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Waste generation, incineration and landfill diversion

De-coupling trends, socio-economic drivers and policy effectiveness in the EU

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Abstract

Waste generation and waste disposal are issues that are becoming increasingly prominent in the environmental arena both from a policy perspective and in the context of delinking analysis. Waste generation is still increasing proportionally with income, and economic and environmental costs associated to landfilling are also increasing.

This paper provides a comprehensive analysis of waste generation, incineration, recycling and landfill dynamics based on panel data for the EU25, to assess the effects of different drivers (economic, structural, policy) and the eventual differences between western and eastern EU countries.

We show that for waste generation there is still no Waste Kuznets Curve (WKC) trend, although elasticity to income drivers appear lower than in the past. Landfill and other policy effects do not seem to provide backward incentives for waste prevention. Regarding landfill and incineration, the two trends, as expected, are respectively decreasing and increasing, with policy providing a strong driver. It demonstrates the effectiveness of policy even in this early stage of policy implementation. This is essential for an ex post evaluation of existing landfill and incineration directives. Eastern countries appear to perform generally quite well, thus benefiting from their EU membership and related policies in terms of environmental performances. We may conclude that although absolute delinking is far from being achieved for waste generation, there are first positive signals in favour of an increasing relative delinking for waste generation and average robust landfill diversion, and various evidence of a significant role of the EU waste policies implemented in the late 1990s and early 2000s on landfill diversion. Waste prevention is nevertheless the next necessary target of waste regulatory efforts.

Jel: C23, Q38, Q56

Keywords: Waste Kuznets Curves, delinking, waste generation, waste disposal, landfilling, landfill policies, evaluation methodology, incineration

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1. Introduction

Indicators of 'decoupling/delinking' are becoming increasingly popular for detecting and measuring improvements in environmental/resource efficiency with respect to economic activity. The Organisation for Economic Cooperation and Development (OECD, 2002) has conducted extensive research into use of decoupling indicators for reporting and policy-evaluation purposes and the European Environment Agency's state-of-the-environment reports (EEA, 2003a, b, c) use a number of decoupling or resource-efficiency indicators. EEA (2006) also highlights the importance of market based instruments for achieving stronger degree of delinking for waste indicators.

The European Union (EU) policy 'thematic strategies' on both resources and waste, entail reference to 'absolute' and 'relative' delinking indicators (EC, 2003a,b; Jacobsen et al., 2004). The former being a negative relationship between economic growth and environmental impacts associated to the descending side of an inverted U shape according to the Environmental Kuznets Curves (EKC) framework. The latter a positive but decreasing, in size, income-environment relationship, the ascending path. A positive lower than unity elasticity in economic terms. No delinking is observed when we are on the ascending part of the EKC with, in addition, a unitary or higher than unity elasticity. The achievement of increasing delinking experience is of primary necessity for waste, an issue which is not of lower relevancy, regarding environmental impacts and economic costs, than climate change (figure 1).

Andersen et al. (2007) recently estimated waste trends for EU15 and EU10 new entrants, and found that waste generation is linked to economic activities by non-constant trend ratios. This rather descriptive analysis of delinking in EU countries provides forecasts in favour of relative delinking; but it in any case does not confirm WKC evidence. Projections for 2005-2020 for the UK, France and Italy, show a growth in MSW of around 15-20%, which, at least at first sight, may be compatible with relative delinking with respect to GDP and consumption growth.

As recognised by the EEA "It is increasingly important to provide answers to these questions because waste volumes in the EU are growing, driven by changing production and consumption patterns. It is also important because there is a growing interest in sharing best practice and exchanging national-level experience across Europe, with the common goal of achieving more cost-effective solutions to the various problems being faced" (EEA, 2007).

The EEA shows that countries can be categorised under three waste management 'groupings', according to the strategies for diversion of municipal waste away from landfill and the relative shares of landfilling, material recovery (mainly recycling and composting) and incineration. From an economic science standpoint, though costs and benefits should be evaluated in each specific situation (Pearce 2004; Dijkgraaf and Vollebergh, 2004), calling for a possible better efficiency of decentralised policy implementation – at country, regional level, a 50% target of recycling may be judged as economically and environmentally sensible in theoretical terms (Huhtala, 1997)

The first grouping comprises countries which maintain high levels of both material recovery and incineration, and which have relatively low landfill levels. The second grouping brings together countries with high material recovery rates and medium incineration levels and where there is a medium dependence on landfill. The third grouping contains those countries whose material recovery and incineration levels are both low and whose dependence on landfill is relatively high (EEA, 2007, 2008).

