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Waste generation and landfill diversion dynamics: decentralised management and spatial effects

An analysis of economic and policy transitions

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Abstract

This paper provides analyses of municipal waste generation and landfill diversion dynamics based on a 8-years panel dataset for Italy covering 103 provinces. Although absolute declining for waste generation is a long way off, there are some first signals of increasing relative delinking and robust average landfill diversion. Spatial effects seem to be negligible, probably due to the strong decentralisation of waste management and policies: local, economic, policy and structural factors contribute to explaining the waste dynamics. Though North-South waste performances are showing some signals of convergence, greater efforts towards convergence of waste performances in a decentralised policy scenario are needed.

Keywords: waste generation, waste management, landfill diversion, decentralised waste policies, landfill tax, separated collection, spatial effects, convergence

JEL classification: C23, Q38, Q56

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1. Introduction

Indicators of ‘decoupling/delinking’ are used to measure improvements in environmental/resource efficiency with respect to economic activity. The European Union’s (EU) ‘thematic strategies’ on resources and waste, include reference to ‘absolute’ and ‘relative’ delinking indicators (European Commission, 2003a,b; Jacobsen et al., 2004), the former being a negative relationship between economic growth and environmental impacts while the latter being a positive but decreasing in size relationship. The achievement of some degree delinking is of prime importance for waste (Figure 1), given that the EU evidence (EEA, 2009) shows an absence of even relative delinking (for illustrative purposes see also Figure 2). The European Environmental Agency (EEA, 2007) acknowledges that volumes in the EU are growing, driven by changing production and consumption patterns (see also Andersen *et al.*, 2007), and highlights (EEA, 2006) the importance of flexible implementation of market-based instruments, within a decentralised approach to environmental policy in the EU, to achieve a stronger degree of delinking in (regionally decentralised) waste indicators. Policy endogeneity and spatial phenomena are interrelated and are very important for achieving waste targets thorough effective (diffusion) of policies in the territory. In this paper we address these aspects as key elements in the assessment of delinking and policy effectiveness, which are intertwined in the decentralised policy settings typical of the EU and the US. Italy is a country with high levels of decentralisation in environmental policy making, which is moving towards an even stronger federal set up; moreover it is characterised by major income differences between its northern and southern regions, and historically quite different economic and environmental performance. Divergence or convergence in current and future waste performances is a key issue that is receiving renewed attention since the collapse in 2008-2009, of the waste managements schemes (both practically and financially) in Naples and Palermo.¹ This issue is of great interest given that on the one hand countries are monitored and valued on the basis of their national average performance, and on the other hand that regional system collapses are covered

financially by national taxes. Italy also may provide an interesting case study for informing policy and waste management schemes in other highly decentralised and heterogeneous environmentsⁱⁱ.

Figure 1 : The income–environment relationship

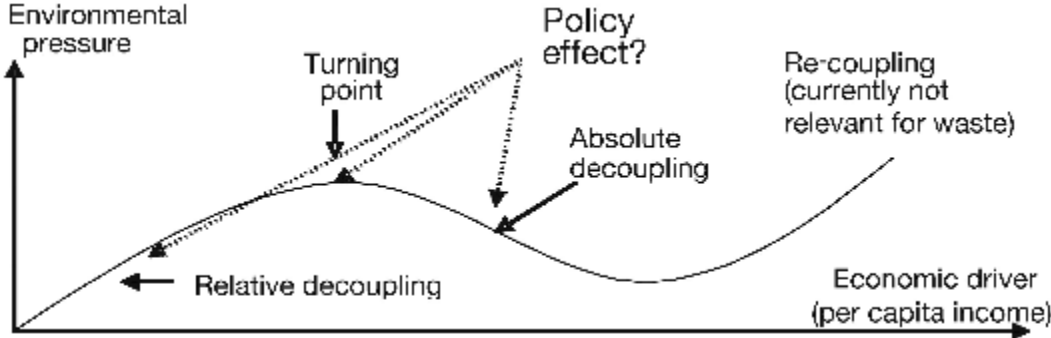
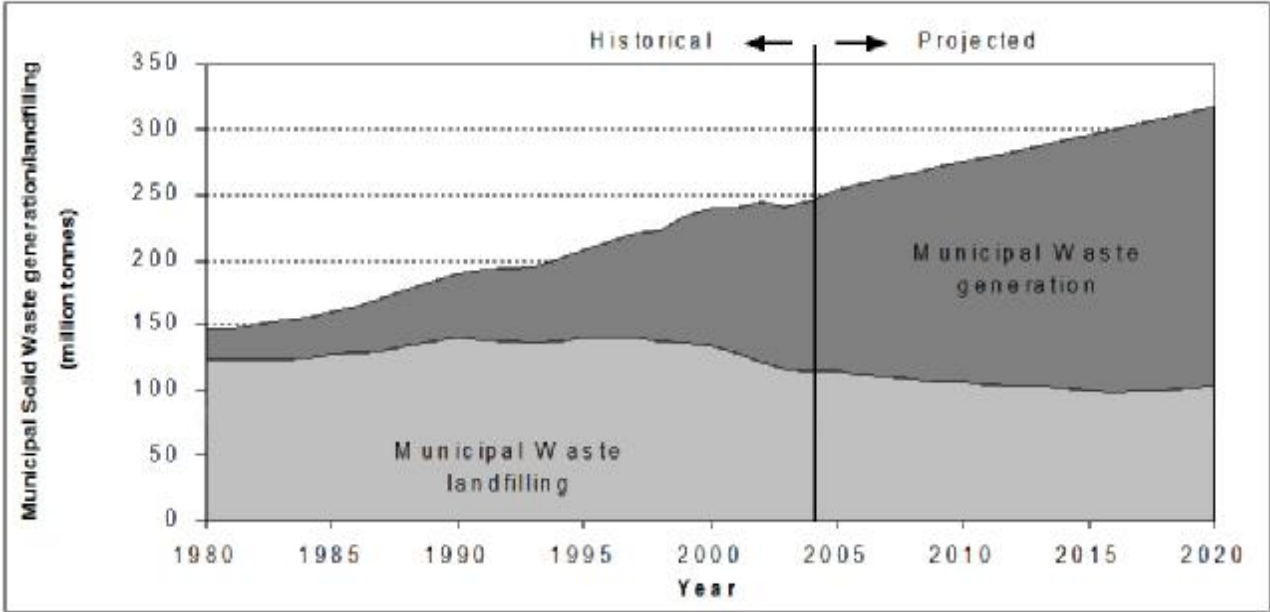


Figure 2: Projected generation and landfilling of municipal waste in the EU25



Source: EEA (2007), Figures from 1980-2004 are data from Eurostat. Figures from 2005-2020 are projections. BMW (Bio degradable Municipal waste)

Theoretically, policy decentralisation may have a positive effect on waste generation via reduction and better waste management performance, based on greater flexibility and specificity in policy implementation, which may be able to take account of local idiosyncratic costs and benefits related to policy (Pearce, 2004). Although decentralisation may improve policy implementation in the EU, including policies for waste prevention, it may have some drawbacks in terms of exploitation of local rents by public and private agents. In principle, rents are neither good nor bad in the environmental

realm. What matters are their effects on static and dynamic elements such as value creation and innovation. Waste ‘markets’, such as land-filling and even recycling, may be associated with rents that could lock a local system in to less than optimal equilibrium. This aspect requires further research.

The high heterogeneity of income and environmental performance makes it necessary to study the dynamic evolution of policy implementation and spatial dependence regarding the waste trends that emerge at regional and provincial levels. In this paper we focus on the provincial level, exploiting socio-economic and environmental data for a large number of provinces (103), over a fairly long dynamic path (8 years), from 1999 to 2006, where there has been drastic change in municipal waste policies and waste management.

