$ (namely, *housing surface*) represents average house surface expressed in square meters, and $\overline{fs}_j$ (namely, *household size*) represents the average number of household components.

In the second step of the analysis, we propose an alternative form of waste tax, based on per capita income, aiming to deal with equity issues. Formally:

$$\widehat{Ta.ri}_{.j} = \beta_0(u_j, v_j) + \beta_1(u_j, v_j)\overline{hs}_j + \beta_2(u_j, v_j)\overline{ipc}_j \quad (6)$$

where $\beta_0(u_j, v_j)$ is the intercept, $\beta_1(u_j, v_j)$ is the coefficient associated to the fixed component of the tax and $\beta_2(u_j, v_j)$ is the coefficients associated to the variable components of the tax. They are the set of territorial coefficients estimated using GWR. Finally, $\overline{hs}_j$ is the average housing surface associated to the fixed term as in the current Ta.ri., and $\overline{ipc}_j$ represents the average *income per capita* at the provincial level (which replaces household size in this alternative proposal) as a factor associated to the variable component. Expression (6) can be rewritten as $\widehat{Ta.ri}_{.j} = \widehat{\alpha}_j \overline{hs}_j + \widehat{\beta}_j \overline{ipc}_j$, where $\beta_1(u_j, v_j) = \widehat{\alpha}_j$, $\beta_2(u_j, v_j) = \widehat{\beta}_j$, and the intercept is omitted. Fig. 1 summarises the steps of the empirical strategy employed in the analysis.

4. Data and stylised facts

The data used in this work are drawn from official records, covering over 110 Italian provinces. We resort to data at the provincial level (NUTS-3 in the Eurostat classification), in order to use information with the highest territorial detail available. The reference year of analysis is 2017, owing to both a higher extent of homogeneity in the financing systems employed across municipalities (see Section 2) and to the fact that these are the most complete and recent data available. The outcome variable is the waste tax, namely *Ta.ri.*, obtained as the average tax at the provincial level and expressed in euro. The data are provided by *Federconsumatori* and by *Cittadinanzattiva*[5], two non-profit associations, whose main objectives are information and protection of consumers and users. They are recognised as consumer organisations, independent from political parties, trade unions, private companies, and public institutions. Among their main objectives, these associations count the promotion of civic participation and the protection of citizens' rights in Italy. Annually, a dossier on waste management is published, reporting the annual amount of Ta.ri. measured as a provincial average.

The waste tax is a function of *housing surface* and *household size* (Law 147/2013, art. 1). In particular, housing surface represents the size in square meters of the house, while household size is the count of people who live there. Information on these variables is drawn from ISTAT (National Italian Institute of Statistics) and is expressed as provincial averages. In addition, data on average annual *per capita income* at the provincial level, employed in the second step of the analysis, are provided by Ministry of Economy and Finance (MEF).

Ta.ri., as seen in Section 2, is computed by local governments on presumptive bases that consider housing surface as a proxy for wealth and household size as a proxy for the waste generated. These two variables, however, might be unable to fully capture those dimensions, thus introducing a bias in the computation of the tax and raising inequality concerns. Based on the computation mechanism, it is reasonable to expect that provinces with higher values of these variables display on average a higher amount of waste tax.

Fig. 2 depicts the territorial distribution of both the outcome variable (Ta.ri.) and the covariates (i.e., housing surface, household size, and per capita income), highlighting some 'contradictions' linked to the variables used as presumptive bases. In particular, Fig. 2**a** shows that many provinces of Southern Italy had, on average, higher amounts of tax owing to a high value of both housing surface and household size (Fig. 2**b and c**). This should mean that Southern areas are wealthier and produce more waste in comparison Central and Northern areas.

It is important to point out two main features (limits) regarding the variables used as presumptive bases. First, although the territorial distribution of the housing surface variable (Fig. 2**b**) is heterogeneous over the space (i.e., the provinces belonging to the highest quantiles are located in the North-eastern, Central, and Southern Italy) it is necessary to consider that the square meters provide only a partial picture of the value of a building, which may vary greatly due to characteristics such as location, and maintenance conditions. In this view, we have calculated a deprivation index that shows the deep gap between Northern and Southern Italy (see the Appendix for a description of the index and its territorial distribution at the regional level). As a result, for the same square meters, the buildings in Southern areas may display significantly lower real values than those in the other parts of the country. Consequently, housing surface fails to approximate wealth. Second, regarding the household size variable, Fig. 2**c** shows that larger households are unevenly distributed towards Southern Italy, which should imply that these provinces generate a higher amount of waste. This variable indeed is a proxy for the amount of waste produced by households, as mentioned above. However as shown by Fig. 2**e**, on average, per capita waste generated is lower in the South with respect to Northern, and Central Italy. In addition, ignoring the strong relation between income level and consumption, which in turn increases waste production, may constitute an additional source of bias when attempting to approximate waste generated by user-payers (Mazzanti et al., 2008; Beigl et al., 2004; Musella et al., 2019; Agovino et al., 2019).

The joint comparison of the territorial distributions of Ta.ri., housing surface and household size with per capita income (Fig. 2**a-2d**) suggests a regressivity of the waste taxation system and, therefore, the aforementioned features (limits) of the presumptive bases. In particular, it is possible to observe that wealthier provinces (featuring higher income per capita on average) are located in Northern Italy and they benefit from a lower average waste tax. In other words, the higher the income, the lower the tax. The comparison between housing surface and income per capita (Fig. 2**b–d**) highlights that many provinces in Southern Italy feature higher house surfaces, but they are characterised by a lower average income per capita. Finally, as shown in Fig. 2**c,d,** Southern provinces display higher levels of household size, but lower levels of income per capita. Based on how the tax is designed, poorer provinces (in Southern Italy) are treated as having higher consumption levels (due to higher household size) than the richer provinces of Northern Italy.