From a 'waste accounting' perspective, waste generation (WG), the amount of collected waste, is disentangled in and consequentially managed by three possible 'options': recycling (R) and material recovery, including composting (C) and incineration (I), if presents energy recovery; incineration (without energy recovery), landfilling (L, that could also witness energy recovery). Incineration is a hybrid option; if we plausibly exclude the current possibility of incineration without energy recovery in the EU, its net social benefit should be positive and its place within waste recovery, not final disposal[2]. It remains that some (treated) amounts of waste flowing out recycling and incineration processes may then be disposed of in (regulated) landfills, that are defined as disposal even if present some recovery. The mass balance equation is then: WG[3]= WR(C+R+I) + L, or WG =WR(C+I) + I + L.

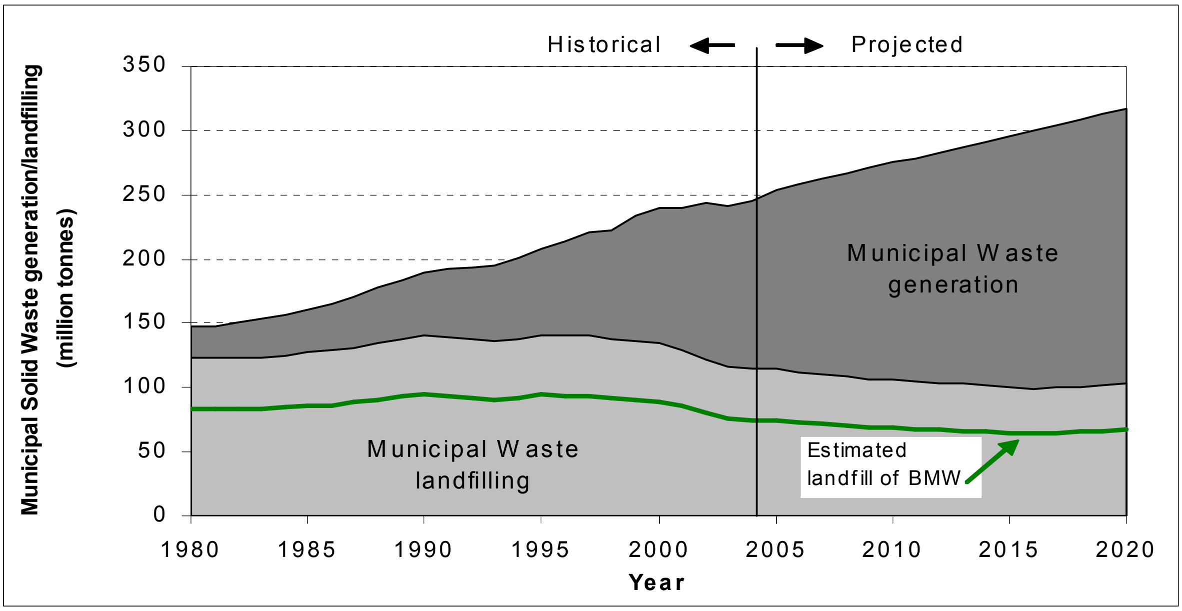
[2] As example, the objectives of the Packaging Directives are fixed in terms of both total recovery, including incineration, and recycling, as a share of it (EEA, 2005).

[3] If we include the possibility of waste prevention /reduction occurring by the implementation of 'closed loops' strategies in household and production processes, WG could be considered the net output of total waste generated by economic growth and the part that is integrated in economic processes before collection. We should note that a shared view across countries over the legal definition of waste does not exist. Waste flows that are recovered by closed loop integration may even be outside a core definition of waste flows as materials without any value for the economic agent that 'produce' them.

We note that landfilling is still the predominant treatment option for the EU's municipal waste. However, there are significant differences in how dependent countries are on landfilling. Figure 2 clearly shows that several countries have already arrived at very low landfilling rates. Those countries not only have a substantial level of incineration; they also have a high level of material recovery. In general, there seems to be two strategies for diverting municipal waste from landfill: to aim for high material recovery combined with incineration, or to aim for material recovery which includes recycling, composting and mechanical biological treatment (EEA, 2007).