Figure 3. Landfilled waste per area in Italian provinces (tons per km², 2006)

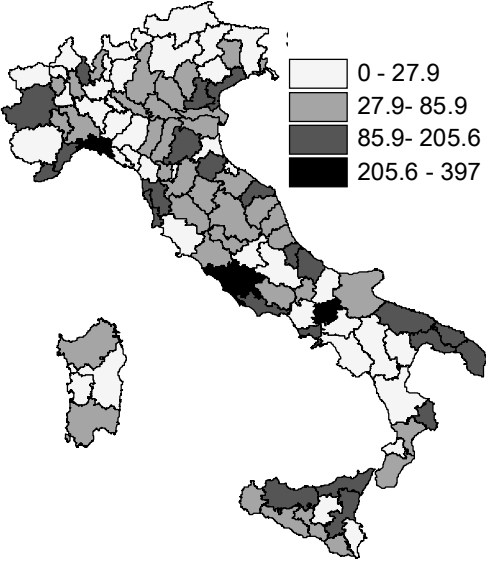
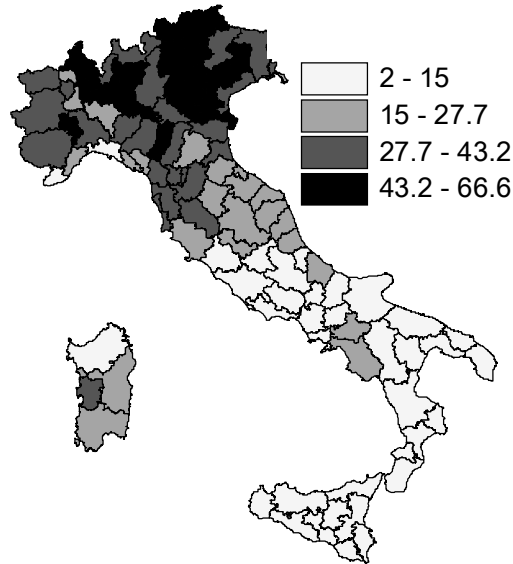


Figure 4. Share of separate collection in Italian provinces (% , 2006)



The paper is structured as follows. Section 2 discusses the relevant literature, highlighting works that deal with delinking, policy effectiveness and spatial analyses. Section 3 presents the research hypotheses, the empirical model and the data source. Section 4 discusses the panel regression results for waste generation and landfill diversion, and then presents the tests for potential spatial correlation. Section 5 concludes, offering policy recommendations for effective decentralised management of waste.

2. The relevant literature

Despite the environmental, policy and economic significance of waste issues, there is very little empirical evidence on delinking, even for major waste streams such as the municipal one and packaging. Analyses of policy effectiveness are similarly scarce. Existing work is largely oriented towards the optimisation of waste management or evaluation of externalities, regarding landfill and

other waste disposal strategies, with a very few purely theoretical analyses of waste management and landfill management (Calcott and Walls, 2005; Daskalopoulos et al., 1998; Andre and Cerda, 2004; Ozawa, 2005). The stronger focus on cost benefit analyses of specific waste streams and policy packages (Pearce, 2004), and landfill siting decisions aimed at resolving the NIMBY (not in my backyard) problem (Quah and Yong, 2007), in part is due to lack of reliable panel data, which is extremely scarce at sub-country level.

Some macro level evidence, based on cross country regression analysis of data from the 1980s, is presented in World Bank (1992). More recent reports (DEFRA/DTI, 2003) provide evidence of positive elasticities between waste generation and income being of primary policy concern. Waste generation seems still to be characterised by a strict relationship between economic drivers and environmental pressures.

A study by Cole et al. (1997) finds no evidence of an inverted U-shape in relation to municipal waste. Cole and colleagues use data on municipal waste for the period 1975-90, for 13 OECD countries; their findings revealed no turning point (TP), and they find environmental indicators (municipal waste generation) monotonically increasing with income over the observed range. Similarly, Seppala et al. (2001), in a study of five industrialised countries including Japan, the US and Germany, and covering a similar period (1970-1994), find no evidence of delinking regarding direct material flows too. However, Fischer-Kowalski and Amann (2001), analysing the richer OECD countries, find that the intensity of material input with respect to GDP shows relative, but not absolute delinking, with material growth over 1975-1995 for all countries. They note that absolute delinking holds for landfilled waste, but not for waste generated.

There is some evidence of delinking. For example, Leigh (2004), which uses a waste/consumption indicator derived from the environmental sustainability indexes (ESI), and Berrens et al. (1998) and Wang et al. (1998), who find evidence of a negative elasticity for US stocks of hazardous waste as an environmental impact indicator, based on a county-based cross sectional dataset.

A study by Johnstone and Labonne (2004) uses panel data on solid waste in the OECD countries to provide evidence on the economic and demographic determinants of rates of household solid waste generation, regressed over consumption expenditure, urbanisation and population density. They find positive elasticities, but lower than 1, in the range 0.15 to 0.69. Few studies include waste policy analyses. The study by Karousakis (2006), which deals with policy evaluation, presents evidence on the determinants of waste generation and the driving forces behind the proportions of paper/glass recycled, and the proportion of waste that goes to land-fill. She finds for OECD that municipal solid waste (MSW) increases monotonically with income and that urbanisation exerts an even stronger effect on waste generation, while the time-invariant policy index is not significant. At country level, Mazzanti et al (2008) analyze waste generation dynamics, showing that only the richest provinces are close to a turning point in the waste income relationship, with strong north south gaps and an effective role of waste management systems like tariffs, which are nevertheless associated to endogeneity with respect to income.

Mazzanti and Zoboli (2009), based on panel data for a group of European countries, finds also neither absolute nor relative delinking, for municipal or packaging waste for 1995-2000 and 1997-2000 respectively. Estimated elasticities of waste generation with respect to household consumption are close to unity.

In terms of the main landfill oriented works, the focus, as already indicated, has been on cost-benefit analyses and landfill siting decisions, due in part to the lack of reliable country level and within country data (Pearce, 2004). Some scholars have attempted to evaluate the EU landfill Directive and the implementation in the UK of a landfill tax in 1996. Some of this work is informed by a specific evaluation of the externalities. Given the lack of hard data, these studies present interesting but only qualitative assessments. During the first phase of the UK landfill tax implementation, Morris et al. (1998) investigated its potential contribution to sustainable waste management, analysing its general structure, comparative landfill costs and the waste hierarchy. Morris and Read (2001), Burnley (2001), Davies and Doble (2004) provide additional qualitative

evidence. Phillips et al. (2007) is a UK specific regional assessment of waste strategies, but regional based analyses are still rare.

The works discussed above sometimes touch on the spatial (dependence) factors that may impact on environmental performance spatial phenomena, have been prominent in analyses of waste siting (Jenkins et al., 2004; Miranda et al., 2000; Ley et al., 2002). This rather specific stream of waste-related works includes studies of mainly Scandinavian and UK experience, due mostly to the lack of data for most countries. Hage et al. (2008) investigate the main drivers of rates of collection of household plastic packaging waste in certain Swedish municipalities, using spatial econometrics for a cross section of 282 units. They find that spatial issues (collection is positively correlated for neighbouring municipalities) and policy levers (weight based waste fees), are relevant (see also Hage et al., 2009; Hage 2008). Our analysis is much more general; it focuses on an entire country and 103 provinces rather than a sample of municipalities, and covers a quite long period. This enables better integration of economic, environmental, policy and spatial issues in a more dynamic scenario.

The literature on waste determinants referred to above, underlines that waste indicators generally tend to increase with income or other economic drivers such as population, and that, in general, full delinking is not supported by the data. A decreasing trend (negative elasticity) may be found in industrialised countries where waste management and policies are more developed. Nevertheless, the risk is that bell shapes (absolute delinking) are associated with only a few rich countries or areas, and can be divisive in terms of countries' waste performance indicators (Mazzanti and Montini, 2009).

3. Research hypotheses and data sources

In order to embed waste generation and landfill diversion dynamics in socio-economic, geographic and policy regional contexts we exploit a rich vector of explanatory variables that enhance the conceptual model that is used for applied investigations of delinking (Dijkgraaf and Gradus, 2004, 2008; Cole et al., 1997). We here summarise the hypotheses with respect to landfill diversion and

waste generation in terms of the expected signs of the coefficients of the explanatory variables, and offer a descriptive sketch of the variables.

First, we verify delinking and the eventual non-linearity (bell shape) in the income-waste relationship. For waste generation, we expect either a linear relationship with eventual relative delinking, or a (to our knowledge never found) a reasonable TP. In the case of landfill diversion, since in the EU and Italy a decreasing trend started in 1995-1997, we expect either a negative relationship, or a U shape if performance has deteriorated.

Second, we examine the expected effects of socio-economic and structural variables, mainly population density and tourist flows. Population density may be negatively or positively linked to waste generation. We would expect to find the latter effect, especially based on the findings in the literature. In more densely populated areas, only economies of scale spurred by urbanisation could invert this trend and reduce waste generation. Regarding landfill diversion, we definitely expect a negative linking, on the basis of the studies reviewed above, and on the joint role of higher economic opportunity costs of land and harsher environmental externalities in urban areas. Tourist flows per capita are a nice structural control for countries like Italy. Waste generation could be spurred by tourist flows. However, we could also expect that in the most popular tourist areas, diversion might be driven down in favour of incineration or recycling for the same reasons as in the case of population density, that is, high local economic and environmental opportunity costs.

