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Waste Dynamics, Country Heterogeneity and European Environmental Policy Effectiveness

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ABSTRACT *We empirically test the decoupling of waste dynamics with regard to economic growth and the effectiveness of environmental and specific waste-related policies, by exploiting an integrated data set for the EU15 over 1995–2007. We find that absolute delinking for waste generation is far from being achieved in the European Union (EU) despite the fairly stringent and longstanding policy commitment, which was and is still probably too biased towards waste management and waste disposal targets, rather than towards waste prevention* per se. *On the other hand, policy action as well as country structural factors seems to have an impact on landfill diversion. Country heterogeneity fairly matters: the seemingly unrelated regression analyses that we adopt, including models that tackle policy endogeneity, show that EU average figures often hide high variance in decoupling performances. EU countries can be consistently grouped according to their waste sustainability performances. The results provide food for thought for setting comprehensive EU waste policy strategies jointly aimed at waste reduction and landfill diversion. This is a relevant outcome and food for thought within an EU framework that is strongly oriented towards allowing countries to decide about the implementation of EU Directives.*

KEY WORDS: Waste generation, landfill diversion, SUR estimator, EU environmental policy, delinking, policy effectiveness, policy endogeneity

JEL Classification: C23; q38; q56

1. Introduction and Relevant Frameworks

The aim of our analysis is to bring together delinking analysis and policy assessment. Over the last decade, European environmental policies have become more oriented towards reducing the amount of municipal solid landfilled

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waste and the promotion of other forms of waste disposal, such as recycling and incineration. In this context, decoupling or delinking, that is, improvements in environmental/resource indicators with respect to economic activity indicators, is increasingly used to evaluate progress in the use/conservation of natural and environmental resources (OECD, 2002). Various decoupling or resource efficiency indicators are included in the state-of-the-environment reports of the European Environment Agency (EEA) (EEA, 2003), and a few European countries have begun to include indicators of delinking in official analyses of environmental performance (DEFRA/DTI, 2003). Furthermore, the importance of market-based instruments for achieving a higher degree of delinking for waste indicators is stressed by European institutions (EEA ETC/RWM, 2006). The European Union (EU) policy thematic strategies on resources and waste include reference to absolute and relative delinking indicators (EEA, 2009; Jacobsen *et al.*, 2004). The former is a negative relationship between economic growth and environmental impacts, associated with the descending side of an inverted U-shape, according to the environmental Kuznets curve (EKC) framework. The latter, the ascending side of the U-shape, is a positive but diminishing income–environment relationship. This represents a positive which is lower than unity elasticity in economic terms. There is no delinking observed on the ascending part of the EKC and, in addition, there is unity or higher than unity elasticity. An extensive overview of the main theoretical issues (first developed by Andreoni & Levinson, 2001, in a static framework)[1] can be found in Brock & Taylor (2004). The field of economics of waste includes empirical and theoretical studies that date back to the 1980–1990s (Beede & Bloom, 1995; Choe & Fraser, 1999) and that increasingly emphasize policy aspects (Palmer *et al.*, 1997; Keeler & Renkow, 1999; Walls & Palmer, 2001). Due to data availability, which was probably more problematic in the EU, applied analysis has lagged behind theoretical analysis until recently (Johnstone & Labonne, 2004).

Increased delinking is the primary aim for waste (EU) policy and management strategies, which, in terms of its environmental impacts and economic costs, is no less relevant than climate change and is also related to it, given the greenhouse gas emissions generated by various disposal options (Andersen *et al.*, 2009). EU performance on waste generation is still characterized by at least relative delinking in most countries, with minor exceptions where reduction of waste generated was observed (Mazzanti & Montini, 2009; Mazzanti & Zoboli, 2009; Sjöström & Östblom, 2010). Andersen *et al.* (2007) estimated waste trends for the EU15 and the EU10 new entrants and found that waste generation projections over the 2005–2020 period show growth in municipal solid waste (MSW) of around 15–20%, which may be compatible with relative delinking with respect to GDP.

Differences in performance across EU countries and the western and eastern EU are relevant in understanding the role of innovations in achieving future policy targets as defined and stimulated by the recent 2008 Waste Framework Directive. The achievement of absolute delinking is therefore a long-term goal of the EU for overall environmental impacts and for waste and climate change in specific terms.

Figures 1–2 show the trends in the EU regarding waste generation and landfilling across countries.

Although costs and benefits should be evaluated specifically for each situation, the environmental impacts of landfilling and waste sites mostly in urban

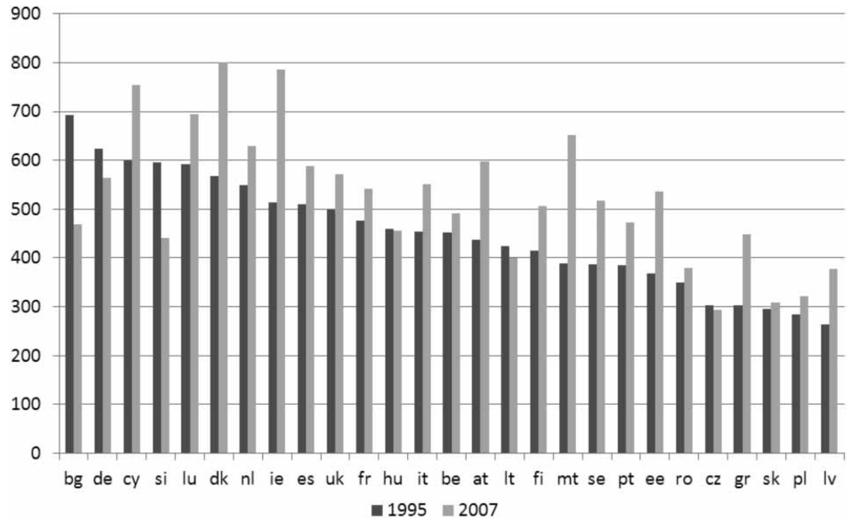

Figure 1. MSW generation in Europe, 1995–2007 (kg *per capita*).
Source: Eurostat, Environmental Data Centre on Waste (Available at: http://epp.eurostat.ec.europa.eu/portal/page/portal/waste/introduction/). An acronym list is given in Table A1 in the appendix.