To overcome these limitations, the analysis tests whether replacing the variable part in the Ta.ri. computation with per capita income might reduce equity concerns in terms of taxation among the Italian provinces. In fact, as suggested by the current economic literature, per capita income is related to both wealth and waste produced (see Hoornweg and Bhada-Tata, 2012; European Commission, 2012; Messina et al., 2018). This substitution may

[5] The link to website homepages of the two non-profit associations are the following: Federconsumatori: https://www.federconsumatori.it/; Cittadinanzattiva: https://www.cittadinanzattiva.it/

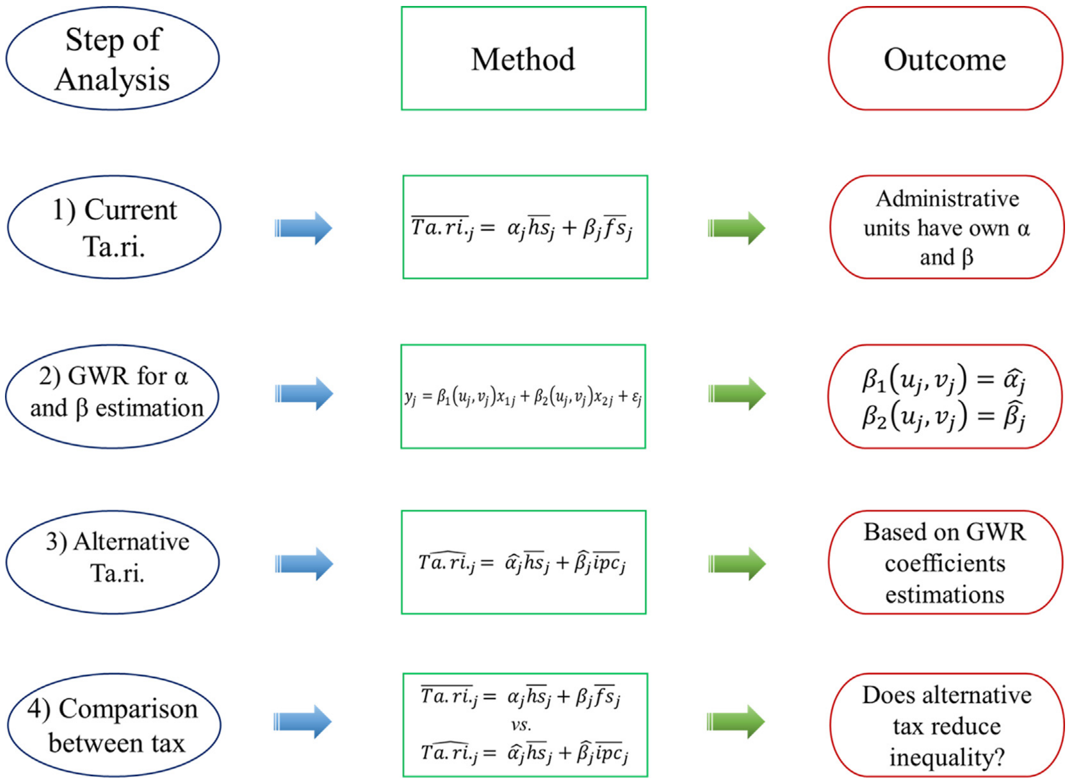

Fig. 1. Graphical representation of the empirical strategy.

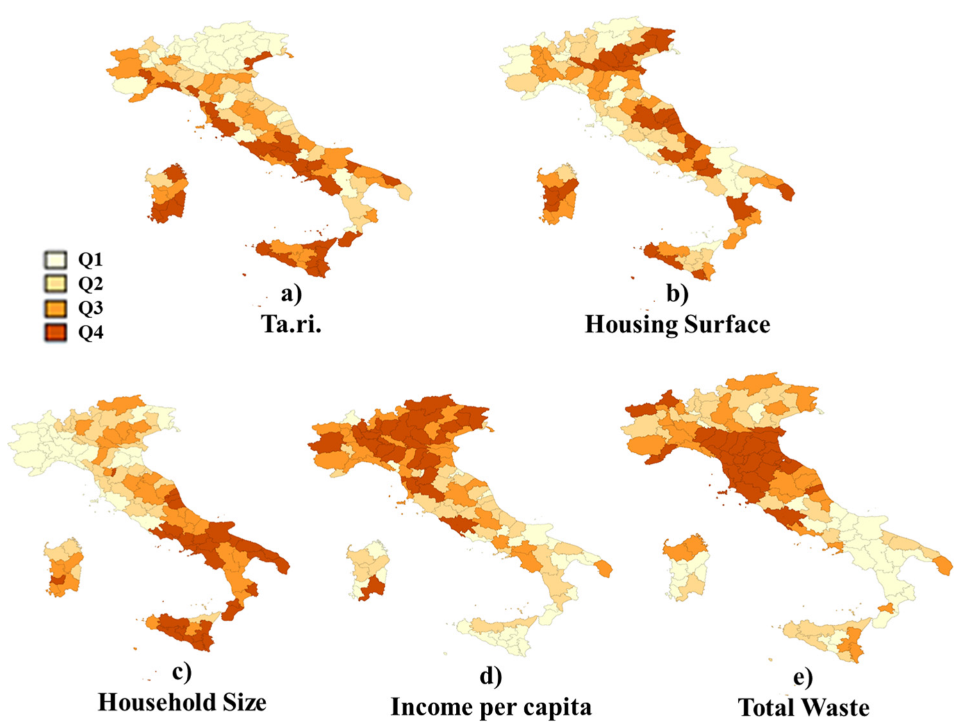

Fig. 2. Territorial distribution (provincial level) of variables by quantiles.

therefore allow to design and implement of a new, fairer, and more equitable tax, taking into account the fiscal capacity of each province, while responding to the polluter pays principle and acting like a Pigouvian tax. Last, it is useful to point out that the regressivity (progressivity) analysis of the taxation, at the provincial level, is carried out by analysing the taxation at the aggregate level and not by separating its single components (see the Gini index and the Lorenz curve in the next Section).

5. Empirical findings and discussions

The distinctive feature of the GWR model is the estimation of a set of local parameters for each province. However, in the first step of the analysis, the procedure estimates a global regression, similar to classic OLS, that produces an average parameter representative of all geographical units for each covariate. The results of the global regression, the standard deviation (between the global coefficient and the set of local ones), and the spatial variability controls are illustrated in Table 1.