Third, we check the role of decentralised policy-related variables. In both cases (waste generation and landfill diversion), we expect policy variables to drive down the income-environment relationship. Recent work shows that policy endogeneity with respect to income needs to be considered and could lead – at least in the short run - to a positive correlation between policy stringency and waste performance, mediated by income. The waste management/policy proxies considered are: (a) share of separately collected waste, which we consider to be a policy element associated with waste management; (b) share of provincial municipalities and provincial population affected by the new ‘waste tariff’ regime, which replaces the previous ‘waste tax’ regime.ⁱⁱⁱ The tariff

should move waste management towards full-cost pricing/polluter pays principle (PPP) based system;^{iv} (c) percentage of waste management costs covered by the tariff; and (d) main environmental tax in the waste realm, the landfill tax, implemented at regional level in Italy.

Fourth, in the landfill diversion analyses we control for provincial ‘investment choices’ in landfill and incineration, by including incinerated waste per capita and number of landfill sites per area (km^2), and number of incineration plants per area (km^2). We aim to test for the existence of lock in dynamic effects when a province decides to invest in a single main disposal option.

Finally, we implement a proper spatial analysis to test for the spatial autocorrelation of waste generation and landfill diversion at provincial level, by setting up contiguity and distance weight matrixes (see Section 4.2). We investigate three short time periods (1999-2000, 2002-2003 and 2005-2006], to verify whether spatial correlation is relevant and if its eventual presence and effect on waste drivers has changed over time. This test has some methodological and policy implications. The absence of a clear spatial correlation could be interpreted as lack of policy cooperation within a regional area with similar income levels, with single provinces behaving independently as far as waste policy implementation is concerned. This evidence should be taken in conjunction with evidence on the performance of the entire system and that of regional subsystems, since spatially correlated performance data are not preferable to non-correlated performance data.

Table 1: Descriptive analysis and research hypothesis

Acronym	Variable description	Mean	Min	Max	Research hypothesis
MSW-GEN	MSW yearly generated (kg per capita)	520.28	251.91	893.24	Dependent variable
LAND-WASTE	MSW yearly generated and landfilled (kg per capita)	325.4	0	1898.47	Dependent variable
VA	Provincial yearly value added per capita (€2000)	17,718.22	9,369.12	28,796.07	Positively correlated with income, the objective is assessing whether relative or absolute delinking is present
DENSITY	Population/surface (inhabitants/km ²)	244.76	22.99	2,640.92	Positive and negative correlations may emerge depending on factors such as economies of scale and land opportunity costs in urban and densely inhabited areas
SEP-COLLECT	Share of separated collection (%)	19.32	0.03	67.57	Negatively affecting landfilled waste per capita
TOURISM	Annual touristic presence	3,337,308	91,033	3,200,000	Positively affecting MSW generated Negatively affecting landfilled waste per capita
TAR-POP	Share of population living in municipalities that introduced a waste tariff substituting the former waste tax (%)	10.53	0	101.72	Possibly reducing MSW generation through indirect feed back effects, though the direct effect is at waste management level. Possible endogeneity given the positive correlation with respect to income.
TAR-MUN	Share of municipalities that introduced a waste tariff substituting the former waste tax (%)	6.01	0	100	
INCper AREA	Number incinerator plants /surface (km ²)	0.0000226	0	0.0000472	Negatively affecting landfilled waste per capita
LANDper AREA	Number landfill sites/surface (km ²)	0.0000111	0	0.0000454	This may be a proxy for technological lock-in
INCINERATED	MSW yearly incinerated (kg per capita)	50.57	0	581.81	Negatively affecting landfilled waste per capita
LANDFILL TAX	Regional Landfill Tax (€/kg)	0.01	0.005	0.02	Possibly reducing MSW generation, incrementing the relative cost of landfilling.
NORD	Dummy, =1 if the province is in the North	0.44	0	1	Different areas of the country show very different economic and institutional performance. These differences may be reflected in different amounts of waste generated and landfilled.
ISLAND	Dummy, =1 if the province is in the Islands (Sicily and Sardinia)	0.12	0	1	
SOUTH	Dummy, =1 if the province is in the South	0.18	0	1	

The data are derived from the rich regional/provincial information available from the Italian Environment Agency's waste reports (APAT, 2001, 2002, 2003, 2004, 2005, 2006, 2007), produced according to Eurostat and EEA guidelines.

The APAT dataset includes data on MSW generated and landfilled in all the Italian Provinces (103 distributed over 20 regions) and covers the period 1999-2006. It also provides information on waste tariff diffusion, landfill taxes and separated collection. We merge these data with official data on provincial level economic and other drivers. Although consumption is often used as a driver in analyses of waste trends (Andersen et al., 2007), we have only regional not provincial level data on consumption; thus, value added is the only reliable economic driver available. Finally, other socio economic factors are derived from national and regional official datasets available from the Italian statistical agency (ISTAT). Merging of all these data produces a fully balanced panel of 8 years and 824 observations, that as far as we know possess great value at international level for variable richness, cross province heterogeneity, and dynamic extension.

4. The model and empirical evidence

After discussion of the model, we comment on the empirical evidence addressing first waste generation (4.1) and landfill diversion drivers (4.2), and second investigating the relevance and nature of spatial phenomena (4.3). Finally (4.4), we present a convergence analysis aimed at showing whether Italy although showing drastically different waste performance in the south and weak signs of spatial correlation, is characterised by a catching up of the poorer less performing regions.

We estimate a model by specifying the following general panel based reduced form. Given the nature of data (and Hausman test outcomes - not shown), we opt for fixed effect LSDV (least square dummy variable) estimations which account for individual fixed effects by including N-1 dummies. Linking to the comments above, we tackle the potential endogenous nature of waste management factors, depending on simultaneity and ‘measurement errors’ of some variables, by lagging or instrumenting.

$$(1) \text{Log}(\text{MSW-GEN per capita}) \text{ or } \text{LAND-WASTE per capita} = a_i + \beta_1 \log(\text{value added per capita})_{it} + \beta_2 \log(\text{structural factors})_{it} + \beta_3 \log(\text{environmental policy factors})_{it} + \beta_4 (\text{other factors})_{it} + \varepsilon_{it}$$

The (vector of) coefficient(s) β_2 , refers to factors that are added to the core specification and possible additional drivers of waste generation, such as population density and tourist flows. We add each variable separately to the core specification, which includes value added and population density. β_3 refers to waste policies tested in the analysis, that are in logarithmic forms when it is possible.^{vi}

4.1. Waste generation drivers

In order to take account of the presence of heteroschedasticity and temporal correlation among individual drivers, we further cluster-corrected the traditional fixed effects LSDV.^{vii} These results are presented in Table 2 below.^{viii} First, the core income-waste relationship appears to be linearly shaped.^{ix} This evidence confirms the scientific evidence and the findings of institutional reports that reducing waste generation is a major challenge. Even a decade of waste (management) policies has not drastically affected the relationship. Nevertheless, we note that the elasticity is well below unity. Relative delinking, then, is present, which is an improvement on the unitary elasticity that many – somewhat older - works highlight. Product eco-innovations, environmental household behaviour and waste management actions may be responsible for this change from delinking into the current relative delinking. The other key driver, population density, has the expected positive sign, confirming other evidence for the EU (Mazzanti and Zoboli, 2009): economies of scale in waste management do not exert potential impacts in densely urbanised areas. Even tourist flows, the other structural factor, show the expected positive sign. Touristic provinces plausibly face stronger challenges and possibly need differentiated financing schemes and stricter waste management and disposal policy.^x

Second, we add to the core specification the main waste management/policy factors for which we have sufficient data. We note that the inclusion of additional covariates does not affect income and population density elasticities. Of these (separated collection, diffusion of waste tariffs, landfill tax), only separated collection is statistically significant. Waste tariffs show a weaker significance overall

and are partially model dependent, while landfill tax is not (TAR-POP is significant, TAR-MUN is not). The latter results are expected given the distance between the instrument, the landfill tax, and the target (waste generation), as noted by EEA (2009). The positive coefficients related to separate collection and waste tariffs recall the endogeneity issue, and the fact that policy actions and commitment at local level can be partially explained by local institutional and economic factors. Certain some institutional local factors unfortunately are not observable (e.g. environmental activism, social capital, political stability, and green party turnovers).^{xi} However, income can be a policy driver in a dynamic setting where environmental quality is a luxury and local public agents are challenged by stronger environmental preferences and have more resources (taxes) to invest in waste management. Nevertheless, it is evident that this result is a coherent with the fact that policy efforts are directed towards achieving better waste management rather than reducing waste at source. All EU and national targets have been set in terms of recovery and recycling, given the amount of waste, and only in the new 2008 waste framework directive timid signals of waste generation targets are proposed for future years (EEA, 2009).