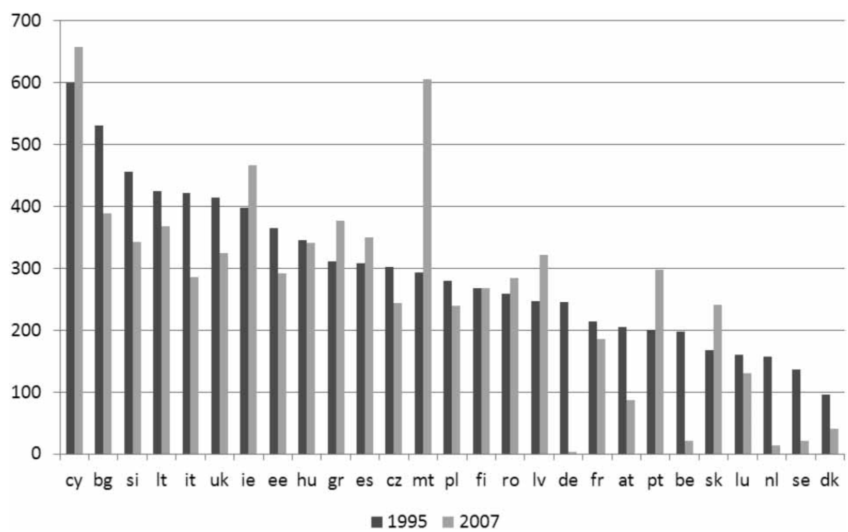

Figure 2. MSW landfilled in Europe as share of total waste management, 1995–2007 (kg *per capita*).
Source: Eurostat. Eurostat, Environmental Data Centre on Waste. An acronym list is given in Table A1 in the appendix.

areas are massive (Eshet *et al.*, 2004; Seok Lim & Missios, 2007). And although recycling is at the top of the environmental waste hierarchy of the EU, it should not automatically be taken as the best economic practice in all situations; its costs and benefits are influenced by economic and technological factors (Dijkgraaf & Vollebergh, 2004; Pearce, 2004).

In the long run, waste reduction at source, through the imposition of policy targets in terms of waste generated *per capita*, is probably the most effective and most efficient answer to the problem. Given the potentially high costs in the short run and resistance from member states, the first phase of policy implementation at the EU level focuses on landfill diversion and increased shares of recycling/recovery, including incineration. For the purposes of our analysis, it is worth noting that by 2013, following the guidelines in the 2008 new Waste Framework Directive, members states are expected to set up and propose a waste policy strategy to the EU Commission that includes waste prevention. This might even include waste generation *per capita* targets. Even the revised 2008 Waste Framework Directive does not ultimately set waste prevention targets. Art. 9 on waste prevention sets future actions only in terms of stating that by the end of 2014, waste prevention and decoupling objectives for 2020 will be presented, and art. 29 indicates that countries should prepare waste prevention programmes by 2013 (the EEA is required to report annually on this evolution from 2008 to 2013), with delinking performance to be evaluated every 6 years.

In light of future scenarios, policy effectiveness analysis is relevant to assess the short- and long-run effects of policies on the ultimate objective (IVM, 2005). In the absence of effective policies, we can expect a somewhat linear positive relationship between waste generation and growth, with landfill diversion being affected only by market prices and the opportunity costs (of land). Policies can then influence the amount of landfilling and the industry structure as well (Blair & Hite, 2005).

One of the earliest Waste Kuznets curve (WKC hereafter) studies is that of Cole *et al.* (1997), which finds no evidence of an inverted U-shape in relation to municipal waste and lacks policy assessments. Recent studies by Mazzanti & Zoboli (2009) have analysed EU panel data for all waste trends (from generation to landfill, including recycling and incineration) for the 1995–2005 period and found some weak evidence of delinking and signs of policy effectiveness; others have focused on the international and policy-relevant issue of transboundary shipments of waste (Baggs, 2009).

This article is based on the cited literature and aims at providing empirical evidence on delinking trends for generated MSW and landfilled MSW, given that they are the two main targets of past and future policies.[2]

The set of research hypotheses revolves around decoupling assessment and *ex-post* policy effectiveness. First, it provides a deeper investigation into delinking trends for waste indicators across European countries through the use of a Seemingly Unrelated Regression Estimation (SURE) procedure, which is implemented in both cross-section and panel data. The latter have received much emphasis in terms of the number of applications over the past few years (List & Gallet, 1999). SURE technique is mainly useful in accounting for cross-sectional correlation between units (firms, in the original Zellner example, or countries in most studies) and might be adapted for estimating single countries' income–environment relationships (decoupling performances and elasticity coefficients), instead of typical average effects.[3] Second, it provides *ex-post* evaluation of different policy-related variables.

The main attractions of Zellner's (1962) SURE is that it makes it possible to exploit cross-sectional correlation in the panel (if present), then eventually estimate single equations for each individual country. This is highly relevant in policy-oriented studies that try to disaggregate the income–environment relationship and rank environmental performance (List & Mchone, 2000; List

& Gallett, 1999; Pagoulatus *et al.*, 2004). This enables us to correct for the presence of contemporaneous correlations across cross-sectional units, allowing the slope to change across different individuals.[4] It enhances the efficient properties of fixed effects if correlation is present. It is worth noting that SURE, which, remarkably, is not a tool that deals with spatial dependence, is also used extensively in homogenous panel frameworks just to correct for correlated disturbances. The independence assumption is, in fact, often at odds with economic theory. For instance, according to many economic models, agents tend to interact within and between cross-sections. Second, dependence could also be the consequence of unobserved heterogeneity due principally to *omitted observed common factors, spatial spill-over effects, unobserved common factors or general residual interdependence* (Breitung & Pesaran, 2008). Standard techniques that do not take account of this dependence would yield incorrect inference (Mazzanti & Musolesi, 2010).

Policy efforts are analysed in terms of their effectiveness in reducing waste generation, on the basis of the actions taken in response to the implementation of the policies relevant to the case considered here: namely the 1999 Landfill and Incineration Directives and more generally the commitment and effort of EU countries to implementing waste policies, including early 'policy actions' with regard to formal policy ratification by some countries (e.g. Germany and Austria put in place a packaging waste management system and Ireland introduced a pay-by-use mechanism[5]). It is worth noting that the Landfill Directive adopts two approaches: first, it introduces stringent technical requirements for landfills; second, it diverts biodegradable municipal waste (BMW) from landfills by setting targets for the landfill of BMW in 2006, 2009 and 2016. The Incineration Directive (2000/76/EC on the incineration of waste) is an ancillary and complementary piece of EU waste policy strategy.

We exploit both existing official data on environmental policy and an original specifically constructed waste policy stringency indicator for EU countries. We stress the uniqueness of long panel and merged data at the world level for waste and the relevance of testing both official EUROSTAT environmental policy indicators and newly constructed—from EU waste official sources—indices of policy stringency.

The article is structured as follows. Section 2 presents the data and the empirical model. Section 3 presents the main results for delinking and policy effectiveness by means of constrained and unconstrained SUR models that also tackle policy endogeneity in some specifications. Section 4 concludes, commenting on results with policy implications.