Since Ta.ri. is a function of housing surface and household size, the results of the global regression confirm the expected relations. Once the global model is estimated, GWR allows to control for local relationships between the outcome variable and the regressors at each location. The model is based on adaptive gaussian Kernel, which is the optimal choice for the data used in this analysis (see Table A1 in the Appendix, for AIC_c, and log-likelihood values). Table 1 also shows the findings of the spatial variability test, which are of central interest to determine whether the GWR model is more suitable to describe the relationship patterns locally than OLS. The F-statistic indicates the presence of spatial variability for at least one regressor and it confirms that GWR and OLS estimates are significantly different (Fotheringham et al., 2003a,b). Once the existence of local pattern is established, we wonder which regressors vary across the space. Following Nakaya et al. (2016), we resort to an AIC_c-based comparison – known as 'Diff of Criterion' (third column in Table 1) – to assess the spatial variability of each regressor (see Section 3). We assume the existence of spatial heterogeneity for *housing surface* and *household size* because the statistical tests return the values of −2.621 and −2.565, respectively, both lower than −2 (so null hypothesis must be rejected, see Nakaya, 2015). The variability of the coefficients over space is due to the vast extent of provincial autonomy in setting the amount of the fixed, and variable components of the waste tax. Last, we perform a set of diagnostic tests on the residuals, in order to avoid inconsistent estimates. One problem concerns the distribution of the residuals, because GWR is not robust to outliers (Harris et al., 2010). The presence of outliers indeed may distort local parameter estimates. We resort to widely known statistical tests – for both OLS and GWR – that allow us to confirm the normal distribution (i.e. Jarque-Bera, and Shapiro-Wilk), and the homoscedasticity (i.e, Breusch-Pagan, and Koenker's studentised Bruesch-Pagan) of the residuals (see Table A1 in Appendix). In particular, the results of Koenker's studentised Bruesch-Pagan test – i.e., accept the null – suggest using the classic standard error and p-value rather than the robust ones to verify the statistical significance of coefficients. Moreover, the box plots shown in Fig. A2 (see Appendix) highlight that, unlike the global model, local regressions do not suffer from the presence of outliers in the error terms. In the OLS regression, an issue is the spatial autocorrelation in the error terms, which could lead to potential problems with inference, due to the underestimation of standard errors. As stated by Fotheringham et al. (2003a,b), GWR can be a suitable solution when OLS exhibits spatial autocorrelation in the residuals. To control for this issue, we calculate Moran's I for the residuals of the global, and local model (Table A1 in Appendix). The results show that the GWR removes the problem of spatial autocorrelation encountered in OLS. Finally, in the Appendix (Table A1 and Fig. A3) we report the local R^2_{adj} obtained by GWR. The goodness of fit deeply improved since it is 0.118 for the global model while it varies in the range 0.247–0.373 for the local regressions[6]. In other words, the spatial variability of the parameters, the normal distribution of the residuals, and the goodness of fit improvement strongly, while spatial autocorrelation is overcome, suggesting that local estimation must be preferred. Finally, for the estimation procedure (models, and diagnostic statistics) we have resorted to GWR4, Stata, Excel, and R software in their latest available version.

Table 1
GWR global model, variability, and spatial variability test (F test).

	Coefficient	Variability	Diff of Criterion
Housing surface (*hs*)	0.285 (0.107)***	0.1615	−2.621***
Household size (*fs*)	0.154 (0.075)**	0.2189	−2.565***
Intercept	0.582 (0.401)*	0.129	−1.297
F-statistic			4,829
N	108	–	–

*Significant at 10%, **Significant at 5%, ***Significant at 1%; Standard errors in brackets

The local parameters obtained by GWR are presented in Fig. 3**.** It shows, in sequence, the quartiles of the parameters of local regressions, and the statistical significance at 10%, 5%, and 1%.

The empirical findings highlight how the fixed component of the tax, linked to *housing surface*, has a higher magnitude on Ta.ri. in the provinces of Southern Italy with respect to the rest of country. Indeed, the presence of clusters of provinces belonging to the 3rd and 4th quantiles in the regions of Apulia, Calabria, and Sardinia (regions of Southern Italy) is clearly visible. Most of the provinces in these regions show a statistical significance at the 5% and 1% (Fig. 3**c–d**). This result is relevant, in that it confirms the inequity of the waste tax as it is designed, because it measures the value of buildings only thorough size, ignoring many factors that influence actual market value. In fact, as stated in Section 4, house location, maintenance conditions, neighbourhood safety, and the level of healthcare assistance available deeply influence the real value of buildings (see Appendix for details on the deprivation index for Italian regions). Since the current normative framework does not consider these factors, it creates the contradiction that in many deprived areas the amount of the tax is higher.

As regards the variable component of Ta.ri., linked to *household size*, it is a proxy of the waste produced in the areas. The results of the analysis highlight that the magnitude of household size is higher in the provinces of Central and Northern Italy, where the average number of household components is lower (Fig. 3). This finding does not sound strange, because the regression coefficient goes beyond the descriptive statistics (as the average household size is), but it is a measure of the average variation in the outcome variable when the regressor increases by one unit *ceteris paribus*. In other words, in Central and Northern Italy the amount of tax is more influenced by housing size than in Southern Italy. As a result, on the basis of Section 4, the variable component seems to be inadequate to measure the amount of waste produced, and the level of services effectively granted to tax-payers. An alternative formulation of the waste tax that considers the income level may lead to a more equitable tax. A wide body of literature stressed the relation between waste production, and income per capita (Hoornweg and Bhada-Tata, 2012; European Commission, 2012; Grover and Singh, 2014; ISPRA, 2017; Kaza et al., 2018).

On this basis, and following Messina et al. (2018), we propose an alternative Ta.ri. (see Eq. (6) in Section 3), in which income per capita (in replacement of household size) plays a pivotal role in the determination of a more equitable tax. As a first step, we calculate equivalent income through the equivalence scale of Coulter

[6] In addition to lin-lin model, we also implemented the log–log model that allows us to normalise the variables and improve the estimates. This model allows us to interpret coefficients as the elasticity of the outcome variable as compared to covariates. This procedure could improve the goodness of fit (R^2). In our case, the values of R^2_{adj} of log–log models (global and local) remain almost the same of lin-lin model. We do not report the values of log–log model in this paper because this does not add relevant information to our analysis.