The environmental impacts of landfilling are massive (Pearce, 2004; El Fadel et al., 1997; Eshet et al., 2007)). Nevertheless, though at the top of EU environmental waste hierarchy, landfilling should not be taken by default as the best economic practice in all situations, costs and benefits being influenced by economic and technological factors. See among others, for examples of economic assessments of different waste disposal strategies, Pearce (2004) and Vollebergh and Dijkgraaf (2004). It is worth noting that waste generation reduction at source, by imposing policy targets in terms of waste generated per capita, is probably the most effective and efficient way of handling the problem in the long run. Given its potential high cost in the short run, the first phase of policy implementing at Eu level has focused on landfill diversion and recycling/recovery increasing shares, thus including incineration. There is a need to empirically analyse whether such policies have been effective so far in changing the endogenous relationship between economic growth and waste trends. In other words, given that waste policies are motivated by the various negative externalities arising at different stages of the filieres (at source, at disposal level), as CBA should inform ex ante which option to pursue and what tax level to impose, ex post effectiveness analysis has the aim of assessing short run and long run effects of policies on there main target: driving down the WKC curve. In absence of such policies, we may expect a somewhat linear positive relationship between waste generation and growth, and landfill diversion would be affected only by market prices and opportunity cost (of land)[4].

Figure 1: Projected generation and landfilling of municipal waste in the EU25

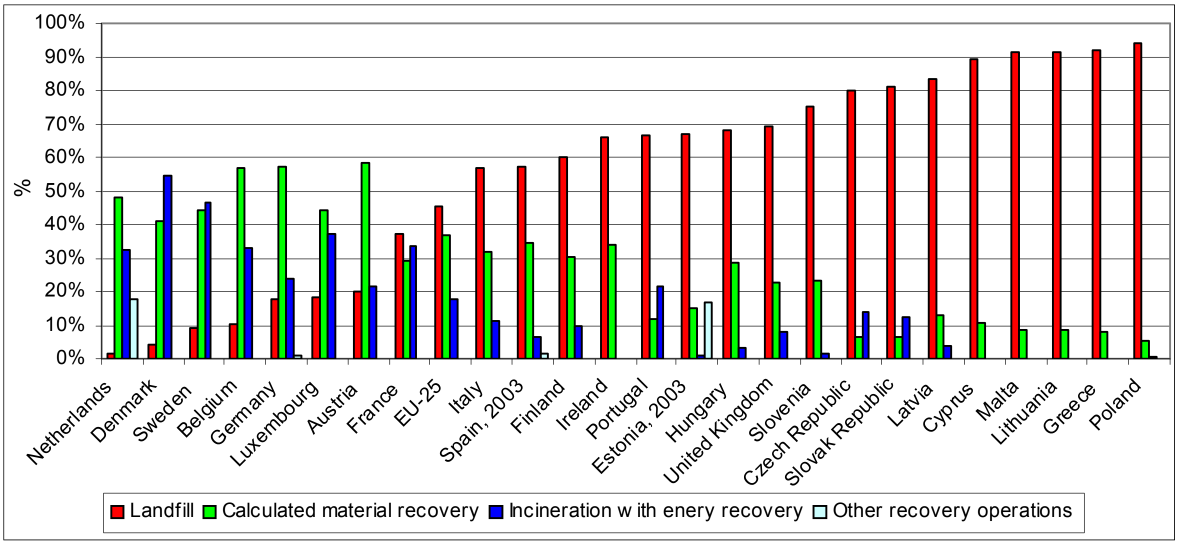


Source: ETC/RWM (2007), Figures from 1980-2004 are data from Eurostat. Figures from 2005-2020 are projections. BMW (Bio degradable Municipal waste)

It is clear that market evolution and policy introduction may both change the 'economic' notion of waste, not always fitting the mere legal counterpart. An example is the big issue of Construction & Demolition waste, where the industry has claimed and lobbied to have the allowance of re-using materials in the same or nearby construction sites, instead of being forced to dispose of such often valuable materials in specific landfills.

[4] A qualitative assessment of landfill and incineration policy tools at EU and country level is provided by ETC/RWM & EEA (2008).

Figure 2. Use of landfilling, incineration and material recovery as treatment options in 2004



Source: EEA (2007), Eurostat Structural Indicators on municipal waste generated, incinerated and landfilled, supplemented with national statistics.

This paper provides empirical evidence on delinking trends for municipal solid waste (MSW). The main contribution and motivation of the paper is primarily the total lack of robust and updated empirical evidence, for a vast regional area like EU, regarding economic and policy drivers for waste dynamics. Main EU waste policies, though they witness a sufficiently long life and are a pillar of EU environmental policy, have not been empirically scrutinised, if not by qualitative methods. Empirical evidence on waste Kuznets curves (WKC) dynamics for waste is still scarce. Research on delinking for materials and waste is far less developed than research into air pollution and greenhouse gas emissions.