2. Data and Empirical Model

We exploit a data set composed of the 15 European countries for the period 1995–2007 to test delinking paths and the effectiveness of policy, controlling for socioeconomic and structural factors.[6] The two dependent variables are collected MSW and landfilled solid waste, expressed in *per capita* ratios. Our main economic driver is data on final consumption expenditure by households because this is considered to be more coherent than GDP in this kind of study, although the correlation is obvious (Andersen *et al.*, 2007). We include some other variables,

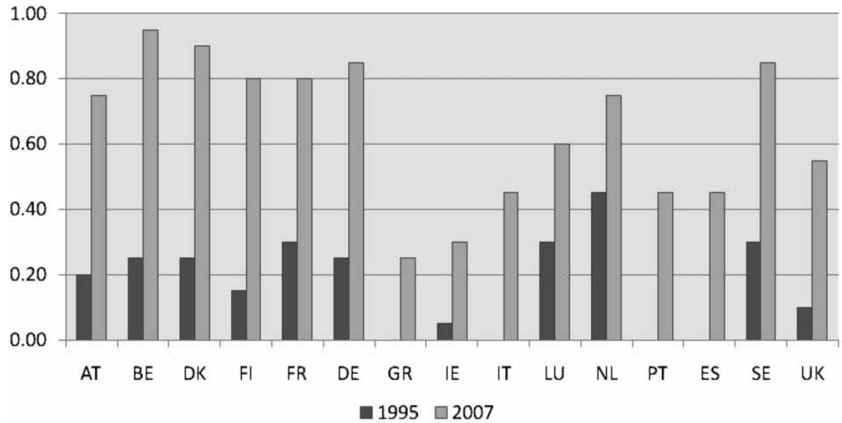

Figure 3. The policy index.
Source: Own calculation on EIONET data. An acronym list is given in Table A1 in the appendix.

adding them to the baseline WKC form, to control for socio-economic and policy aspects.

Population density is likely to impact positively on waste generation (if economies of scale do not compensate for scale effect) and negatively on landfilled waste (due to higher environmental and economic opportunity costs in more densely populated areas). In terms of construction of the policy indices, we exploit the country fact sheets available at EIONET[7] to compile an original index of policy stringency, which, interestingly and originally, varies over time and across countries. The original index that we constructed (Figure 3) is a proxy for the stringency of national waste policies. It captures all possible information on national implementation of waste-related policies (MSW, packaging waste, end-of-life vehicles, landfill taxation, etc.). This index is extremely comprehensive with regard to Landfill Directive-related variables and captures some of the waste prevention features of national policies.[8] It is consistent with a comprehensive environmental/waste policy approach (EEA, 2009), which is not based on single economic instruments, discussed theoretically by Walls and Palmer (2001).

Thus, in any given year, each country is associated with an index value, where 1 is the maximum potential value (assuming the presence and effective implementation in the country of all the policies that we may consider in EIONET). We weight the presence of a policy action according to the 'mere presence' of a waste *strategy* (e.g. a waste policy framework, for the action of which we assign a lower value) and *the real presence of regulatory policy* (e.g. a landfill tax, which has a high value). Weights are thus defined by giving 1 to mere presence of a strategy and 2 to an effective policy in place (e.g. landfill tax, covenants and permit market). We highlight that our results do not change if we use an index derived from factorial analyses, which we applied for sensitivity. Results are available upon request. We also refer to Eliste and Fredrikkson (1998); Dasgupta *et al.* (2001); and Cagatay and Mihci (2003, 2006) who presented various indicators.

The specification that we test is a common WKC-based (Cole *et al.*, 1997; Maddison, 2007) reduced form (for waste-related studies, see Dijkgraaf & Gradus, 2004, 2008; Mazzanti & Zoboli, 2009). We do not include a third term in the income–environment polynomial due to its irrelevance in the waste framework (at best the presence of relative delinking is proved) and provided we find statistical insignificance of that term in preliminary estimations:

$$\text{Log (Waste performance indicator)} = \beta_{0i} + \alpha_t + \beta_1 \text{Log(CONS)}_{it} + \beta_2 \text{Log(CONS)}^2_{it} + \beta_3 (Xi)_{it} + \beta_4 (Zi)_{it} + e_{it}, \quad (1)$$

where X includes socio-economic/structural factors (DENSPOP) and Z is policy lever (POLIND). The relation is estimated with SURE technique,[9] constraining all the slopes in a first phase and setting them free to change across individual estimations in a second one.[10] The analysis is conducted first using MSW as the dependent variable and then landfilled MSW, in order to assess the trends in two of the main variables in waste management. Wherever possible, logarithmic values are used (Table 1).

3. Econometric Evidence

3.1 *Waste Generation Drivers*

Table 2 summarizes the regression results from the first of the two SURE models for waste generation.[11] The results of the Pesaran[12] and Breusch–Pagan tests show that the residuals of the fixed-effect model are affected by contemporaneous correlations across cross-sectional units, which can be exploited by techniques such as SURE models, which allow efficiency gains. In such a context, we refer to a Breusch–Pagan statistic for cross-sectional independence in the residuals of a fixed-effect regression model, following Greene (2000, p. 601).[13]

As we can see, this ‘correction’ does not significantly alter the economic and statistical meaning of previous studies in this field (Mazzanti & Zoboli, 2009).[14] Some new insights emerge, however. If, on the one hand, both specifications that we test show significance of the squared term, demonstrating a Kuznets-like path, this is nonetheless associated with a turning point which is very high and clearly ‘out of range with respect to the observed values’. In other words, there is still only relative delinking. This may be preliminary evidence that the EU15 group is still far from absolute delinking, although progress is being made towards delinking. In any case, this may be seen as a problematic result, considering that, on the one hand, waste prevention is at the top of waste hierarchy of the EU along with recycling, while, on the other hand, and even more importantly, prevention at source is probably the most effective way of promoting waste management sustainability. In this case, population density is linked to a negative and economically and statistically significant coefficient (Ziliak & McCloskey, 2004), suggesting that economies of scale related to agglomeration may have a positive effect with respect to waste prevention. We recall that there are no *a priori* expectations about this sign since opposite forces are at work. On the other hand, the policy index is not statistically significant. We supposed the total amount of environmental taxes[15] to be negatively correlated to the total amount of waste generated. Nevertheless, this result is not unexpected, considering that waste policies have not put specific emphasis on waste prevention and that environmental taxes have decreased in real terms since the 1990s in most—even Nordic—countries (Andersen & Ekins, 2009).