Finally, we present the econometric exercises to cope with endogeneity. We deal with SEP-COLLEC, TAR-POP and TAR-MUN in different ways: lagging one year, instrumenting the covariate with VA or the first lag of the same variable (the regressions results are presented in Table A.1 in the appendix). Across the three cases, the evidence for SEP-COLLECT and TAR-POP is stable: the coefficients are highly significant with positive signs.^{xii} TAR-MUN is significant only when its instrument is VA. We can say that our basic evidence is fairly robust.

4.2 Landfill diversion drivers

We comment on the main evidence from the model that specifies the dependent variable – waste landfilled per capita - in non-log form.^{xiii} Table 3, following the reasoning mentioned above, presents the results of the fixed effect LSDV estimations with cluster correction. As in the case of waste generation, the relationship with income is linear, but with the expected negative sign. Population

density, confirming as noted above other evidence for the EU, is linked to a negative and very significant coefficient.^{xiv} In our view, this is a structural factor that recalls economic rationales: the significance of density and urban population, which above are positively correlated to waste generation, is as expected, and shows that where opportunity costs are higher (in urban, and densely populated areas) and disamenities/external effects influence more people, landfill diversion is stronger. For example, in situations where the value of land is especially high and population density is reaching world peaks, such as in Asia, landfill studies proliferate (Lang, 2005, Ozawa, 2005). Also, anecdotal evidence shows that Milan closed its landfill in 2003 for reasons related to environmental externalities and because of the very high economic opportunity costs deriving from the constraints to land development stemming from the presence of a landfill site. Such factors could explain the degree of delinking and landfill diversion in the endogenous scenario, even without policy interventions. Economic rents may lead either to bad situations (Mafia manages illegal landfill sites and thus is interested in maintaining a landfill based disposal system), or drive landfill diversion (legal market rents linked to alternative developments). Economic development and legal rent creation is thus another lever exploitable by public policy use at local level. The only unexpected result is the non-significance of tourism in explaining the reduction of landfilled waste. One hypothesis is that DENSITY probably captures much of the geographical heterogeneity, since 'regional dummies' are not significant.

The evidence related to waste management/policy covariates is interesting. SEP-COLLECT is significant with an associated negative coefficient, and TAR-POP and TAR-MUN are significant drivers of landfill diversion - the first showing a higher statistical significance: it is more effective at provincial level at capturing population, since it focuses on more heavily populated areas, rather than spreading the policy across all the municipalities involved. It is probably to be expected that urban areas matter more for waste performance. Further works on this issue would be useful given the transitional situation in the change from a tax to a tariff system.

To sum up, the quite heterogeneous performance (between the North and South, and within the North and South areas) we observe in Italy, based on the evidence from our analysis, depends on economic-structural (VA; DENSITY) and waste management policy-related factors. Given the strong decentralisation and idiosyncratic local nature of both economic and policy features, it follows that waste performance is driven by elements operating at a very decentralised level, some exogenous (DENSITY), others quite heavily influenced by local policy priorities and socio-political preferences. This could explain the differences between North and South and across provinces in areas of northern and southern Italy with similar levels of income.

Ultimately, we show that landfill tax is not effective, although this may depend on the time invariant nature of our information, which is a minor flaw given that the tax is adjusted not yearly, but every 4-5 years. Not also that the not significant impact of landfill tax may be due not to its quite recent implementation (the tax was formally introduced in 1996), but to its relatively low level compared to other EU countries, and to ‘weak enforcement’ and slack implementation in some regions.^{xv} Nevertheless, even in the EU leading countries, such as the UK, some authors are doubtful about the effectiveness of this instrument (Martin and Scott, 2003). Policy effectiveness in the environmental and even more in the waste area, depends on the structure of the policy package rather than on the individual instrument (EEA, 2009).

In terms of landfill diversion we investigate whether provinces that invest in the main alternative disposal route, incineration, which *may be* more socially beneficial under some circumstances (Dijkgraaf and Vollebergh, 2004), show stronger landfill diversion. Using information on incinerated waste per capita, we find a negative and significant effect on the amount of waste going to landfill. Incinerating activity, where present, seems to be able to promote landfill diversion.

The Appendix includes a further robustness check for potential endogeneity. Across the three considered cases, SEP-COLLECT and TAR-MUN are significant, while TAR-POP is generally only slightly significant (see Table A2).

Table 2: Waste Generated - drivers

Variables	Waste Generated – Log Log Model – Cluster correction						
	1	2	3	4	5	6	7
CONSTANT	-0.9826795	-1.239424	3.926287***	-0.4126362	-0.7466809	1.645581***	0.8638574*
VA	0.5378776***	0.4799152***	/ ²	0.5084183***	0.5250006***	0.4584976***	0.5291237***
DENSITY	0.3838825***	0.2318264*	0.4291315***	0.3280365***	0.3620628***	0.0502183**	0.0603915***
TOURISM		0.11206***					
SEP-COLLECT			0.0411589***				
TAR-POP [^]				0.0004003**			
TAR-MUN [^]					0.0002832		
LANDFILL TAX						0.0326485	
NORTH [^]							-0.1805646***
ISLAND [^]							0.0194857
SOUTH [^]							-0.0929674*
N	824	824	824	824	824	824	824
Model ³	FEM	FEM	FEM	FEM	FEM	REM ⁴	REM

Significance at 10%, 5% and 1% is denoted by *, ** and ***, respectively. R² presents reasonably high value for panel settings. [^] Variables not in Log format.

² Not included given that the correlation between VA and COLLECT is 0.77

³ In fixed effects models all the individual effects are significant. F test not shown.

⁴ Since landfill tax is a time invariant model a random effects model was used.

Table 3: Waste Landfilled - drivers

Variables	Landfilled Waste – Lin Log Model – Cluster Correction								
	1	2	3	4	5	6	7	8	9
CONSTANT	7524***	7495.396***	4477.85***	5987.921***	5834.446***	3092.827***	7598.889***	3131.948***	7271.041***
VA	-333.98**	-340.5877**	Not incl for collinearity	-254.5681**	-241.760**	-244.3936***	-339.7764**	-262.028***	-301.2105***
DENSITY	-767.1***	-784.5001***	-795.840***	-616.6274***	-610.90***	-41.69647*	-770.1361***	-40.15741	-776.5502***
TOURISM		12.76637							
SEP-COLLECT			-24.93373**						
TAR-POP^				-1.079003**					
TAR-MUN^					-2.028524*				
LANDFILL TAX						39.69075			
INCarea^							-965138.7**		
NORTH^								-47.65389	
ISLAND^								-35.65135	
SOUTH^								-85.04208	
INCINERATED^									-.3531898***
N	824	824	824	824	824	824	824	824	824
Model ⁵	FEM	FEM	FEM	FEM	FEM	REM ⁶	FEM	REM	FEM

Significance at 10%, 5% and 1% is denoted by *, ** and ***, respectively. R² presents reasonably high value for panel settings. ^ Variables not in Log format.

⁵ In fixed effects models all individual effects are significant. F test not shown.

⁶ Since landfill tax is a time invariant model a random effects model was used.

4.3 Spatial analysis

Spatial econometric analysis of the main determinants of waste generation and waste disposal is important if it can be argued that neighbouring provinces will exchange experience and, in this way, influence each other's policies and waste management behaviour. From an econometric point of view, if such spatial interactions exist ordinary least square (OLS) methods produce parameter estimates that are biased and inefficient and OLS regression models need to be replaced with opportune spatial regression models.

Thus, we analyse and test spatial autocorrelation in Italian per capita landfilled waste and per capita waste generation using yearly provincial values. The literal meaning of spatial autocorrelation is self-correlation (autocorrelation) of the observed values of a single attribute, according to the geographical (spatial) ordering of these values^{xvi}.

There are two kinds of spatial autocorrelation: positive, when the relationship between the value at a location and the values of its neighbours is positive; or negative when the relationship is negative. One class of spatial autocorrelation measures is given by Moran statistics.^{xvii} Spatial autocorrelation measures, such as Moran's I, require a weights matrix that defines a local neighbourhood around each geographic unit. The value at each unit is compared with the weighted average of the values of its neighbours. Substantially, a weights file identifies the neighbours.