The still limited research results could be a serious problem from a policy perspective. Secondly, analyses that exploit cross country highly disaggregated panel data on waste is even scarcer. Only single-country case studies using data at regional, provincial or municipal level have recently emerged in the literature. In spite of the significant environmental, policy and economic relevance of waste issues, there is very little empirical evidence on delinking even for major waste streams, such as municipal and packaging and other waste. Analyses of policy effectiveness are also scarce. Studies of waste management optimization schemes or evaluation of externalities largely prevail. Economic analyses have in fact predominantly focused on cost benefit assessment of relative waste sites externalities (of fixed and variable nature) and on the acceptability for local communities, with or without compensations, aimed at achieving Kaldor-Hicks Pareto improvements for society as a whole (Gallagher et al., 2008). Works oriented towards waste management optimization or evaluation of externalities thus largely prevail, regarding mainly landfill and also other waste disposal strategies. The focus on cost benefit analyses and landfill siting decision has prevailed so far, partly due to the lack of reliable data at country level and within country level (Pearce, 2004)[5].

Our main objective is to provide new empirical evidence on WKC and policy effectiveness for a policy relevant region, such as the EU, disentangling socio-economic and policy factors. The waste Kuznets curve is a relevant field where assessing the effects of socio-economic and structural factors in the BAU scenario, and the additional role of policy levers in explaining the eventual delinking between environmental pressure and growth. Absent policy, we expect a lower delinking or even no delinking, that has characterised the evidence for waste so far. A secondary objective is to identify differences between the EU15[6] group of countries and new entrants to the EU with respect to waste drivers, delinking trends and policy effects, depending on both actions

[5] We quote among the others Powell and Brisson (1995), Miranda et al (2000); Eshet et al (2004), Brisson and Pearce (1995), Dijkgraaf and Vollebergh (2004). Recently Caplan et al (2007) offer an example of how economic evaluation techniques may inform landfill siting process. Instead, Jenkins et al (2004) present a sound and very interesting econometric analyses on the socio economic factors that explain the level of monetary compensation paid to landfill host communities.

[6] We hereafter refer to EU15 for the group of western EU member countries, EU25 for the total group of EU countries after recent incoming members got in 2006, mainly eastern EU countries, which we define EU10 (e.g. Poland).

taken as a consequence of the 1999 Landfill Directive Implementation[7] and from 'early policy actions' taken by some countries even before (e.g. Germany)[8].

We find that although complete delinking is far from being achieved, especially for waste generation, some positive signals are emerging, with a quite significant role played by EU waste policies implemented in the late 1990s and early 2000s in diverting waste away from landfill and towards incineration and recycling. Nevertheless, the role played by other socio economic and technological factors (R&D) should not be overlooked. Policies interact with other socio-economic and economic factors within a scenario of endogenous development in which vicious or virtuous circles drive regions' and countries' performance in relation to waste.

The paper is structured as follows. Section 1 presents recent evidence on WKC, in order to highlight the urgent need to intensify research in this area to enable policy evaluation. Section 3 defines the conceptual framework and the empirical model. Section 4 discusses the original dataset used in this study and comments on the empirical results regarding waste generation, incineration, and landfill and recycling options. Section 5 concludes.

2. Waste indicators, EKC and delinking analysis: recent empirical evidence

Since the pioneering work of Grossman and Krueger (1995), World Bank (1992) and Holtz-Eakin and Selden (1992) interest in the so-called Environmental Kuznets Curve (EKC) has increased[9]. The EKC hypothesis is that, for many pollutants, relationships between per capita income and pollution show inverted U-shapes, following the more famous original Kuznets hypothesis which has been considered over time in its original and revised forms. Most investigations have focused on major air emissions, though evidence for other externalities like local atmospheric and water emissions, and waste has begun to accumulate. A decoupling between income growth and CO_2 emissions is not (yet) apparent for many important economies in the world (Vollebergh and Kemfert, 2005); where it is observed, it is a relative rather than the absolute delinking assumed by the EKC hypothesis (Fischer-Kowalski and Amann, 2001). See fig.3 below for a sketch of the framework.

Theoretically based works do not predominate in studies of EKC[10] though some contributions have aimed at establishing some foundations for the empirics of EKC. They generally try to explain EKC dynamics by a preference based on technological externality type, and policy factors. Some of these works are worthy of further comment. Andreoni and Levison (2001) is a seminal work that suggests that EKC dynamics may be quite simply technologically micro founded, and not strictly related to growth and externalities issues. Kelly (2003) shows that the EKC shape depends on the dynamic interplay between the marginal costs and benefits of abatement. Chavas (2004) also provides a dynamic theoretical scenario that motivates EKC.