Table 1. Descriptive statistics and summary of research hypotheses

	Variables	Acronyms	Units of measurement	Mean	Min	Max	Research hypotheses
Dependent variable	MSW generation	MSW-GENER	(kg/capita)	545.26	302	804	
	MSW landfilled	MSW-LAND	(kg/capita)	228.91	3	554.1	
Economic drivers	Consumption	CONS	(€ per inhabitant)	13,663	5700	28,400	Linear or quadratic (inverted U) shape
Structural variable	Population density	DENSPOP	(inhabitants/km^2)	157.06	16.8	484.2	MSW-GENER: either positive or negative effects can be expected depending on economies of scale *vs.* opportunity cost of waste management MSW-LAND: negative correlation mostly expected due to economic and environmental external and opportunity costs of landfilling
Policy variables	Waste-related policy	POLIND	0–1 index	0.45	0	0.95	Negative correlation[a]
	Environmental tax	ENVTAX	% national consumption	1.19	0.25	3.90	
POLIND Determinants (IV)	Gini coefficient	GINI		28.70	21.55	36.22	Negative effect on policy
	Unemployment	UNEMPL	Rate (%)	7.509	1.9	20	Negative effect on policy
	GDP *per capita*	GDP	US$, current prices, constant PPPs, OECD base year	0.0284	0.0116	0.0819	Positive effect on policy
	Political stability	POL STAB	Index of country political instability (comparative Political Data Set I)				Negative effect on policy

[a]Although positive correlations between policies and country environmental commitment can be and were found, dependent on endogeneity of policy action with respect to income level, the production of public environmental goods being a public good and luxury goods being helped by income conditions and by the health of public finances. Vicious or virtuous circles thus are possible paths in the environment–income dynamics.

Table 2. Waste generated SURE model, constrained slopes

	Constrained slope SURE	Constrained slope SURE—all variables
CONS	0.95***	1.19***
CONS^2	−0.03***	−0.038***
DENSPOP	–	−0.29***
POLIND	–	−0.002
TP (CONS *per capita*, millions of €)	7.521	6.311
Breusch–Pagan tests of independence (p-value)	0.000	0.000

Note: (−) means not included.
*Significance at 10%.
**Significance at 5%.
***Significance at 1%.

The last model that we present for waste generation (Table 3) gives evidence of country heterogeneity in the income–waste relationship at the EU15 level. The analysis refers only to the main economic variable consumption. The main advantage, from an interpretative point of view, is the possibility of comparing the trends in different countries within the same framework of analysis, which highlights common elements and discrepancies. For instance, Table 3 shows that it is possible to split countries into three groups: the first group includes Austria, Germany, Greece, Portugal and Spain, characterized by the presence of absolute delinking. This result is as expected for Austria and Germany, which are leaders in the waste sector and waste management and show performances above the EU average. Germany's national waste policy encourages implementation of EU waste directives.

Germany's role and behaviour depend on at least two different aspects: first, the country's real commitment to green strategies (for instance, waste and

Table 3. Waste generated SURE model, unconstrained model

Countries	CONS	CONS^2	TP (€)	Delinking evidence
Austria	84.31***	−4.33***	16,646.52	Absolute
Belgium	−3.73	0.210	7075.36	No delinking
Denmark	−11.26	0.62	8051.13	No delinking
France	3.57	−0.17	33,767.68	No delinking
Germany	1.89***	−0.12***	1633.113	Absolute
Greece	17.36***	−0.91***	13,548.99	Absolute
Italy	−8.73***	0.487***	7842.28	No delinking
The Netherlands	9.28***	−0.47***	16,578.1	Relative
Portugal	8.89***	−0.48***	9983.131	Absolute
Spain	24.03***	−1.29***	10,885.79	Absolute
Sweden	−17.5***	0.96***	8700.899	No delinking
UK	5.09***	−0.25***	21,529.84	Relative
Breusch–Pagan tests of independence (p-value) = 0.000. F-test of slope homogeneity (p-value) = 0.000				

Note: SURE estimations refer only to 12 countries. The Breusch–Pagan tests for cross-sectional independence in the residuals are used, while the F-test is a test of slope homogeneity.
*Significance at 10%.
**Significance at 5%.
***Significance at 1%.

renewable energy) and eco-innovations, and second, idiosyncratic energy-related country aspects. An anecdote of Germany's influence was the 1989 Toepfer law setting strict objectives on packaging waste recycling and recovery and producer responsibility. Given the necessity of a homogenization of packaging laws to avoid trade distortions in the common market, this law drove the 1994 Packaging EU Directive (EEA, 2005). With regard to energy, the commitment of Germany to renewable energy, waste recycling and eco-innovations relies on the scarcity of national sources. The UK, instead, has historically placed lighter emphasis on recycling—mainly plastic—for many different reasons, which are also worth specific country-based investigations as a complement to our research. Among them, we can highlight that in the past this 'policy attitude' was to some extent due to the abundance of oil; however, nowadays things are somewhat changing. UK oil production has decreased (from a monthly oil figure of around 14,000,000 in 1987 to 7,000,000 m^3 in 2008), and other factors will play a more relevant role, but not population density, which is almost equal, for example, in Germany and the UK. Regulation-based reasons are more relevant. For example, the use of more market-based approaches—a more widespread use of 'waste-related tradable certificates' (EEA, 2009)—tends to be a rather cheaper efficient policy option, but probably less effective than cost recovery waste management regulations that heavily involve the responsibility of producers and various stakeholders, as in Germany and Italy. Cost-effectiveness nevertheless matters at the end of the day: the 'German' and 'UK' models differ in terms of costs they impose on both firms and waste recovery performances. Further research is still needed to fully assess and compare the different policy systems. So far, the German model, which has developed around high recovery targets, very low landfilling and technological contents, has prevailed at least in terms of influence on EU Directives. All in all, Germany's leadership is not undermined by oil/energy-related considerations: other countries such as Italy are not rich in energy sources, but have adopted far lighter green strategies.

The evidence for the three other countries is more unexpected. From the graphical evidence plotted in the appendix (Figure A2), we believe that only Spain can be associated with real absolute delinking, while Greece and Portugal show, respectively, stabilization of waste generation and an N-shape which could derive partly from waste accounting over some years.[16] The turning point is always inside the range and relative to relatively high levels of income, except in the case of Germany, which is consistently associated with a very low turning point (€1633). Germany preceded and influenced EU policy by achieving higher performance through diffuse and stringent policies introduced in the early 1990s (EEA, 2009).

The second group of countries characterized by the presence of relative delinking includes the UK and Holland. In this case, there is a turning point, but it is out of the possible range of income.

The remaining countries, in the third group, show no evidence of delinking, but have differences between them. Coefficients are not highly significant for Belgium, Denmark[17] and France, but a specific time-series analysis conducted on these countries—not included here for reasons of space—shows an increasing and significant relationship.[18] Italy and Sweden show a U-shaped relationship, characterized by a clear positive marginal effect. Overall, the tendency in this last group is for an increasing relationship between waste and income.

To summarize, we see that, leaving the slopes free to move across the different individual countries, we can categorize countries into three groups, based on the big differences between them. From a statistical point of view, this result is also confirmed by the *F*-test presented in the final row of Table 3, which confirms that letting the slopes move freely across countries provides more valuable information.[19]

During the period analysed, some countries were able to reduce the amount of waste and to change the income–environment relationship, promoting a process of delinking, driven by structural and policy factors. At the same time, some other countries showed an increasing relationship, in which an increase in income combines with an increasing trend in the total amount of waste generated.[20] This evidence should be very useful for the EU Commission and member states in transition for fixing a set of country-diversified targets and policy tools on waste generation, under the umbrella of the Waste Framework Directive and EU regulatory guidelines.