Weights can be constructed based on contiguity to the polygon boundary (shape) files, or calculated from the distance between points (points in a point shape file or centroids of polygons)^{xviii}. Formally, the spatial weights matrix is an $n \times n$ positive matrix (W) which specifies "neighbourhood sets" for each observation. In each row i , a non-zero element w_{ij} defines j as being a neighbour^{xix} of i . According to convention, an observation is not a neighbour to itself, so that the diagonal elements are zero ($w_{ii} = 0$) (Anselin, 2002).

A second type of problem occurs when the spatial weights are based on a *distance* criterion, such that two units i and j are defined as neighbours when the distance between them (or, for units of area units, the distance between their centroids) is less than a given critical value. When there is a high

degree of heterogeneity in the spatial distribution of points or in the areas of regions, there may be no satisfactory critical distance. In those instances, a “small” distance will tend to yield a lot of islands (or, unconnected observations). Also, a distance chosen to ensure that each unit has at least one neighbour may result in an unacceptably large number of neighbours for the smaller units. A common solution to this problem could be to constrain the neighbour structure to the *k-nearest* neighbours, thereby precluding islands and forcing each unit to have the same number of neighbours (Anselin, 2002).

A third issue may arise when the weights are based on “*economic*” distance or another general metric, such as derived from a social network structure. Care must be taken to ensure that the resulting weights are meaningful, finite and non-negative. In addition, the “zero-distance problem” must be accounted for. This problem occurs when a distance measure, such as $d_{ij} = |z_i - z_j|$, becomes zero, due to rounding problems or because two observations show identical socio-economic profiles. As a result, inverse distance weights such as $w_{ij} = 1/d_{ij}$, are undefined.

Because it is also important to maintain the weights matrix as *exogenous*,^{xxx} in our analysis we do not consider a weights matrix based on “economic” distance; thus we use: (i) a contiguity matrix (queen, 1st order); and (ii) a proximity matrix based on the distance between centroids (with minimum threshold distance to ensure that each province has at least one neighbour).

Empirical results, according to the global Moran’s I statistic, suggest that the landfilling of MSW is not strongly related to landfilling in neighbouring municipalities. Only for the years 1999, 2000 and 2006 (Table 4) the global Moran’s I statistic is slightly significant, but the ambivalent signs for those three years and across the interval considered, suggest that there is not a definite and significant spatial pattern. Moreover, the empirical results are not invariant with respect to the weight matrix used. In fact spatial autocorrelation for landfilled waste and the three years referred to above occurs if we consider only one of the weight matrixes (contiguity or proximity).

Table 4. Moran's I for landfilled waste and waste generation for several years (p-values in brackets)

	Moran's I (contiguity matrix, <i>Queen</i>)	Moran's I (proximity matrix, <i>Euclidean distance</i>)
Landfilled waste 1999	0.0845* (0.0910)	0.0057 (0.4360)
Landfilled waste 2000	-0.0085 (0.5170)	-0.1029* (0.0860)
Landfilled waste 2002	-0.0340 (0.3840)	-0.0550 (0.2840)
Landfilled waste 2003	0.0229 (0.2970)	-0.0155 (0.4890)
Landfilled waste 2005	-0.0390 (0.3360)	-0.0183 (0.4660)
Landfilled waste 2006	0.0828* (0.0930)	0.0372 (0.2320)
Waste generation 1999	0.9361*** (0.0010)	0.9279*** (0.0010)
Waste generation 2000	0.0189 (0.3120)	0.0535 (0.1850)
Waste generation 2002	0.0629 (0.1310)	0.0627 (0.1610)
Waste generation 2003	0.0582 (0.1490)	0.0576 (0.1460)
Waste generation 2005	0.1332** (0.0230)	0.1035* (0.0560)
Waste generation 2006	0.0008 (0.4240)	0.0097 (0.3980)

When we consider waste generation, we find a positive autocorrelation for 1999 and 2005, which is nevertheless more significant (and invariant with respect to the weight matrix) with respect to the case of landfilled waste. However, the other years do not present spatial dependence, although the signs are always positive. The positive spatial autocorrelation in the case of waste generation for 1999 and 2005, and the general absence of spatial autocorrelation for landfilled waste, can be explored in the context of the map of the local clusters. A local indicators of spatial association (LISA) cluster map indicates significant cases and types of spatial association based on the LISA, which shows high-high (red) and low-low (dark blue) clusters (i.e. positive spatial autocorrelation) and high-low (bright orange) and low-high (blue) clusters (i.e. negative spatial autocorrelation). Figures 5 and 6 show the respective LISA cluster maps for landfilled waste and waste generation. Figure 6 shows two very big clusters located in the North and in the South of Italy, which explain the strong positive spatial autocorrelation in 1999 for waste generation. A percentile map for waste generation in 1999 confirms this (Figure 7).

A possible interpretation of the substantial lack of the spatial autocorrelation in landfilled waste could be that the policy definition and implementation^{xxi} of landfilling has effectively happened at a very decentralised level, maybe even at the sub-provincial municipal level. It is provinces not regions

that ultimately have to manage the waste, often in very flexible ways, and via delegation to municipalities or consortia of municipalities within the provinces. This could explain why there are no relevant spatial clustering phenomena in the landfilled waste data: policy decentralisation is very high for both waste tariffs and effective implementation of landfill tax. We arrive at a somewhat different conclusion based on the spatial analysis of waste generation. Starting from an initial situation, the 1999 case, with strong positive spatial dependence, the following years (with the exception of 2002) present a substantial absence of spatial autocorrelation, which could be related to a spatial progressive homogenisation in per capita waste generation. Spatial analyses of waste are quite rare. We believe that the recent find of significant spatial correlation for the UK (Ham, 2009) regarding recycling rates is related to the different level of analysis - UK local authorities (388). We cannot conduct analyses at the same level due to data unavailability, but we can assume that the higher the level of decentralisation analysed, the more likely spatial correlations will arise. From a policy perspective, both province and municipality levels are of interest, as they represent governance at the various levels and vary across regions. What we find is that the current *de facto* situation, which originated in the evolution of this complex decentralised waste system, is characterised by provinces acting as the 'waste economic-policy jurisdiction', with eventual homogeneity of actions and performance within provinces. Whether this 'positive' empirical fact fits with the normative elements related to efficiency is a matter for further research, which should analyse local costs and benefits for this environmental local public good, and economies of scale, in the spirit of Oates and Buchanan's models of optimal decentralisation of local public/club goods.

Figure 5. LISA (local indicators of spatial association) cluster maps for per capita landfilled waste (1999 and 2006)

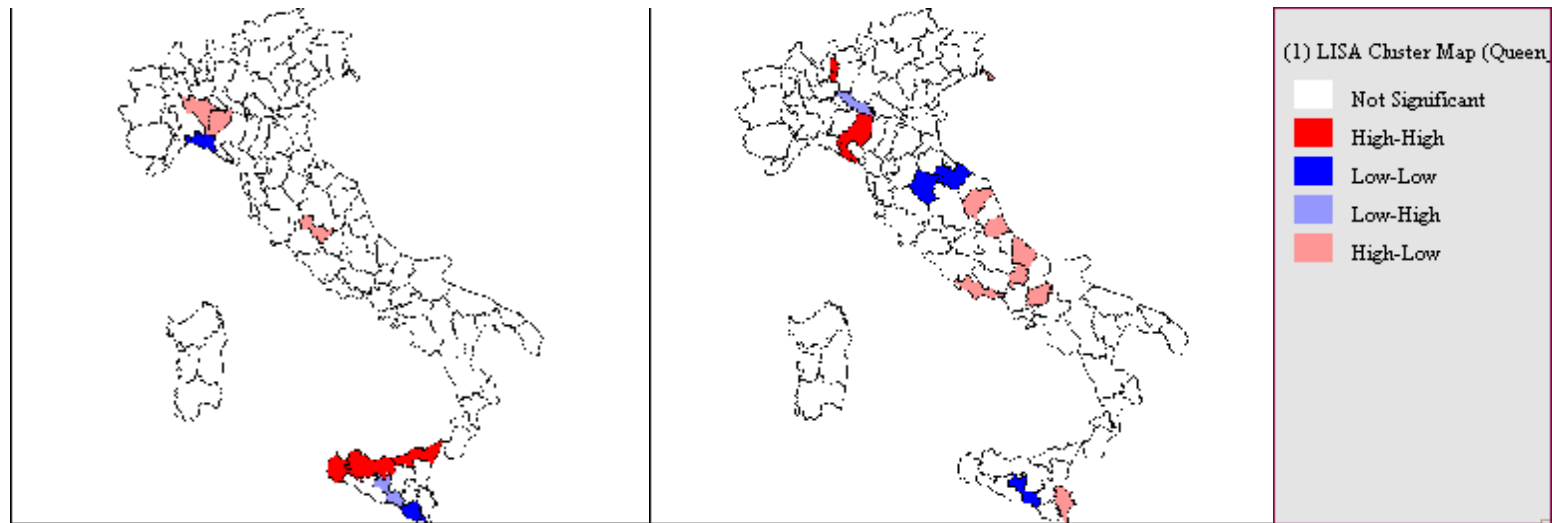


Figure 6. LISA (local indicators of spatial association) cluster maps for per capita waste generation (1999 and 2006)