At a more macroeconomic level, Brock and Taylor (2004) integrate the EKC framework with the Solow model of economic growth; they show that this revised model generates an EKC relationship between both flow of pollution emission and income per capita, and the stock of environmental quality and income per capita, with the resulting EKC being either an inverted U shape or strictly declining. Chimeli and Braden (2005) integrate the EKC into a model of total factor productivity. Low levels of income involve high values of discount rate, which are obstacles to the adoption of a pollution abatement policy. Only when the discount rate

[7] "The Landfill Directive pursues two approaches: firstly to introduce stringent technical requirements for landfills; and secondly, to divert biodegradable municipal waste (BMW) from landfills by setting targets for the landfill of BMW in 2006, 2009 and 2016. Even more ambitious targets for the post-2016 period have recently been proposed by the European Parliament. The targets are based on the quantity generated in 1995, and the main implication of this approach is that there is an absolute limit placed on the quantity of biodegradable municipal waste (in tonnes) that can be landfilled by the specific target dates" (EEA, 2007). The Incineration directive (Directive 2000/76/EC on the incineration of waste) is an ancillary and complementary piece of the EU waste policy strategy.

[8] To date, the Landfill Directive has been effective in terms of improving the waste treatment standard (e.g. closing old landfills) and increasing the capacity for alternative waste treatment. For example, the directive has had less effect on the diversion in Germany and the Flemish Region where a diversion had begun years before the adoption of the directive, and who also were among the initiators/supporters of the Landfill Directive. For the New Member States, the EU accession has been a major driver.

[9] We refer to Cole et al. (1997), Dinda (2004), Stern (2004), Andreoni and Levinson (2001), Copeland and Taylor (2004), Brock and Taylor (2004, 2003) and Galeotti (2007) for major critical surveys and discussion on the theoretical underpinnings of delinking and EKC studies, which has so far analysed air and water emissions, mainly CO_2, with a limited focus on waste streams. A full critical survey of this very vast and mounting literature is outside the scope of this study.

[10] A recent seminal paper by Copeland and Taylor (2004) surveys the literature and presents a model in which sources of growth, increasing returns to abatement, income and threshold effects are the main drivers of EKC.

falls, as a consequence of growth, is it possible to implement measures for emissions reductions, leading to an inverse U-shaped income-pollution pattern.

Notwithstanding the increasing relevance of theoretical studies on EKC, it is the quantitative side of the analysis that has dominated, and nevertheless still provides scope for research improvements at the margins. In fact, with some exceptions which we comment on below, studies using macro-panel data generally assume slope homogeneity across countries, and employ the classic fixed or random effects estimators or the more recent panel cointegration approach.

At a technical/econometric level, recent research directions have explored parametric and semi parametric specifications and heterogeneous panel estimations or Bayesian procedures (Cole, 2005; Mazzanti et al., 2008). We can summarize the advances and possible research steps by saying that different improvements are still possible to achieve by focusing on (i) slope heterogeneity in panel settings, (ii) dynamic specifications (e.g. GMM, Kiviet LSDV correction); (iii) single country panel datasets where within-country heterogeneity is exploited at regional level; (iii) specific time series at national or state/regional level, provided data are available for sufficiently long times. We argue that future empirical efforts should be concentrated using newly constructed, more heterogeneous and longer datasets at country level or for samples of countries in homogenous relevant areas, rather than cross country international datasets which may produce too general results and hide some important aspects in the 'average' figure that arises from econometric analysis (Brock and Taylor, 2004).

In general, although some recent works cast into doubt the very foundations of EKC results, by stressing their contingency on the empirical model and specifications used (Harbaugh et al., 2002; Stern, 2004, 1998), we believe (with other authors) that the EKC setting is a frame which may still generate useful insights for the understanding of ecological-economic dynamics and for policy evaluation (Copeland and Taylor, 2004).

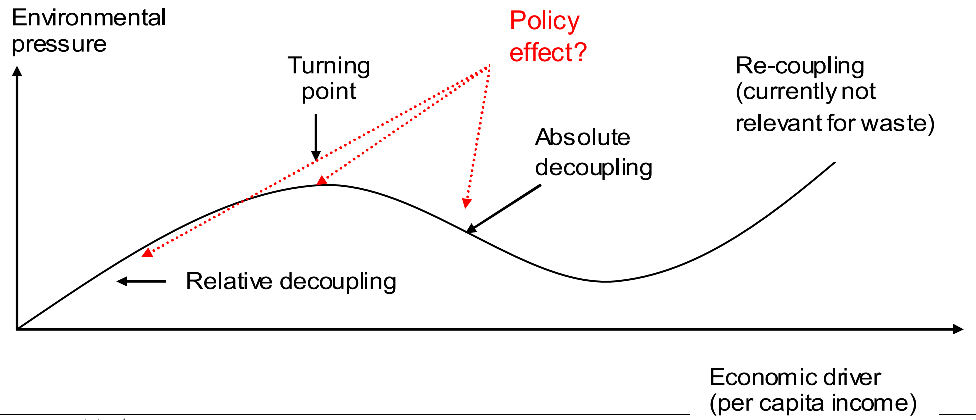
We here briefly review the evidence on waste delinking and waste management / policy evaluation, taking mainly a chronological perspective. See table 1 for a summary of main works.