3.2 *Landfilled Waste*

The relationship between landfill and economic growth was hypothesized to be bell shaped, in accordance with the previsions of the more traditional WKC studies. In fact, although some EU15 countries are still increasing their share of landfill, on average—due to policy failure and land-based idiosyncratic features, and heterogeneity being rather striking across Europe (Figure 2)—shares of landfilled waste have been constantly decreasing. Therefore, we can expect to find a bell-shaped or even a strictly negative relationship in the turning points for some countries. Ireland, Portugal, Spain, Italy, and surprisingly Denmark and the Netherlands actually show a U-shape, where the lowest peak around 2005 is followed by a slight increase in landfilling (a recoupling in technical terms) over the 2006–2007 period, which stands to reason, given that these were two years of robust economic growth.

This expectation is confirmed by the following results, suggesting that from an EU average viewpoint, the period 1995–2007 is already on the descending side of the inverted U-shaped relationship, as far as the relationship between landfill and economic growth is concerned.

Even for landfilling, the results of the Pesaran and Breusch–Pagan tests confirm the presence of contemporaneous correlations across cross-sectional units (not shown). Table 4 summarizes the results for the constrained SURE. The core specification shows quite a low turning point (1,659.39€). In terms of averages, this means that 1995–2007 is already along the descending side of the inverted U-shaped relationship.

New and more interesting elements emerge from the other specifications, again showing the presence of a delinking trend, but this time associated with a high and out-of-range turning point (47,328€, while the income range is 5700–28,400€). This specification also sheds new light on the variable population density, which is highly statistically significant from both an economic and a statistical point of view (the size of the parameter is larger than in the waste generation case, higher than 3) and negatively related to landfilled waste. Both the opportunity costs linked to the higher value of land in densely populated and urban areas (value of land, of commercial activities crowded out by landfill sites, and other public investments) and the higher externality costs in more

Table 4. SUR: landfilled waste

	Constrained SUR	Constrained SUR—all covariates
CONS	1.49***	4.27***
$CONS^2$	−0.10***	−0.19***
DENSPOP	–	−3.68***
POLIND	–	−0.82***
TP (€)	1659.39	47,328.06
Breusch−Pagan tests of independence (*p*-value)	0.000	0.000

Note: (–) means not included. SURE estimations refer only to 12 countries.
*Significance at 10%.
**Significance at 5%.
***Significance at 1%.

densely populated areas, *ceteris paribus*, seem to be driving down the use of landfill as a disposal option (Mazzanti, Nicolli, & Zoboli, 2009).

Moreover, the policy index is significant and associated with a negative coefficient of relevant size. This means that the policy efforts implemented so far at the national level have promoted a stronger delinking between landfilled waste and domestic consumption. This is an important result because it underlines the potentially high level of effectiveness of—decentralized—European policy, in terms of diverting waste from landfill. Policies help in the effort to *tunnel through* the business-as-usual, endogenous delinking trend that is driven by economic drivers. This new insight, combined with the high significance of the population density-related variable, probably explains the progression from the previous strong absolute delinking to the relative delinking found in the last specification. To summarize, the use of a constrained SURE model in this analysis would suggest that the baseline income−waste relationship does not on its own explain landfill diversion. Other forces, such as population density, impact upon waste performance. This does not infringe the core evidence that we found to support the general effectiveness of environmental and waste policy efforts in driving down disposal by landfill.

Finally, Table 5 presents the results of the fully unconstrained SURE model. The regression results generally confirm the previous evidence of a bell-shaped income−landfill diversion relationship, with the exceptions of Spain, the Netherlands and Denmark—three cases of relatively worse performance envisaged above. All the other countries analysed show an absolute delinking in the waste−income relationship over the considered period.

In Denmark and the Netherlands, although in both countries there is space for landfilling, the U-shape seems to capture some statistical irregularities (see Figures A2−A3) within a still clear absolute delinking over the entire period.[21] Spain is the only case that does not show a clear 'marginal effect' that is more in line with the evidence of relative delinking. In other words, the size of the two estimated coefficients leads to a calculated weight of CONS and CONS2 biased towards the former. This is the only case where the turning point is within the estimated range.

The country-specific evidence from the SURE model shows its potential for interpreting *ex-post* dynamics and informing future policy. The threat of a recoupling is looming even for countries with relatively good performance. For

Table 5. Unconstrained SUR: landfilled waste

	CONS	$CONS^2$	TP (€)	Delinking
Austria	3.71***	−0.33***	269.7	Absolute
Denmark	−120.6***	6.05***	21,160	Absolute
Finland	43.74***	−2.32***	12,296.32	Absolute
France	84.01***	−4.45***	12,358.26	Absolute
Germany	12.97***	−1.3***	142.27	Absolute
Greece	17.38***	−0.92***	12,210.49	Absolute
Ireland	15.59***	−0.82***	12,204.52	Absolute
Italy	22.7***	−1.25***	8642.7	Absolute
The Netherlands	−144.14**	7.28**	19,837.1	Absolute
Portugal	40.9***	−2.27***	8052.68	Absolute
Spain	−10.14***	0.54***	10,209.04	Relative
UK	48.21***	−2.54***	12,930.44	Absolute
Breusch–Pagan tests of independence (p-value) = 0.000				
F-test of slope homogeneity (p-value) = 0.000				

Note: SURE estimations refer only to 12 countries. The Breusch–Pagan tests for cross-sectional independence in the residuals are used, while the F-test is a test of slope homogeneity.
*Significance at 10%.
**Significance at 5%.
***Significance at 1%.

instance, the evidence for Denmark and the Netherlands may divert greater attention to potential future real recoupling.

3.3 *Robustness Checks and Policy Endogeneity*

The above results, however, can be biased by the potential presence of simultaneity—a source of endogeneity—between the policy variable and the dependent variable and the consequential correlation between the disturbance term and the 'endogenous' regressor. It is, in fact, reasonable to presume that countries with the worst waste management performances may tend to enact stricter regulation in order to fill the gap with relatively more efficient ones. As robustness checks, we perform a three-stage least squares (3SLS) model analysis using the Stata command 'reg3', in which (i) in the first stage, we regress the policy variable (POLIND) against some of its possible determinants, (ii) in the second stage of the analysis, we obtain a consistent estimate for the covariance matrix of the equation disturbances, and (iii) in the final stage, we perform a generalized least squares (GLS)-type estimation using the covariance matrix estimated in the second stage and the 'instrumented values' in place of the right-hand-side endogenous variables (for further references, see the Stata manual and Greene, 2000, pp. 405–407). In particular, the first step of this procedure is crucial, as it drives the choice of 'good instruments'. We present here the following variables which are often used in the literature that deals with 'policy endogeneity' as possible instruments for the first stage: social polarization-related variables (e.g. Gini coefficient) and GDP. In particular, we expect the Gini coefficient to be negatively and significantly correlated with the policy effort (Vona & Patriarca, 2011), while, considering environmental protection as a normal good, we expect GDP *per capita* to be positively correlated with the environmental policies (Diekmann & Franzen, 1999).