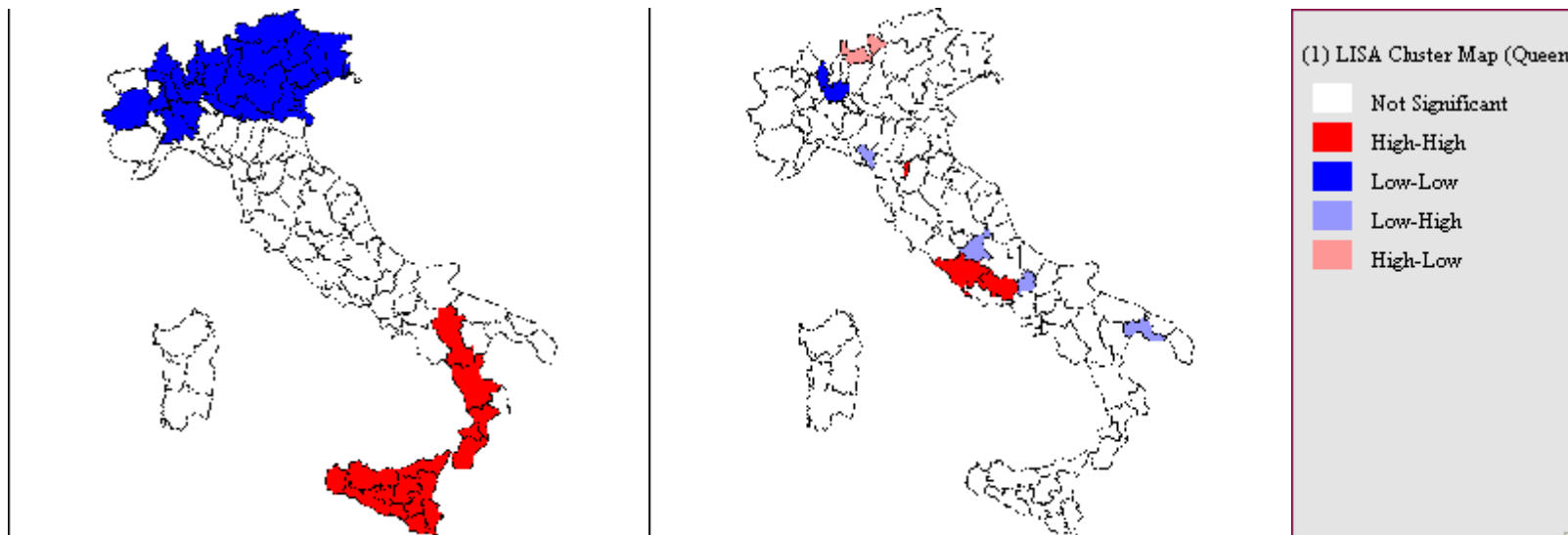
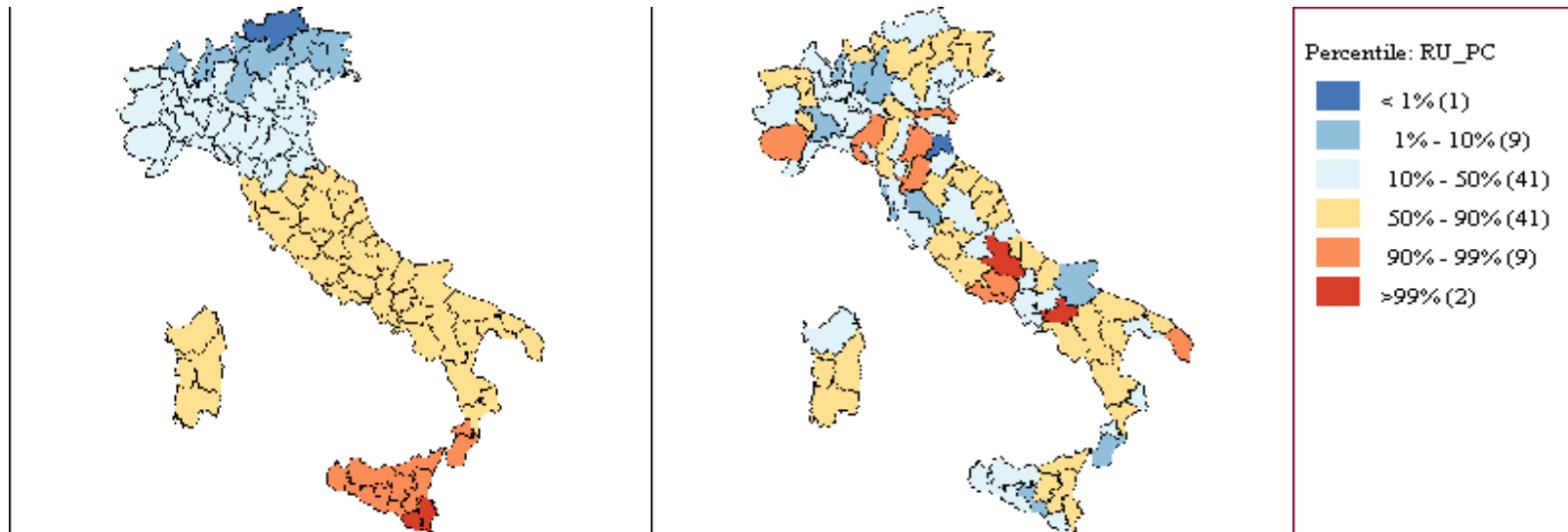


Figure 7. Percentile maps for per capita waste generation (1999 and 2006)



4.4 Convergence

We carry next to examine convergence in waste generation and landfill diversion trends. This is an instrumental exercise aimed at assessing whether at least the different performance in the northern and southern regions, a hot issue for Italy and other federal states in the EU, is showing some convergence. The topic of convergence is seldom applied to the waste realm, although the UK study by Ham (2009) brings together spatial and convergence analyses. She finds that, as far as recycling rates are concerned, in a quite similar environment characterised by regional disparities, there are both convergence and spatial effects. Interest in convergence studies is increasing due to increased interest in the field of environmental economics, especially in relation to air polluting emissions. Among these studies, List (1999) performs convergence tests on a long panel dataset of sulphur dioxides and nitrogen oxide emissions in the US, and finds evidence of convergence. Strazicich and List (2003) using data on carbon dioxide emissions in 21 OECD countries, find strong and robust evidence of convergence. Aldy (2006) performs a series of tests on carbon dioxide emissions in period 1960-2000 in two different samples, a 23 OECD country sample and a wider 88 world country dataset. He finds significant convergence for the OECD sample, but insignificant convergence for the other sample. Barassi et al. (2007), perform a series of advanced panel root unit tests on a sample of OECD countries for the period 1950-2002 but find no evidence of convergence in the amount of carbon dioxide produced per capita. In all these studies, the concept of convergence adopted is taken from the more traditional analyses of income convergence originally introduced by growth economists (Barro and Sala-i-Martin, 1991, 2003). The more usual test in this field, known as β -convergence, refers to what is generally called absolute convergence, and is aimed at checking whether the poor countries are “catching up” with the richer ones. In the emissions context this means checking whether the pattern of emissions in the less-polluting countries is increasing more quickly than in other countries. If so, we can say that emissions are converging to the same level among countries. If not, then the rate of emissions in the more

polluting countries would be increasing. Such analyses are common in emissions studies because of the implication of their findings for climate change policy makers and modellers of climate change.

In our case a series of convergence test should provide a deeper understanding of the waste sector. We have seen that, for the whole of Italy, there is an overall trend in waste management characterised by a process of relative delinking for waste generation and absolute delinking for total waste landfilled. In this context of a major regulatory change, a convergence test should help to understand how the process is developing and whether the reorganization of waste management in Italy is producing greater convergence or is widening the differences among provinces. In particular it will show whether amounts of waste generated are increasing, and whether the growth in different areas is converging or whether more the amounts of waste in waste-intensive provinces are growing more quickly. Furthermore, testing for the amount of waste landfilled should tell us whether the process of landfill diversion over the last decade is being driven by a few big provinces or is occurring across the whole country.