Some evidence based on cross country regression analysis of data from the 1980s was presented even in the report (World Bank, 1992), which gave birth to the EKC literature. No WKC was presented. More recent reports (DEFRA; 2003) highlight the positive elasticities of waste generation to income as a primary policy concern: waste generation seems still to be characterised by a strict relationship between economic drivers and environmental pressures.

Fig.3 Box: Income-environment relationships, dynamic trends and the De-coupling

The reasoning around de-coupling can be framed by referring to the Environmental Kuznets Curve (EKC) model, that describes the state of the dynamic relationship between environmental pressures and economic drivers. This model proposes an inverted U shape relationship between per capita income and environmental pressure (figure below). The model implies that in the first stage an increase in income leads to an increase in environmental pressure. In a second stage, above a certain level of income, the environmental pressure will decrease as the economy will be able to invest in less polluting technology, consumers will reallocate expenses in favour of greener products and there will be more awareness raising campaigns, etc. Even policies, that are aimed at re-shaping the 'business as usual' trend towards more environmentally efficient and sustainable paths, are likely to be implemented with an increasing strictness and effectiveness along economic development. At a later stage, there might be a potential re-coupling, observed for some pollutants, where environmental pressure grows in spite of increasing income. Scale effects of growth again outweighs improvements in efficiency of resource use and management. Recoupling could thus emerge in well-organised waste management systems, if pressures from production of the goods and final disposal economic and environmental effects are taken into account following an LCA perspective .

In this context environmental pressure is either: waste generation, landfilling or incineration. We further explore how this relationship is altered by the inclusion of socio-economic and policy drivers. Drivers are divided into three categories: economic, socio-economic and policy-based. Economic drivers include: consumption per capita and the share of R&D in GDP. The socio-economic drivers such as population density, urban population degree, household size and the share of manufacturing in the economy help explaining structural variations between countries. Information on possible policy drivers come from a variety of sources including the ETC/RWM country fact sheets on waste.



Source: ETC/RWM (2008)

One of the earliest WKC studies was by Cole et al. (1997), who found no evidence of an inverted U-shape in relation to municipal waste. Using data on MSW for the period 1975-90, for 13 OECD countries; their findings reveal no TP. Similarly, Seppala et al. (2001), in a study of five industrialised countries including Japan, the US and Germany and over almost the same period (1970-1994), also found no evidence of delinking regarding instead direct material flows. There is some emerging evidence in favour of delinking, though on quite specific (waste) indicators. Leigh (2004) presents evidence for WKC concerning a waste/consumption indicator derived from the environmental sustainability indexes (ESI). Berrens et al. (1998) and Wang et al. (1998) also find evidence in favour of a negative elasticity, focusing on US stocks of hazardous waste, exploiting a county-based cross sectional dataset. Panel investigations have more and more emerged.

Fischer-Kowalski and Amann (2001) analysed the richer OECD countries and found 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. This suggests, as clear from descriptive analyses, that the recent evidence varies for waste generation and waste disposal, depending on increasing performances in waste recovery. A recent study by Johnstone and Labonne (2004) is of interest; they use a panel database of 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. For a group of European countries, Mazzanti and Zoboli (2005) found neither absolute nor relative delinking. Using European panel datasets they found no WKC evidence for municipal waste or packaging waste respectively for 1995-2000 and 1997-2000. Estimated elasticities of waste generation with respect to household consumption were here close to unity.

Few WKC studies have included waste policy analyses. Kaurosakis (2006) deals with policy evaluation, and 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. The panel database is for 30 OECD countries. MSW increases monotonically with income. Urbanisation exerts an even stronger effect on waste generation, while the time-invariant policy index is not significant.

Other studies have investigated policy actions but at the level of single countries, exploiting the richness of regional data, which on the other hand allows moderate generalisation of results. Mazzanti et al. (2008), who find some WKC evidence and signals of waste management instruments effectiveness in driving waste generation reductions in Italy, where economic, policy and structural geographical differences are of primary interests in explaining trends.