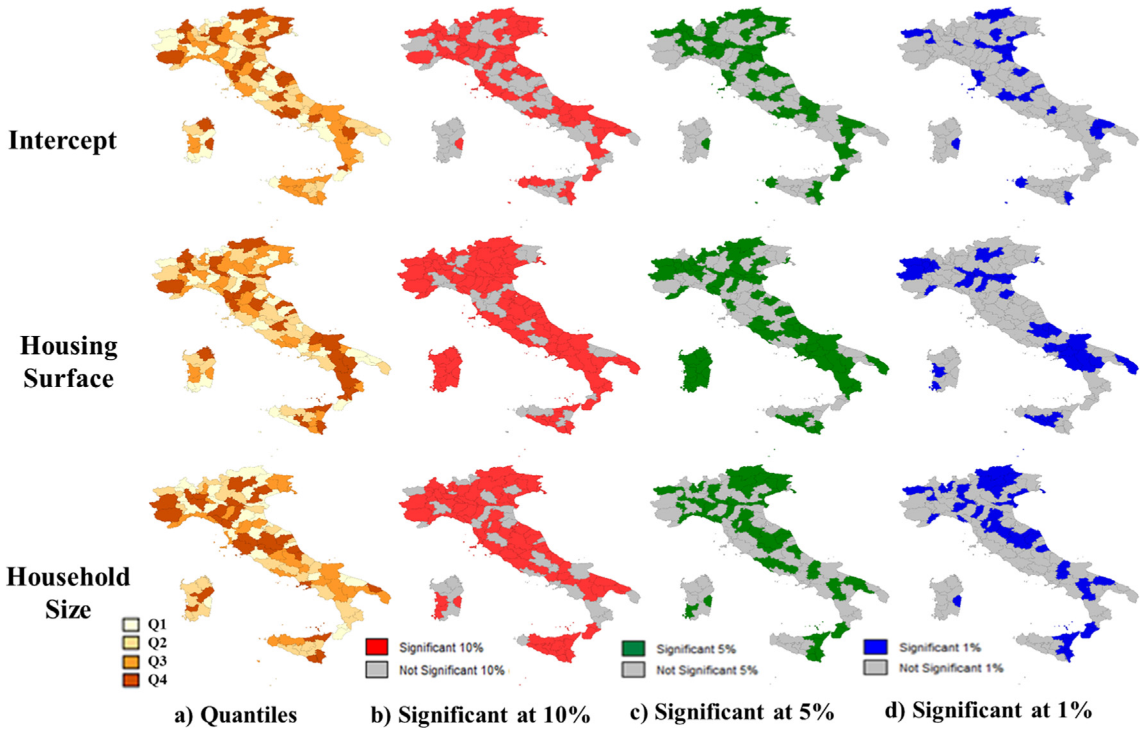

Fig. 3. Quantiles of coefficients (a), Significance level at 10% (b), at 5% (c), and at 1% (d).

et al. (1992), determining equivalised income as a ratio between income and the square root of the number of household members (i.e., $Y_{eq} = Y/\sqrt{N}$).

Messina et al. (2018) stated that the share of income destined to the payment of Ta.ri. is around 1%. Following this evidence, we consider this share of equivalised income in the alternative formulation of the tax. Then, by using the estimated GWR local parameters as fixed and variable components – a function of housing surface and income per capita, respectively – we obtain the alternative determination of Ta.ri., which is labelled '*alternative Ta.ri*' (Fig. 4).

Our results empirically confirm the inequal nature of Ta.ri. and its inability to levy resources proportionally to the wealth and waste production of the areas. In particular, as shown in Fig. 4**a**, the *Alternative Ta.ri.* would deeply change the territorial distribution of the tax burden. Based on the modifications in the computation of *Alternative Ta.ri.*, the provinces of Northern Italy, which are also the richest of the country, would bear a higher burden.

Fig. 4**b** depicts the difference between *Alternative Ta.ri.* and the *Ta.ri.* currently in force. This difference has a negative sign because *Alternative Ta.ri.* is generally lower than actual Ta.ri. and it can be interpreted as the redistribution that should be implemented in Italy. Since the more inequal the tax in a location, the higher the difference, at lower quantiles we have the provinces where the amount of Ta.ri. should be reduced the most. The difference between the two formulations of the Ta.ri. provides a picture of the redistributive policy that should be activated in Italy, with the richer provinces of the Northern Italy that should pay the higher amounts (i.e., areas belonging to Q3, and Q4 in Fig. 4**b**), while Southern and Central provinces would benefit the most from a formulation based on income levels. Moreover, we quantify the differences in terms of inequality through the Gini index, which amounts to 0.1533 for the current Ta.ri. and to 0.0798 for the alternative formulation. This point is shown graphically in Fig. 4**c**, where we overlap the Lorenz curve of the actual system (the blue line) with that of the alternative formulation (red line). The

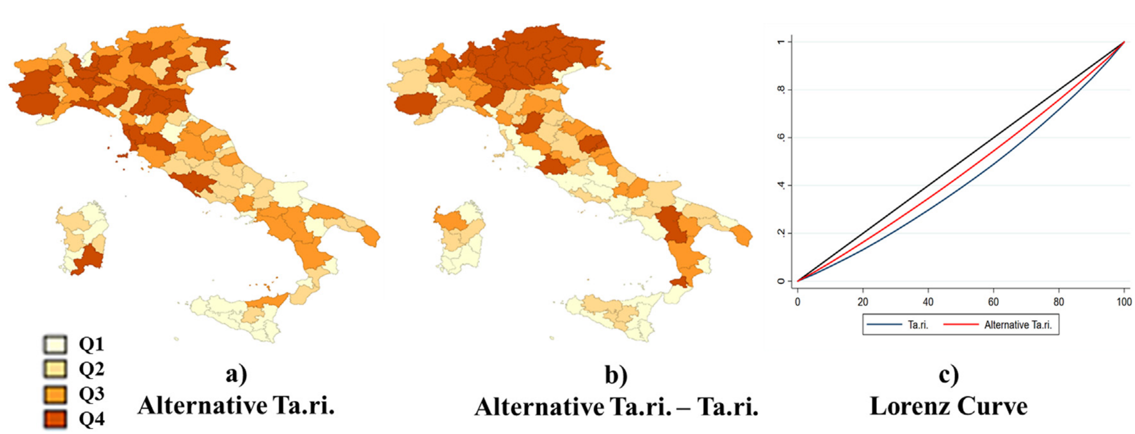

Fig. 4. Alternative Ta.ri. (a), Difference between Alternative Ta.ri. and Ta.ri. (b), Lorenz Curves (c).

analysis based on both the Gini index and the Lorenz curve proves how linking the tax to income would allow to take into greater account the fiscal capacity of each province, pursuing the path of fairness and equality.