In order to test for convergence in our panel, we estimate a regression where the dependent variable is given by the variation in the growth of our log dependent variable against the lagged variable itself. This allows us to test whether the rate of change of the variable at time t depends by its previous value. In other words, a significant and negative coefficient of the lagged dependent variable means that we are in the presence of convergence. Furthermore, in order to avoid problems of endogeneity based on the nature of the regression, the lagged dependent variable is instrumented with the lag for the previous year.^{xxii} The specification is shown below and the regression results are summarised in Table 5.

$$(2) \log \text{waste}_{it} - \log \text{waste}_{it-1} = \alpha_{it} + \beta \log \text{waste}_{it-1} + \varepsilon_i$$

Table 5: Convergence, Waste generation and landfilled Waste

	Waste Generated	Waste Landfilled
I.MSW-GEN	-0.3920663***	
I.LAND-WASTE		-0.6080219***
CONSTANT	Not present/estimated	3.405887***
MODEL	IV FEM (cluster correction)	FEM (cluster correction)
Davidson-MacKinnon test	0.0158	0.5457

From a methodological point of view, both the previous regressions were estimated using a fixed effect model with cluster correction for heteroskedasticity. Moreover, based on the results of the Davidson-MacKinnon test for exogeneity, we preferred an OLS estimator of the same equation for the waste landfilled analysis.

The two analyses show similar results: the coefficients - significant and with a negative sign - prove the presence of convergence in both cases. The only important difference is in the value of the coefficient, which can be interpreted as the speed of convergence. This difference tells us that the process of convergence is occurring more quickly for landfill diversion. This is a positive signal, and to some extent mitigates the current dramatic difference between southern and northern regions in terms of average waste management and waste disposal performance, although local problem in Naples and Sicily remain. Nevertheless, the existence of a gap, even if consistent in part with different socio-economic conditions, highlights the need for great attention to achieving convergence of waste performances in the current transition towards a more decentralised policy scenario.

5. Conclusions

Waste disposal is becoming increasingly problematic and important in policy terms in the EU, and especially in Italy given this country's high policy decentralisation and wide structural difference in terms of income between southern and northern regions. This paper analyses the process of delinking in waste generation and landfilled waste trends through the consideration of economic, structural, policy and spatial factors.

The analysis of the core income-waste generation relationship do not support the evidence of negative elasticity, even at higher income levels. Despite the fact that even a decade of waste (management) policy has not affected the relationship in a substantial way, we take it to be a positive sign that elasticity is below unity, which points to the presence of at least relative delinking. Moreover, population density drives up waste generation as well: economies of scale in waste management do not exert potential impacts in densely urbanised areas. This result confirms the major findings in the literature.

In terms of landfill diversion dynamics, the observed decoupling between economic growth and landfilling was expected, but is probably not sufficient per se if waste generation (the scale) continues to increase: it is driven by a mix of economic-structural factors, such as population density, which here is weighted more heavily than mere income: local opportunity costs and landfill externalities, which are higher in heavily populated areas, matter in shaping waste policies and local commitment to landfill diversion. This may be food for thought for regional and development policies at local level and useful insight for assessments of the income-environment relationship. Income plays a role in driving different regional waste performance, but rather indirectly, although opportunity costs have a more direct effect through their income dynamics, such as in the simplistic interpretation of the income-environment relationship.

It is not only structural factors that are relevant. Although landfill tax is not shown to be a significant driver of the phenomenon, as in other EU countries (policy package may matter more) the set of waste management instruments, such as separated collection, and the accompanying tariff-based evolution of local waste services, implemented both within privatised and public owned utilities, are associated with a significant negative effect on landfilled waste. It is worth noting that, as far as waste management is concerned, robust evidence of 'policy endogeneity' is found: the dynamics is one where richer provinces (income drivers local preferences for green public goods, local authorities receive more taxes to fund such goods) implement stricter and more costly waste management systems, that have (so far) not generated absolute delinking, but are aimed at that and

could soon revert the waste-income relationships. Such endogenous dynamics are of high interest in contexts where the central state fully delegates all the management to local levels of governance.

Given the strong north-south heterogeneity, the endogeneity of waste management commitment and the transition towards highly decentralised policy implementation, we analysed spatial dependence regarding provinces, the effective level of waste management decision making. Landfilled waste data do not present evidence of spatial autocorrelation. In addition, if there were any spatial phenomena regarding waste performance, they disappeared during the transition since 2000 to a new waste management system. Thus, it is reasonable also to argue that neighbouring provinces are unlikely to exchange experience, and thus also unlikely to influence each others' policies and waste landfill habits. This substantial lack of the spatial autocorrelation might be due to the fact that, as acknowledged by experts and anecdotal evidence, the definition and implementation of landfill policy effectively has happened at a very sub-provincial decentralised (even municipal) level. However, we can draw a different conclusion based on the spatial analysis of waste generation. Starting from an initial situation with a significant and positive spatial dependence before the effective introduction of economic based management instruments, the years after 2000 show a substantial absence of spatial autocorrelation for landfilled waste, which could be related to a spatially progressive homogenisation in per capita waste generation, and no clustering at regional or interregional levels. The stronger association of waste generation and income levels, and the lower, with respect to landfilling, effect of waste management instruments and local opportunity costs, might explain this result.

Another conclusion relevant to environmental policy making, is related to the possible (huge) difference between a country's average performance and its negative and positive outliers, a situation that may be exacerbated by environmental externalities tackled through a very high policy and management decentralisation. The evidence provided in this paper would seem to suggest that divergence is a risk and a possibility that we need to tackle: accompanying the lack of economic convergence experienced by Italy over recent decades, there is an income-driven divergence in

socio-economic and institutional performance. The introduction and the enforcement of 'new' waste management options (tariffs, separated collection) are stronger and more concentrated in the northern regions. The southern and northern regions are characterised by vicious and virtuous circles related respectively to income and waste policy implementation. The risk of overall divergence is evident: this could lead to more and more frequent local crises related to waste, which would undermine national performance and require national intervention in terms of financing, as the costs of cleaning up would be beyond the individual regions 'responsible' for this dire performance.

Though our analysis finally shows that there is some convergence in action for both waste generation and landfill diversion (the latter a more positive fact) along this dynamic evolutionary process, attention should be paid in managing such a highly decentralised process of managing waste. If it is true that the process of landfill diversion seems occurring in a scenario in which the relatively less performing provinces (in the South) have started to reduce the gap (with the North), and this represents a small light at the end of the tunnel, which should be taken as a stimulus to a further strengthening of regional convergence, notwithstanding structural socio-economic differences that explain different levels of waste performance, but along a converging path, on the other hand in terms of waste generation this confirms previous results. Environmental policies have not been able to promote a reduction in the amount of waste generated, and those provinces that were less waste-intensive, since 2000 have registered even higher growth rate.

Finally, we could say that this is partly an old tale: although policy decentralisation is preferable in theory, given that it may ensure higher coherence with the local preferences for defined public goods and the fact that different regions are experiencing different stages of economic development, the basic and we think misleading interpretation of environmental Kuznets curves that income drives environmental performance, does not take account of the fact that along these dynamics income, from social, economic and political perspectives, helps the financing and enforcement of stronger and better environmental management and policy efforts. This is a possible drawback of a

strongly decentralised policy process and should provide food for thought in terms of future research, and future policy in the EU and US and countries in the initial phases of waste policy efforts.

APPENDIX:

Table A.1: Further tests in cases of endogeneity. Waste generation.

	SEP-COLLECT			TAR-POP [^]			TAR-MUN [^]		
	IV Estimation (VA as instrument)	Using the first lag of the variable	IV Estimation (Lags as instruments)	IV Estimation (VA as instrument)	Using the first lag of the variable	IV Estimation (Lags as instruments)	IV Estimation (VA as instrument)	Using the first lag of the variable	IV Estimation (Lags as instruments)
CONSTANT	3.988506***	2.620096***	2.713269***	9.425374***	0.6674112***	0.9528525	8.875068***	0.3411253	0.4274984
VA		0.1981252***	0.1649368**		0.4169227***	0.3955181***		0.4292366***	0.422698***
DENSITY	0.4027496***	0.314313***	0.3484448***	-0.6357739***	0.2926517***	0.2769891***	-0.5275321**	0.3332481***	0.3286678***
SEP-COLLECT	0.0701332***	0.0303273***	0.0492306***						
TAR-POP [^]				0.007308***	0.0003701**	0.0006074***			
TAR-MUN [^]							0.011831***	0.0001507	0.0002543

Significance at 10%, 5% and 1% is denoted by *, ** and ***, respectively. R² presents reasonably high value for panel settings. [^] Variables not in Log format.