Some studies have instead appeared in relation to the specific evaluations of the Landfill Directive, we recall the main driver of regulatory actions in the EU, and of the UK landfill tax, introduced in 1996 (a rare case of real environmental tax informed by the evaluation of marginal external costs). Such studies, given lack of data when written, present interesting but only qualitative assessments. Among others, Morris et al (1998) offered insights on its potential and expected contribution to sustainable waste management. Morris and Read (2001) and Burnley (2001) consequently update the analysis highlighting some operational weaknesses and debating some preliminary assessments. Then Martin and Scott (2003) stress that tax intended to contribute to a transition away from landfilling of waste, towards recovery, recycling, re-use and waste minimization has failed to significantly change the behavior of domestic waste producers. They affirm that available evidence finds that there is reasonable data to monitor progress towards recycling, but not for re-use or waste minimization.

Outside EU countries, analyses are rare. Taseli (2007) recently presented an assessment of EU landfill directive on Turkey, a potential incoming country that may be compared to some eastern Eu newcomers. The study highlights the great difficulties of such countries in achieving the targets even in the long run, and shows a clear analysis of the EU framework. Outside Europe, landfill diversion and waste generation oriented studies have flourished in Far East settings where the value of land is especially high and population density reaches world peaks (Lang, 2005, Ozawa, 2005; Yang and Innes, 2007). Population density and policies emerge as complementary drivers in achieving stronger delinking for both waste generation and landfilling, though more active recycling.

The literature on waste determinants and WKC analyses thus underlines that waste indicators still generally tend to increase with income or other economic drivers, such as population, and, in general, an inverted U-shape curve is not fitting data. Some authors have suggested that for stock pollution externalities, for example, waste to a great extent, the pollution income relationship difficulty turns into a WKC shaped curve, with pollution stocks monotonically rising with income (Lieb, 2004).

A decreasing trend (negative elasticity) may be found in industrialised countries where waste management and policies are more developed. Nevertheless, the risk is that WKC trends (absolute delinking) are associated with a few rich countries or areas and can divide countries in terms of waste performance indicators. Another structural motivation concerning the lack of evidence on waste may be that the change in sign for the income elasticity of the environment/income function should occur at relatively lower income levels for pollutants whose production and consumption can be easily spatially separated, for example, by exporting associated pollution or by relocating activities. This will likely be more difficult for waste flows.

The survey of the literature highlights the necessity and value of in-depth investigation around the waste driving forces and policy effectiveness. We thus here aim at bringing together different pieces of he puzzle: WKC analyses with policy effectiveness studies and an extensive evaluation of waste drivers. We would stress that the general value added of delinking analysis is not (only) to show whether economic drivers produce decoupling effects, but more especially, to assess whether and to what extent, there are additional factors that influence the core relationship, which increase the explanatory power of the model proposed. Our work allows a greater degree of generality since it focuses on a homogenous and policy relevant regional area; most studies have in the past analyses circumscribed local situations, with a focus on specific waste streams and waste management instruments, unit based pricing among the others (Sterner and Bartelings, 1999; Ferrara and Missios, 2005). All in all, micro based and locally focuses analyses are a complement to macro based analyses in the understanding of waste trends with reference to socio-economic and policy issues.

3. Empirical Analyses

3.1 The empirical model and the data

In order to verify the actual delinking relationships between waste indicators (from generation to disposal) and economic, socio-economic / structural[11] and policy drivers, we refer to the established EKC framework. As known, though we noted that some theoretical based works have been developing over the recent years, the EKC models derives from 'stylised facts' that were proposed about the relationship between pollution and economic growth, which became know as the 'Environmental Kuznets Curve' (EKC), because of their similarity with Simon Kuznets' suggestions on long-run income distribution patterns. The EKC hypothesis, which is a natural extension of delinking analysis, holds that for many pollutants, there may be inverted-U shaped relationships between per capita income and pollution.

The main methodological problem for the applied analysis in this delinking-related framework is how to specify the WKC functional relationship. Some authors adopt second order polynomial, others have estimated third and even fourth order polynomials, comparing different specifications for relative robustness. Third or fourth level polynomials could lead to N rather than U shaped curves, introducing new problems for our understanding of income-environment phenomena for policymaking. N shapes are not relevant here given that evidence has proved that even bell shapes are hardly found[12].

Here, we test our hypotheses by specifying the proper reduced form usual in the EKC field (Stern, 2004; Cole, 2005; Cole et al., 1997; Dinda, 2004)[13]:

(1) $\log(\text{waste indicator}) = \beta_{0i} + \alpha_t + \beta_1 \text{Log}(\text{consumption}^{14})_{it} + \beta_2 \text{Log}(\text{consumption})^2_{it} + \beta_3(Xi) + \beta_4(Zi) + e_{it}$

where the first two terms are intercept parameters, which vary across countries, and years. X refers to all other structural and socio economic drivers that are added to the baseline specific both in order to correct for the omission of relevant variables. Z is a vector of policy related variables (see tables 2a-b for a description of

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[11] We define such factors structural since they are, with respect to waste trends, a set of exogenous potential drivers that are influenced by the historical, institutional and cultural development of the country, and also, relevant for waste management and disposal, by idiosyncratic geographical aspects (population density).