Table 6. Robustness checks and endogeneity: 2SLS and 3SLS

	Waste generated 3SLS	Waste landfilled 3SLS	Waste generated 2SLS	Waste landfilled 2SLS
CONS	0.4727***	29.544***	7.209***	21.016***
$CONS^2$		−1.348***	−0.3849***	−1.028**
DENSPOP	0.0378***	−0.3568***	−1.2645	−1.841
POLIND	−0.1851*	−9.687***	−0.3310*	−2.9342***
First-step equation	POLIND = $\alpha + \beta_1$(GDP) + β_2(GINI) + β_3(MSW-GENER) + ε	POLIND = $\alpha + \beta_1$(GDP) + β_2(GINI) + β_3(MSW-LAND) + ε	POLIND = $\alpha + \beta_1$(UNEMPL) + β_2(POL-STAB) + β_3(GINI) + ε	POLIND = $\alpha + \beta_1$(UNEMPL) + β_2(POL-STAB) + β_3(GINI) + ε
Country FE	No	No	Yes	Yes
Overid. test (Sargan, *p*-value)			0.2652	0.2210
N	195	195	143	156

Note: First-step equations are available upon request.
*Significance at 10%.
**Significance at 5%.
***Significance at 1%.

Moreover, as a second robustness check, more traditional two-stage estimators (2SLS) are also adopted, using a different set of instruments and controlling for country fixed effects. In such cases, besides the Gini coefficient, we use as 'exclusion restriction' the proxy of political stability and unemployment rate. The link between social polarization and policy stability has been stressed in many contributions. Following Easterly *et al*. (2006) and Keefer and Knack (2002), it is possible to argue that politicians might not be able to enhance good policies if the community in which they live experiences significant social constraints or, in other words, that the absence of social cohesion and the presence of social polarization can make the policy environment less secure and less stable. These elements have a direct consequence on environmental policies, which, in turn, may have important effects on waste management choices. Consequently, the presence of social polarization may affect waste management choices through the lever of environmental policies.

Regression results are presented in Table 6. The main results mainly confirm previous empirical evidence. In all cases except the 3SLS waste generation estimates, we are in the presence of delinking, and the covariates tend to perform very similarly to the previous analysis. This is reasonable given that delinking for waste generation is more dependent upon some EU countries and is a less diffuse phenomenon overall.

Interestingly, once we controlled for the potential simultaneity bias, we obtained a higher coefficient level for the policy variable in the case of landfilled waste. The effectiveness of landfill diversion-oriented policies remains high, but on the other hand, even though the significance of POLIND in waste generation regression increases to 10%, we cannot be confident in taking such a threshold as a sufficient signal of effectiveness. Econometrics tells us that more intense and diffuse policy efforts will be needed to generate a significant policy-driven turning point for waste generation as well.

4. Conclusions

This article provides new evidence on the socio-economic and policy drivers of two main key waste variables: waste generation and landfill diversion. It strictly focuses on policy effectiveness, policy endogeneity and the heterogeneity of country performances in the EU.

The evidence shows that although waste generation–income macroeconomic elasticity has decreased compared with that observed in the 1990s, neither environmental taxation nor specific waste policy efforts have produced substantial 'absolute delinking' regarding waste being generated. This (expected) result is demonstrated even when taking policy endogeneity into account. Given that member states must propose new waste strategies by 2013, including specific waste prevention targets, it is a signal that we need to take urgent action on how to shape efficient and effective policies targeted at reducing waste generated per GDP and *per capita*, in order to complement established but evidently not sufficient waste management and disposal targets defined by the Landfill and Incineration Directives among other normative tools.

In terms of the possibility of identifying 'groupings' of countries through the unconstrained SURE procedures, we find three main groups: the first is Austria, Germany, Greece, Portugal and Spain, characterized by the presence of absolute delinking. This result is as expected, based on the fact that Austria and Germany are leaders in the waste sector and in waste management and show performances above the EU average. The presence in this group of the three other countries is surprising and needs further investigation in the future. The second group of countries, which is characterized by the presence of a relative delinking, is composed of the UK and the Netherlands. The remaining countries show no evidence of delinking: the tendency in this last group is towards an increasing relationship between waste and income.

The picture is different for landfilled waste. For most countries, a turning point was achieved in the mid-1990s. We find that environmental waste policy stringency has affected landfill diversion: stringency has triggered diversion of waste from landfilling. We show that, as expected, policy efforts are endogenous. The 'effectiveness' of policies is even augmented when capturing their endogeneity.

Population density, as expected, is a significant structural factor driving down landfilled waste, for reasons associated with the often very high economic opportunity costs of landfill sites and the higher environmental social costs in densely populated areas.

A bell-shaped income–landfill diversion relationship emerges for all countries, except for Spain, the Netherlands, and Denmark. For Denmark and the Netherlands, despite both countries perhaps possessing land space for landfilling, the U-shape seems to capture more statistical irregularities within a still clear absolute delinking path over the entire period. In contrast, Spain is the only case showing an unclear 'marginal effect', more in line with evidence of relative delinking. Nevertheless, we highlight that our results suggest that the possibility of recoupling is real, which may also be relevant for countries with relatively good environmental performance over the past. For instance, the evidence that we obtain for Denmark and the Netherlands may drive attention towards a potential future real recoupling. Future research could extend waste economics by focusing on unexplored issues such as transboundary shipments of waste, which would overlap the trade and environmental policy fields, the spatial dimensions of waste flows across countries and within regions, new assessments and policy indicators, the influence of socio-demographic trends in forecasting scenarios, the role of the waste market structure in explaining waste-related performance, and differences between advanced countries such as the EU15, and EU transition economies that are only entering the sphere of market-based environmental policy.