Apparently, replacing the number of household members (variable part of the Ta.ri.) with per capita income reduces inequality in terms of taxation among Italian provinces. In reality, the inclusion of per capita income shifts the problem of inequality from Southern to Northern Italy. In fact, both tax formulations (i.e., Ta.ri in force, and Alternative Ta.ri) do not fully satisfy the equity for both the ability-to-pay and benefits principle. Ta.ri. is not calculated considering the real production of household waste. The problem of inequity of taxation on waste may be solved through a charging system based on consumption, such as PAYT schemes (Bucciol et al., 2011; 2015). The main innovation related to PAYT schemes lies in the possibility of saving on the waste bill. Thanks to this system, the amount of tax is no longer calculated only based on house size and household members (fixed part), but also on the quantity of non-differentiated waste produced. In particular, a variable component is added to the fixed component, according to the number of bins containing undifferentiated waste. The link between waste production and the amount to be paid in the PAYT system is very clear. PAYT schemes, in addition to ensuring greater equity, represent an incentive to separate waste collection, as a lower sorting fee is associated with a more intense sorting activity. Analyses conducted on the municipalities of the Veneto region (see Bucciol et al., 2014) show that the municipalities that have adopted a PAYT tariff display a separate waste collection that is 45% higher than the municipalities resorting to flat-fees (such as Ta.ri.).

In summary, until local authorities adopt instruments that allow to measure the quantity of waste produced by each user-payer and link this it to the fee paid (as in PAYT schemes), it is desirable to consider income as a base for the variable component of the waste tax (proxy for consumption and contribution capacity of a citizen). This base makes it possible to address the distributional impact issue of the current tax system. As shown, the current system is regressive because the applied tax imposes a heavier financial burden on low-income households than on higher-income households.

6. Limitations and robustness analysis

The goal of our paper has more to do with accounting than with empirics. From an accounting point of view, the analysis conducted using GWR aimed to determine statistically the magnitude of the fixed and variable component of Ta.ri. for each province – and not their average magnitude, which can be obtained running OLS. This result has been reached by considering only two covariates (tax bases) which are set by law for the whole national territory. On the one hand, this solves the accounting problem that we have set ourselves, but on the other hand, it does not solve the empirical problem. In fact, the aim of this study is not to show how well independent variables can predict the values of Ta.ri. variable.

From an empirical point of view, concerns arise since the parameters estimates associated with the two regressors might be affected by the omission of relevant variables[7]; moreover, a low R^2 values could reinforce this potential concerns. If an R^2 of 0.35 emerges in a locality, it is possible to conclude that in that area the fixed and the variable components explain only 35% of the variability of Ta.ri., while the remaining 65% can be explained by other omitted characteristics. For instance, for each location, the amount of Ta.ri. may be conditioned by the quality of municipal institutions, by the ability of local administrators, and so on.

From an accounting point of view, instead, this apparent empirical limit is a useful way of gathering relevant information on the magnitude of the Ta.ri distortion for each geographical area. The study has also investigated compared across provinces the tax structure which, according to law, does not admit other regressors than those taken into consideration (i.e., housing surface and household size). A low R^2 value can be attributed to variables (tax bases) that are not a good proxies of waste production. This is true not only for waste production but also for all the variables that contribute to the formation of the total cost of waste services that Ta.ri should be covered (e.g., waste collection methods, distance between the municipality and the plants, percentage of municipal waste treated and disposed of in regional plants). A well-designed system should guarantee full-cost coverage, in order to avoid resorting to general taxation (cost recovery principle) and introduce a quantity-based charge system, more closely related to the 'polluter pays' principle. However, these goals seem to have been disregarded, due to the tax structure. On the basis of these considerations, from an accounting perspective, it can be stated that a R^2 value can be interpreted as an indicator of the improper use of the Ta.ri at the local level, (i.e., designed more as a property tax than a quantity-based charge system). Its structure generates distortion not only in terms of equity but also in terms of allocative efficiency (waste production). As a consequence, the tax seems too far away from a negative incentive system (as a PYT) and more similar to a property tax.

Moving from the accounting to the empirical point of view, our estimates have highlighted the presence of unobserved characteristics, suggesting how the *hs*, and *fs* explain only in part the amount of tax. To test whether the presence of unobservable is a limit of our empirical strategy (based on the GWR model), or simply an element of the definition of the Ta.ri. set by Italian Law, we estimate other spatial econometric models, namely the Spatial Autoregressive model (SAR), the Spatial Error Model (SEM), and the Spatial Autoregressive Combined model (SAC). Estimating these models partly solves the problem of omitted relevant variables.

The SAR model assumes that spatial dependence materialises through the dependent variable Y (Anselin, 1988):

$$Y = \alpha + \rho WY + X\beta + \varepsilon \tag{7}$$

where ρ is the autoregressive spatial coefficient, and *WY* is the spatially lagged variable. As a reminder, Y is the vector of dependent variable, X is the matrix of explanatory variables, α and β are the vector of parameters, and ε is the random error term. The SEM model assumes the presence of spatial dependence in the error term (Anselin, 1988):

$$Y = X\beta + \lambda W\varepsilon + \varepsilon \tag{8}$$

where λ is the spatial dependence coefficient, and $W\varepsilon$ represents the spatially lagged error term. Finally, the SAC model is a combination of SAR and SEM, allowing for spatial dependence in both the dependent variable and the error term (Anselin, 1988):

$$Y = \alpha + \rho WY + X\beta + \lambda W\varepsilon + \varepsilon \tag{9}$$

Since we estimate these models for robustness check aims, we refer to other authors (Anselin, 1988; 2001; LeSage and Pace, 2010; Elhorst, 2010) for the methodological details. Table 2 shows the estimates – obtained through the maximum likelihood – as well as the main diagnostic tests. The SAR(1), SEM(1), and SAC(1) columns present the model with *hs* and *fs* covariates, as set by current Italian Law currently. The SAR(2), SEM(2), and SAC(2) columns present the estimation of the alternative tax we have proposed

[7] The addition of relevant variables in the regression analysis could reduce the magnitude and significance of the parameters associated with the fixed, and variable component.