Table A.2: Further tests in cases of endogeneity. Landfilled Waste.

	SEP-COLLECT			TAR-POP [^]			TAR-MUN [^]		
	IV Estimation (VA as instrument)	Using the first lag of the variable	IV Estimation (Lags as instruments)	IV Estimation (VA as instrument)	Using the first lag of the variable	IV Estimation (Lags as instruments)	IV Estimation (VA as instrument)	Using the first lag of the variable	IV Estimation (Lags as instruments)
CONSTANT	4437.886***	4021.835***	4196.6***	1061.97	7638.628***	7250.425	3576.104***	7041.181***	5764.787***
VA					-408.9492***	-379.8387***		-394.9188***	-298.2929*
DENSITY	-778.8923***	-708.3027***	-734.2649***	-134.0417	-646.2248***	-624.9235***	-630.0055***	-555.3378***	-487.6524***
SEP-COLLECT	-43.5478***	-24.35552***	-38.36197**						
TAR-POP [^]				-4.537735***	-0.5033163	-0.8260642*			
TAR-MUN [^]							-2.243737***	-2.227458*** (1)	-3.758221***

Significance at 10%, 5% and 1% is denoted by *, ** and ***, respectively. R² presents reasonably high value for panel settings. [^] Variables not in Log format.

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ⁱ Although northern Italy is rapidly evolving towards high levels of recycling, composting and incineration, the average for the country is still dominated by landfill, confirmed by the dramatic news from areas, such as Campania, in the South. However, even some northern regions are suffering from landfill criticalities given the increasing scarcity of land in physical and economic terms (opportunity costs) and the non-decreasing, at best stabilised trends in waste generation. Figures 3 and 4 depict the current differences in waste management and disposal across Italian provinces (other depictions are available upon requests for incineration and waste generation and tariff diffusions). For a ‘regional politics’ oriented analysis of the recent history of the economic and institutional failures in the Neapolitan and Sicilian waste systems see Pasotti (2009a,b).

ⁱⁱ Our data source, to our knowledge, is one of the richest - at least at EU level and the Italian case presents high heterogeneous (and federal) socio-economic and policy situations similar to other EU and non-EU countries.

ⁱⁱⁱ The waste management *tariff* was introduced by Italian law no. 22/1997, and was meant to replace the former waste management *tax*; however, the latter still applies in many Italian municipalities because the provisions of law 22/1997 allow the transition to be quite gradual. The old tax was calculated on the basis of size of household living space, whereas the tariff is based on the principles of full-cost pricing of waste management services. Effective implementation of the tariff system nevertheless is highly dependent on local policy decisions and practices and in part is down to the choice of the municipality. We note that implementation is heterogeneous even across areas with similar incomes and similar social economic variables, and may depend on the level of policy commitment. The shift from tax to tariff should also capture the incentive effect of the latter, although the impact on waste generation, if any, is not visible in the short term.

^{iv} This is coherent with EU environmental policies, which, in theory, should be rooted firmly in the polluter pays principle. It should be noted that the European court of Justice has been forced to pronounce a legal decision statement (probably during 2009) on the coherence of such a tax with the PPP, following a legal procedure activated by a hotel owner who sued against the tax through the administrative court of the Campania Region (‘TAR’), claiming that that tax was/is based and calculated on parameters such as square meters, but also business income. Legally and also substantially, the problem is one of whether the old tax can achieve the objectives determined by the EU waste legislation. An EU decision in favour of full coherence with PPP could accelerate the transition towards the tariff, which was been halted repeatedly on the basis of unclear instruction from central government in recent years. Note also that many municipalities are not in favour of the new tariff, fearing loss of revenue. This is critical to a clear understanding of the current stalled situation.

^v It is well known that this flaw may depend on the availability of average instead of marginal policy figures.

^{vi} As far as landfill diversion is concerned, and considering that the dataset presents some zero values (5 of the 103 provinces observed in 1999-2006 have no MSW landfill sites and others, e.g. Milan, closed their landfill sites at a certain point resulting in zero values after a certain year) the model specification is of a linear-log type. Further analyses may implement two stage Heckman regressions to account for the discrete choice of having (or not) a landfill facility, and for how much waste is to be landfilled.

^{vii} We use Stata, specifically the option ‘cluster’ after the ‘FE LSDV estimation’. In this way we use the Huber/White/sandwich estimator of variance and we allow observations that are not time invariant within groups, although they must be independent between groups. This means that we consider that $\text{Var}(\varepsilon_{it}) = \sigma^2 \varepsilon_{it} \forall i=1,.., N, t=1,..,T$, and that $\text{Cov}(\varepsilon_{it}, \varepsilon_{is}) \neq 0 \forall t \neq s$.

^{viii} Non-corrected estimates are available; note that they differ very little, apart from the non-linearity of the income-environment relationship which disappears when corrected. The results are coherent.

^{ix} A non-linear specification (not shown) was tested, but the squared VA term was never significant.

^x We also test for geographical dummies, inserting North, South, Island dummies against the ‘centre of Italy’ benchmark. The only significant dummies are North and South, which both have a negative coefficient. While we might expect this for the North, the evidence for the South dummy is less intuitive given the high frequency of poor waste performance in southern regions. Note, however, that here we deal with waste generation, not management. Also, the evidence is coherent with APAT data, which show that the centre regions (especially the touristic Tuscany) are associated with the highest levels of waste generation per capita.

^{xi} This may be scope for further research.

^{xii} Overall, TAR-POP is more significant than TAR-MUN. This could mean a higher impact at provincial level of new policy diffusion in terms of population, rather than municipalities. What matters is its implementation in the largest cities where incomes are probably higher on average, evoking the latent endogeneity of the dynamics.

^{xiii} Elasticity estimates deriving from the log-log estimations (not shown for reasons of space) covering provinces with at least one open landfill, are available upon request.

^{xiv} The highly significant role of density as a covariate, improving the overall fit of the model, is underlined in the UK study by Ham (2009).

^{xv} Interviews with waste experts in some of the Italian regions confirmed that the tax is aimed mainly at collecting revenue (and eventually earmarking it for waste services and landfill sites ex post re-qualification), not at changing relative prices. However, some regions have not implemented strategies for its prioritisation and use the revenue to finance other public services. This is of major concern in terms of improving the effectiveness of this instrument in the

future through greater enforcement and the introduction of real ‘revenue recycling’ elements into the system. Finally, landfill sites operate in a very monopolistic kind of market, where associated rents (deriving from gate fees and rather inelastic demand) are a real constraint to a major movement of waste from landfill.

^{xvi} Formally, spatial autocorrelation is present when spatial randomness is violated. Generally, we have spatial randomness when:

- values observed at a location do not depend on the values observed at neighbouring locations;
- the observed spatial pattern of values is equally as likely as any other spatial pattern;

the location of values may be altered without affecting the information content of the data.

^{xvii} The *global* Moran’s I provides a global autocorrelation statistic that result in a single measure of spatial autocorrelation for an attribute in a region as a whole (in our case, Italy). The *local* Moran’s I provides local spatial autocorrelation statistics, which, for each unit in the region (in our case a single province), result in the unit’s tendency for an attribute value that is correlated with the values in nearby areas. In our analysis we are interested in the global measure. However the LISA cluster maps (figures 5 and 6) show evidence for the local (provincial) indicators.

^{xviii} Even when the weights are based on simple *contiguity*, different weights structures may result for the same spatial layout. The options are referred to as the *rook* case (only common boundaries), the *bishop* case (only common vertices) and the *queen* case (both boundaries and vertices). In our case, with Italian provincial boundaries, the queen and the rook methods end up with the same weight matrix.

^{xix} The neighbours are contiguous spatial units. For ease of interpretation and to make the parameter estimates between different models more comparable, the spatial weights matrix is typically row-standardised.

^{xx} When the same variables are used to compute a general distance metric such as included in the model, the weights are unlikely to remain exogenous. Consequently, the resulting model specification becomes highly non-linear with endogeneity that must be instrumented out.

^{xxi} The transition towards the tariff formally began with the 1999 EU landfill Directive (ratified by Italy in 2003).

^{xxii} A Davidson-MacKinnon test of exogeneity for a fixed effects panel data model was conducted to check whether an OLS estimator for the same equation would yield consistent estimates.