Notes

1. Then other works followed in providing theoretical explanations (Chimeli & Braden, 2005, 2009; Kelly, 2003).
2. Recycling is also an important target. We recall that as far as data availability is concerned, EUROSTAT data calculate recycling of waste as the residuals obtained by detracting landfilling and incineration from waste generation. Statistically speaking, it is not feasible and meaningful to analyse recycling under such premises.
3. National waste management strategies happen to be very different in Europe (Buclet & Goddart, 2001).
4. The literature includes examples of delinking studies that use SURE or a random-coefficients linear regression model (Swamy, 1970), in order to account for the presence of slope heterogeneity (Cole, 2005; List & Gallet, 1999).
5. For the Irish case, see Davies and O'Callaghan-Platt (2008).
6. We do not use EU27 data given the current lower availability and reliability of waste data for 'newcomers' eastern EU countries.
7. EIONET is a partnership agency of the EEA and its member countries.
8. We can hypothesize that the backward effects of landfill policies and waste management actions on the amounts of MSW generated are difficult to be exerted. Nevertheless, since our synthetic policy index also captures the variety of waste measures implemented by a country in addition to landfill diversion actions, some effects may theoretically emerge.
9. More traditional fixed effects which are coherent with the nature of our panel have been tested as a preliminary exercise but not shown for brevity. It is known that SUR specifications deal with slope heterogeneity and/or cross-section correlation. When it is shown that correlation is an empirical fact, the adoption of constrained SUR improves the efficiency of fixed effect (FE). When slope homogeneity is rejected, unconstrained SUR deals with it. We discuss and tackle such issues throughout the article.
10. In the last step, we dropped three countries, in order to allow estimation of the SURE model with unconstrained slopes. This is because we have a relatively small T. We dropped all observations relating to the three countries with the lowest amounts of waste generation and the three countries with the lowest amounts of landfilled waste in the second phase of the analysis.
11. Fixed-effect model (FEM) results (tested as baseline specification, and not shown in the paper, but available upon request) show a relative delinking associated with quite a low elasticity (in the range 0.31–0.38 across all the specifications tested), with population density and the three policy variables being never significant.
12. Table A3 in the appendix shows an FEM estimation in the case of waste generation to highlight this point. Breusch–Pagan tests are available upon request.
13. The test can be performed with the Stata command xttest2, which tests the null hypothesis of cross-sectional independence, while the Pesaran test, performed with the Stata command xtcsd, tests for cross-sectional dependence following the methods described in Pesaran (2004).
14. The countries with the lowest levels of waste production, that is, Luxembourg (330,473 kg), Finland (2,675,416 kg) and Ireland (3,389,645 kg), were dropped from the data set to allow SURE given the constraints. See Table A2 in the appendix.
15. See Table 1. We remark that we use the EUROSTAT data on 'share of environmental taxation—net of energy—on GDP at constant prices', wherein landfill taxation is an important pillar.
16. We refer to Tables A1–A2 in the appendix.

17. Denmark's performance may be influenced by the fact that construction and demolition waste was recently accounted as MSW. This shows how data commensurability is an issue in waste statistics.
18. Analogously, an unconstrained SURE with only consumption as the main economic driver shows a statistically significant and positive relationship between income and waste generated. These results confirm the absence of delinking for Belgium, Denmark and Finland.
19. The test follows an *F*-statistic and tests the hypothesis of slope homogeneity (under the null).
20. From a different but complementary perspective, we calculate the delinking indices following the OECD (2002) formula, which we present in the appendix (Figure A1).
21. A possible explanation for the somewhat counterintuitive result for Denmark and the Netherlands might also be a consequence of forcing a quadratic specification, where we might actually observe reduction and stabilization in landfill use. The last few years of the panel nevertheless show an increase in waste that could be driven by a contingent economic growth. This shows the necessity to additionally research WKC through semi-parametric tools in the future. We thank one referee for this hint.

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Appendix

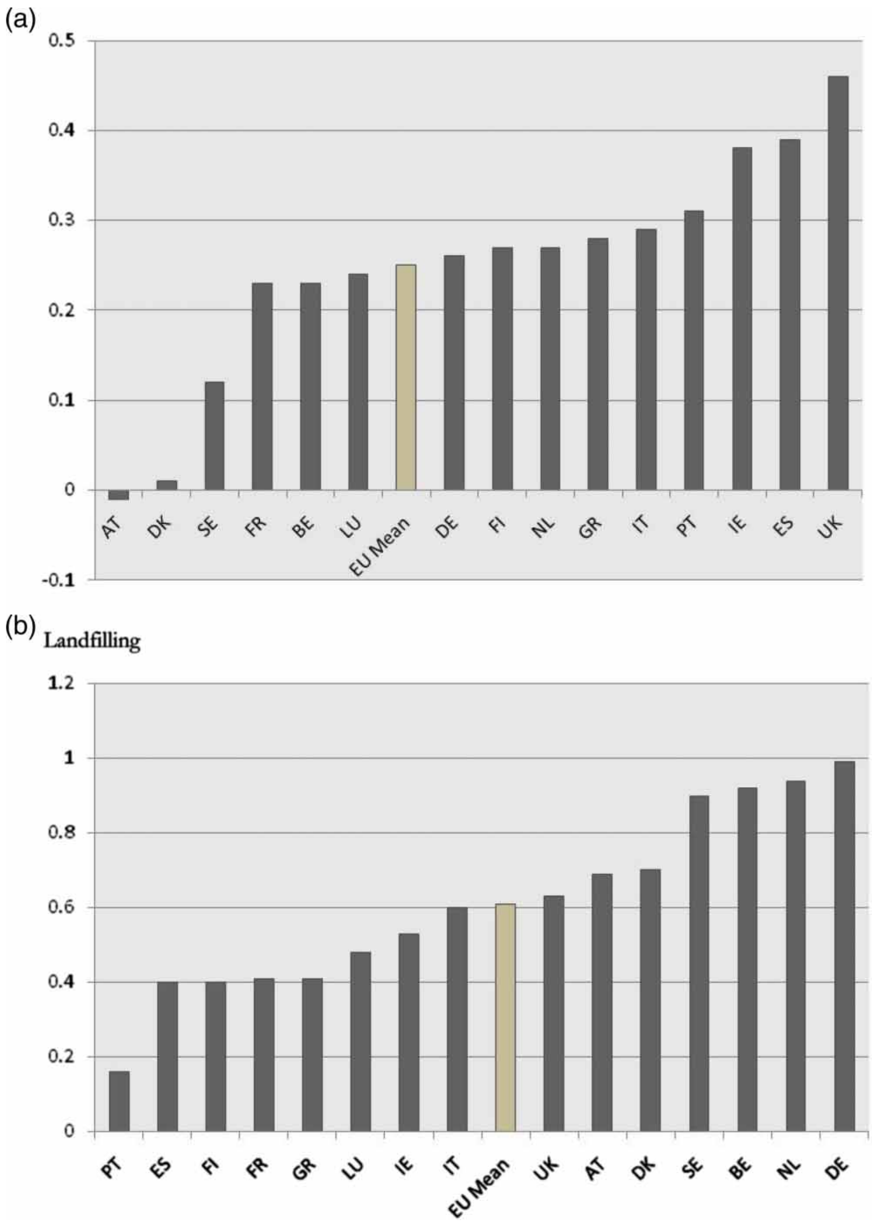

Figure A1. Delinking indices for waste generation (a) and landfilling (b)—OECD (2002).