Table 2
Robustness check, SAR, SEM, and SAC models.

	SAR(1)	SAR(2)	SEM(1)	SEM(2)	SAC(1)	SAC(2)
Housing surface (*hs*)	0.287*** (0.101)	0.467** (0.221)	0.343*** (0.111)	0.234** (0.104)	0.275*** (0.088)	0.135* (0.079)
Household size (*fs*)	0.133*** (0.045)	–	0.0.173*** (0.061)	–	0.124** (0.057)	–
Income per capita (*ipc*)	–	0.064*** (0.023)	–	0.051*** (0.011)	–	0.058*** (0.012)
Intercept	1.185 (1.097)	1.261*** (0.303)	2.135 (1.442)	6.353*** (1.261)	1.115 (0.832)	6.096 (2.187)
ρ	0.459*** (0.096)	0.424*** (0.100)	–	–	0.517* (0.306)	0.057*** (0.116)
λ	–	–	0.471*** (0.098)	0.447*** (0.101)	0.574* (0.297)	0.606*** (0.132)
R^2_{adj}	0.325	0.302	0.326	0.288	0.339	0.295
Jarque-Bera (*p-value*)	0.018	0.022	0.015	0.001	0.248	0.249
Shapiro-Wilk (*p-value*)	0.041	0.003	0.013	0.001	0.299	0.516
Breusch-Pagan (*p-value*)	0.267	0.855	0.169	0.647	0.426	0.476
Studentized Breusch-Pagan (*p-value*)	0.161	0.657	0.096	0.449	0.133	0.145
AIC	6,251.26	6,253.91	6,249.45	6,254.75	6,211.76	6,211.98
Log-likelihood	5,621.632	5,622.956	5,621.724	5,624.376	5,601.881	5,601.988
Likelehood Ratio (*p-value*)	0.000	0.000	0.000	0.000	0.000	0.000
N	108	108	108	108	108	108

* Significant at 10%, **Significant at 5%, ***Significant at 1%; Standard errors in brackets.

(i.e., replacing *fs* with *ipc*). Controlling for other spatial econometric methods allow us to test whether the sign and the statistical significance of the covariates persist after the introduction of spatial dependence. What emerges from all the models estimated is a robustness of the GWR results, since the covariates are still significant although significant spatial dependence patterns also emerge.

The diagnostic tests provide interesting insights. While GWR returns residuals featuring a normal distribution, the SAR and SEM models generate non-normal residuals, as shown by the Jarque-Bera, and Shapiro-Wilk tests. On contrary, in the SAC model, these tests fail to reject the null hypothesis of normal distribution. Regarding the homoscedasticity of residuals, we assess it using the Breusch-Pagan, and Koenker's studentised Breusch-Pagan tests. All the models present this characteristic, just as it was for GWR. The goodness of fit is measured through the R^2_{adj}. It presents values ranging in the 0.30–0.33 interval, highlighting that only up to 33% of the variability of the dependent variable has been accounted for, in line with the GWR results. According to the AIC criterion, SAC is the model that best fits the data. However, the likelihood ratio test shows the persistence of spatial dependence in all the models estimated, highlighting the persistence of some unobserved process, even after the control for autoregressive and error term spatial dependence. Finally, for the estimation of models and the tests, we have used several software in the latest versions available, namely Geoda, Stata, Excel, and R.

In summary, the robustness checks do not reveal that one model should be strongly preferred. SAC seems to provide the best estimation (with respect to SAR and SEM), but this model captures only an average relationship. However, it is not the aim of our work to estimate an average relationship, given the high spatial heterogeneity set by Italian Law in defining Ta.ri. amounts. In other words, the SAC model fails to determine the effects of the fixed and variable components of the tax for each province (it only returns an average across all the provinces) and it fails to capture the territorial inequalities generated by the tax. Thus, while GWR represents the proper model (if not the only one) to cope with the accounting basis of this paper, the robustness checks show that it also returns robust econometric results, in line with the other spatial econometric models.

7. Concluding remarks

Regulatory instability and heterogeneity in the application of the rules on waste management characterise the Italian context and make it a very interesting case study. The empirical analysis on current waste taxation highlights the limits related to its definition and quantification. Furthermore, Ta.ri. turns out to be critical even in terms of equity. Even by acting on the variable part of the waste taxation, the problem of inequality is not solved. On the contrary, it is moved from one area of the country to another.

The only way to solve the problems related to the Ta.ri., improving equity and favouring greater citizen participation, seems to be – given the positive results recorded in some municipalities in Italy (see Bucciol et al., 2015) – the usage of a Pay-As-You-Throw scheme. Although technological innovation has facilitated the transition to these waste management systems, their diffusion in Italy is still confined to a few municipalities. The latest ISPRA report identifies 102 municipalities that have adopted a PAYT scheme. These are small towns (almost all numbering less than 10,000 inhabitants), mainly located in Trentino Alto Adige-South Tyrol, Veneto, Emilia-Romagna, and Lombardy. The ISPRA survey confirms that the adoption of the PAYT scheme triggers a virtuous waste cycle, characterised by a significant increase in the proportion of sorted and recycled waste, with obvious advantages in terms of overall costs of the waste management service. In particular, compared to the municipalities of the same region that apply the Ta.ri., the municipalities that adopt the PAYT tariff record a cost reduction of over 20% in Veneto, of about 9% in Emilia-Romagna, of 7% in Trentino-South Tyrol, and 3.4% in Lombardy. Furthermore, in the municipalities that apply this scheme, the per capita amount of unsorted waste is significantly lower.