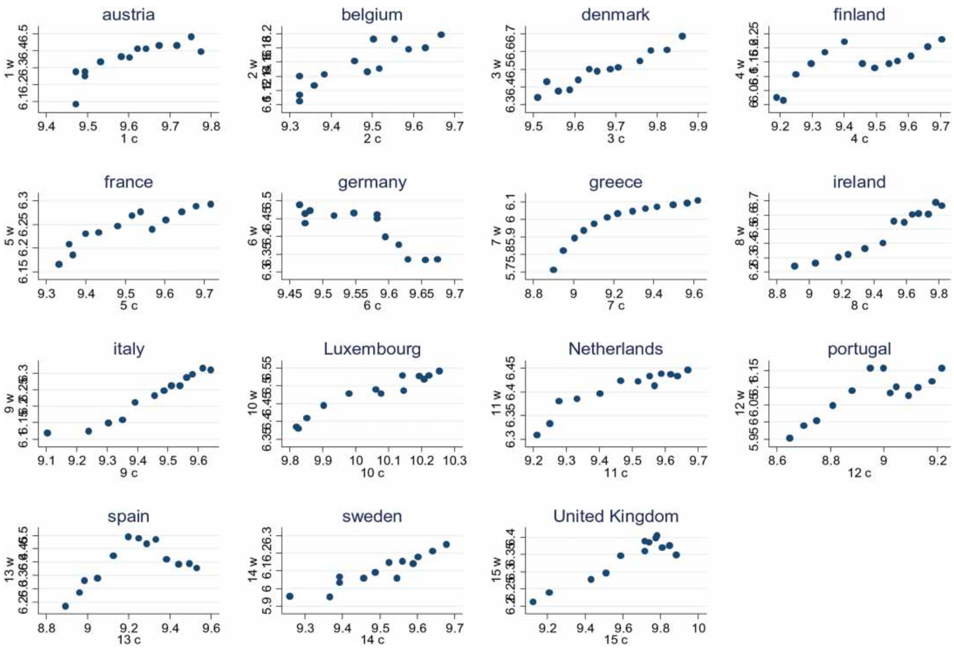

Figure A2. Waste generation *vs.* consumption *per capita*.

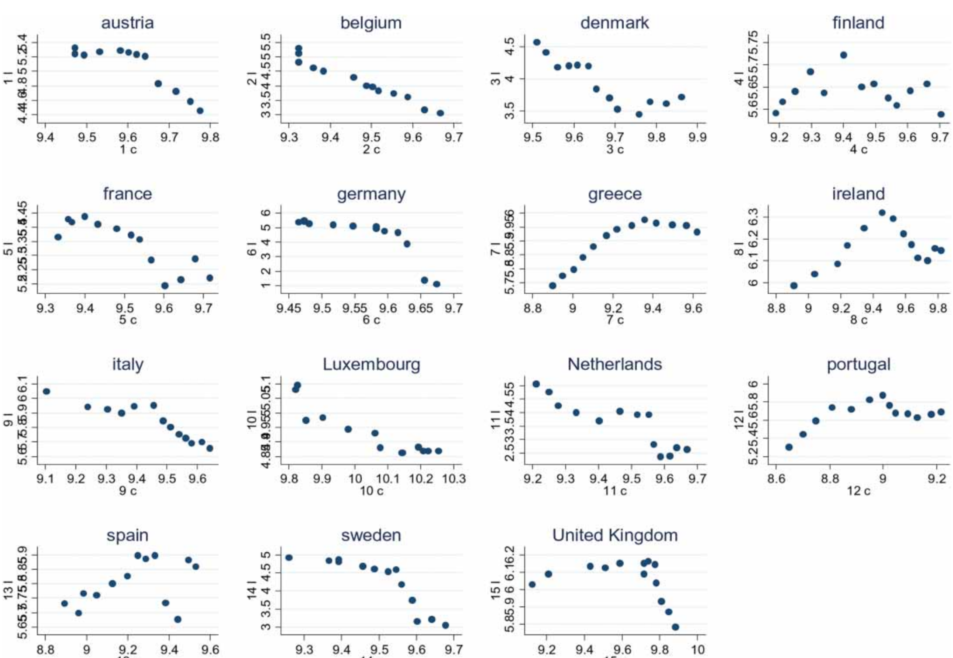

Figure A3. Waste landfilled *vs.* consumption *per capita*.

Table A1. Acronym list

COD	Countries
CY	Cyprus
BG	Bulgaria
SI	Slovenia
LT	Lithuania
IT	Italy
UK	United Kingdom
IE	Ireland
EE	Estonia
HU	Hungary
GR	Greece
ES	Spain
CZ	Czech Republic
MT	Malta
PL	Poland
FI	Finland
RO	Romania
LV	Latvia
DE	Germany
FR	France
AT	Austria
PT	Portugal
BE	Belgium
SK	Slovakia
LU	Luxembourg
NL	The Netherlands
SE	Sweden
DK	Denmark

Table A2. Waste generated and waste landfilled (kg)

Countries	Waste generated	Countries	Waste landfilled
Luxembourg	330,473.78	Luxembourg	61,904.31
Finland	2,675,416.19	Sweden	191,378.40
Ireland	3,389,645.44	Belgium	222,275.21
Denmark	4,363,114.28	Denmark	223,330.44
Sweden	4,720,667.13	Holland	229,011.89
Austria	4,954,457.03	Germany	246,944.72
Portugal	5,002,772.84	Austria	713,707.38
Greece	5,004,939.52	Finland	1,408,946.99
Belgium	5,207,590.73	Ireland	2,013,949.64
Holland	10,305,534.96	Portugal	3,147,931.22
Spain	26,151,083.03	Greece	4,211,745.98
Italy	32,522,207.85	France	11,727,545.90
France	34,295,147.74	Spain	15,566,120.85
UK	34,787,152.97	Italy	16,911,548.08
Germany	46,425,606.98	UK	19,704,611.12

Table A3. Waste generation: FEM, Pesaran tests

	FEM	FEM
CONS	0.35***	0.38***
DENSPOP	0.18	0.17
POLIND	–	−0.02
ENVTAX	–	–
Pesaran test[a] (p-value)	0.0088	0.0090
F-test (p-value)	0.0000	0.0000

Note: In all the estimations, we use the Huber/White/sandwich estimator of variance adjusted for correlations in the error terms over time within individuals (but not across individuals). This means that we consider that $\mathrm{Var}(\varepsilon_{it}) = \sigma^2\varepsilon_{it\,\forall}\, i = 1, \ldots, N, t = 1, \ldots, T$, and that $\mathrm{Cov}(\varepsilon_{it}, \varepsilon_{is}) \neq 0_{\,\forall}\, t \neq s$. (−) means not included.

[a]Breusch–Pagan test results, not shown for reasons of space, are consistent with these results.

*Significance at 10%.

**Significance at 5%.

***Significance at 1%.