Since this work is one of the first attempts to propose an alternative formulation of waste tax, future studies are encouraged. A further step is to perform analyses at finer territorial detail by using municipal data. this kind of studies may be especially interesting in light of the Italian waste management regulations (i.e., Legislative Decrees 22/1997, and 152/2006). They set the administrative responsibilities and identify municipalities as the units bearing the administrative autonomy to formulate plans to find the funds necessary to cover the costs of municipal waste management. Unfortunately, at this stage municipal data are scarce. When they will be available, this could be a remarkable research extension. Another future strand of possible research concerns cross countries comparison, so as to investigate the effect of waste tax on inequality under different fiscal regimes.

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

A1. Deprivation index

The method used to develop the deprivation index (DI) is based on the "*Method of Penalties by Coefficient of Variation*" (MPI) (Mazziotta and Pareto, 2016). The MPI is designed on a non-linear function introducing a penalty for the units with unbalanced values of the elementary indicators. From a computational point of view, the procedure starts by calculating the matrix $Z = \{z_{ij}\}$ of the standardised observed values as follow:

Table A1
Diagnostic tests of residuals and goodness of fit of regressions. OLS and GWR.

Test	OLS		GWR	
	p-value	Test result	*p*-value	Test result
Jarque-Bera	0.134	Accept H_o	0.314	Accept H_o
Shapiro-Wilk	0.119	Accept H_0	0.205	Accept H_o
Breusch-Pagan	0.631	Accept H_0	0.75	Accept H_o
Studentized Breusch-Pagan	0.558	Accept H_0	0.704	Accept H_o
Moran'I	0.355	Accept H_0	0.078	Accept H_0
(*p-value*)	(0.001)		(0.088)	
R^2_{adj}	0.118		Range: 0.247–0.373	
AIC_c	6,151.508		Fixed Gaussian	6,107.586
			Adaptive Gaussian	6,090.085
Log-likelihood	5,994.042		Fixed Gaussian	6,053.542
			Adaptive Gaussian	6,139.353

Notes: Jarque-Bera, and Shapiro-Wilk are tests for error normality; Breusch-Pagan, and Studentized Breusch-Pagan controls for homoskedasticity; Moran'I measures spatial autocorrelation; R^2_{adj} is the coefficient of determination for the regression's goodness of fit.

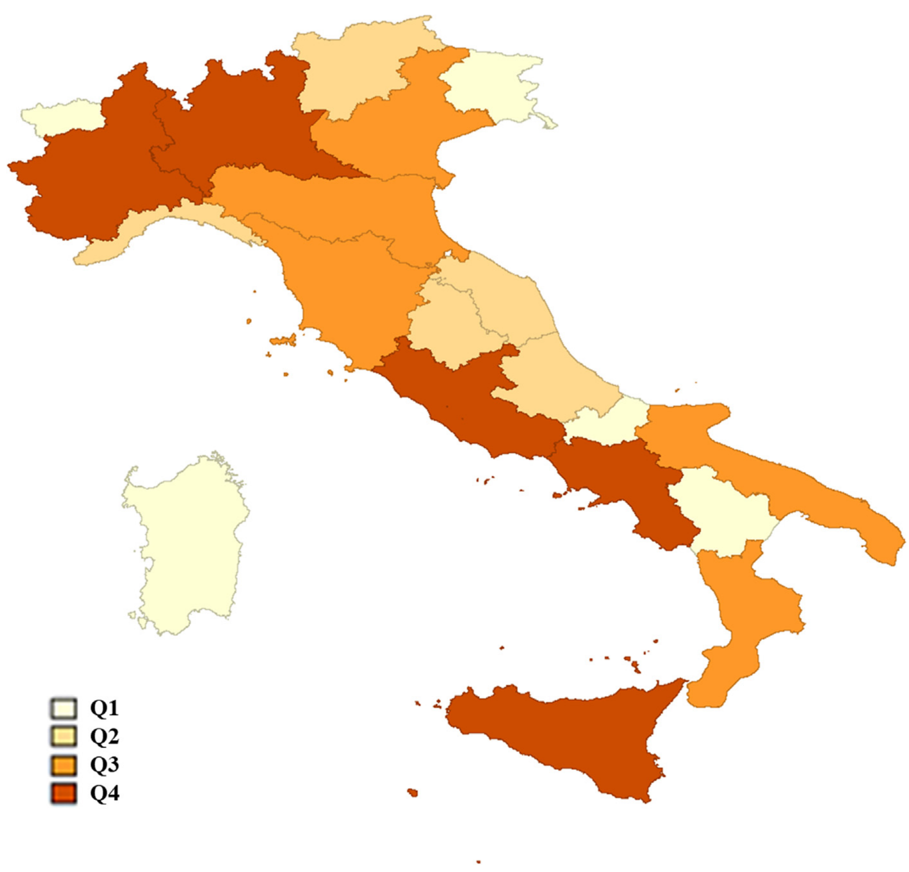

Fig. A1. Territorial distribution (regional level) of Deprivation index.

$$z_{ij} = 100 \pm \frac{\left(x_{ij} - M_{x_j}\right)}{S_{x_j}} * 10 \quad (10)$$

where $M_{x_j} = \frac{1}{n}\sum_{i=1}^{n} x_{ij}$ and $S_{x_j} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(x_{ij} - M_{x_j}\right)^2}$ are the mean and the standard deviation of indicator j, respectively. The sign $\pm$ in the equation represents the polarity of elementary indicator j. In detail, if an indicator is a positive dimension, then the sign is positive; it is negative otherwise. Finally, n is the number of units involved into the analysis (i.e., the 20 regions of Italy for the deprivation index). The MPI also captures variability within units (the so-called *horizontal variability* that, in our study, consists in the variability within the regions of Italy). The procedure calculates the mean, the standard deviation, and the variation coefficient of the standardised values of unit i:

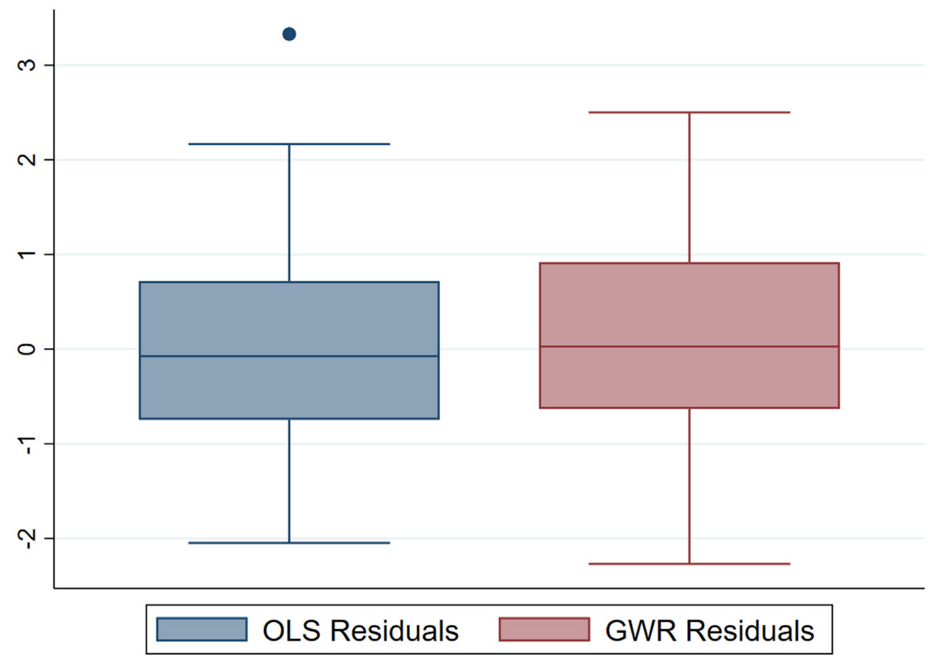

Fig. A2. Box plots of standardized residuals for OLS and GWR.

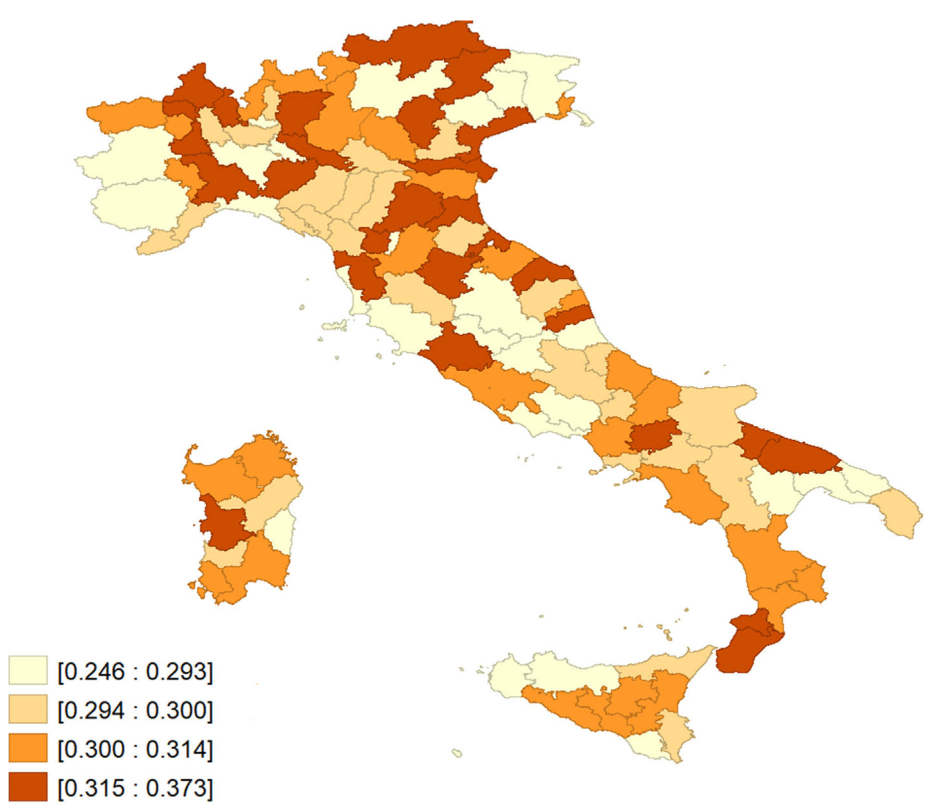

Fig. A3. Adjusted R^2, local regressions.

$$M_{z_i} = \frac{1}{m}\sum_{j=1}^{m} z_{ij}; S_{z_i} = \sqrt{\frac{1}{m}\sum_{j=1}^{m}\left(z_{ij} - M_{z_i}\right)^2}; cv_{z_i} = \frac{S_{z_i}}{M_{z_i}} \quad (11)$$

where m represents the numbers of elementary indicators. The MPI is defined as follows:

$$MPI_i = M_{z_i} \pm S_{z_i} cv_{z_i} \quad (12)$$

As shown in equation (3), for each unit i, the MPI is composed by two parts: *i)* the mean level (M_{z_i}) and *ii)* the penalty ($S_{z_i} cv_{z_i}$). The penalty component decreases the score attached to units with a high level of variability among elementary indicators and its aim is to reward the units featuring greater balance (Mazziotta and Pareto, 2016). Regarding the sign $\pm$, it depends on the type of phenomenon measured. If the MPI is positive (i.e., positive variations of the phenomenon are associated to positive variations of index), then the negative sign is used because the penalty component smooths the value of the indicator pushing it downwards. Conversely, the positive sign in equation (3) is used with negative MPI (i.e., the index varies negatively for negative variations of the phenomenon).

The deprivation index that we developed is obtained considering five pillars: *i)* crime level; *ii)* overcrowding; *iii)* lack of shops nearby; *iv)* healthcare level; *v)* level of citizen services. In particular, we consider the first three dimensions as negative factors which increase deprivation, while both services provided to citizens and healthcare feature a positive polarity. The data are provided by ISTAT and they refer to 2017. Due to the lack of data at the provincial level, we use regional data. Fig. A1 depicts the territorial distribution of the deprivation index. The results highlight how the housing surface does not fully capture the real value of buildings. While Southern regions (in particular, Lazio, Campania, and Sicily) are indeed those displaying the highest extent of housing surface, they also feature the highest level of deprivation. This corroborates the assumption that the housing surface is a biased proxy for the wealth of a location.

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