[12] Cubic specifications for waste are not conceptually or empirically relevant and in fact, as expected, they are not significant.

[13] This panel data model presented refers to baseline FEM model with fixed effects and time dummies.

[14] All analyses are here carried out specifying consumption as the main economic driver, since it is the most plausible in waste dynamics given its strictest link to MSW (Mazzanti and Zoboli, 2005). Nevertheless, results do not change when using GDP. We took household expenditure (consumption) per capita as the main economic driver, following the hypothesis that consumption is a better independent variable for waste collection and disposal (Rothman, 1998, Jacobsen et al., 2004; Gawande et al., 2007).

variables)[15]. In order to mitigate collinearity flaws, when highly correlated to each other, variables included in vectors X and Z are tested separately.

In order to test the various hypotheses we discuss below, we exploit information on waste collected, waste landfilled, and incinerated European countries in 1995-2005 (Eurostat sources). The standard WKC specification includes other variables to control for intra-country heterogeneity. These fall into two main groups: socio-economic / structural variables and policy indexes.

The first group controls for the socioeconomics factors that might differ between countries, such as population density, urban population degree, household size, share of manufacturing in the economy. We derive data mainly from EUROSTAT structural indicators datasets.

As far as the construction of policy indexes is concerned, we exploit as source the country fact sheets available at EIONET[16], and public information on the ratification of the landfill and incineration directives.

We below provide specifications for the three investigated waste indicators[17], highlighting which factors and hypotheses are linked to the three different levels of the waste chain, from generation to disposal. A concise discussion of main hypotheses and, if needed, of variables used in specific regressions is provided for each level (see also table 2).

3.2 Waste generation

This level of analysis provides direct evidence regarding the usual WKC hypothesis in terms of the waste generation-income relationship. Waste generation reduction (that is, 'waste prevention') is the ultimate objective of any social policy targeted towards waste flows, though explicit policy actions do not exist (targets in terms of waste generated per capita), besides some rare countries. Though waste prevention is at the top of the EU waste hierarchy, no action oriented towards waste prevention has been included in formal Directives so far. Waste management (separated collection) and landfill diversion policies have prevailed if not dominated the field, probably given the presumed relative lower implementation and compliance costs.

Let analyse the various research hypotheses we may formulate at this level of reasoning. Regarding economic drivers, a WKC oriented structure of the model allows the estimation of an eventual TP for waste generation. This is generally not observed if not, as noted, in some recent studies and for some richer areas within a specific country. The TP provides a hint about the GDP/consumption level beyond, which the relationship, in this case between waste production and income, turns negative. Econometric and descriptive empirical evidence have always shown that at best relative delinking, if any, is observed. We aim at providing updated new evidence through official data for the EU.

Secondly, we here test various hypotheses on possible effects exerted by socio-economic and structural variables. Waste generation/collection is eventually affected by a diverse set of factors. We always refer the reader to table 3.

First, population density (or urban population)[18] is likely to positively impact on waste generation. Only economies of scale spurred by urbanisation could invert the trend and reduce collection where density is higher.

Household related features may matter at such a level. In fact, we expect that the larger the size of households, the less is waste generated per capita. Nevertheless, even a positive link could be plausible in case collection schemes and waste management at home level (composting) is poorly developed on average. Accordingly, more single households should drive waste generation up.

We also use as control variable an age index. From a socio-economic point of view, we believe any outcome could be possible. Opposite forces may play a role: if on the one hand older people may produce less waste than younger ones, but it is also true that older people may be less accustomed and committed to collection and recycling of waste. Nevertheless, we may add that the opportunities cost of time is lower for older people, and waste collection actions require time. The sign of the relationship is then highly unpredictable. The interaction

[15] The model is based on a shared framework derived from the EKC literature. All variables are specified in logarithmic form using per capita values, to provide elasticity values and to smooth data. Except where it is not feasible, logarithmic transformations are used for all covariates.

[16] EIONET is a partnership agency of the EEA and its member countries; it is fundamental to the collection and organisation of data for the EEA.

[17] Waste generation, incineration, and landfilling disposal. Waste generation data are measured by waste collection, the observable factor. We do not present results for recycling though they are available. The main reason is that recycling is only calculated as a residual (MSW generation – MSW landfilled – MSW incinerated). Outputs emerge also as 'residual' with regard to other analyses.

[18] Those two variables are used alternatively, given their high correlation, here and below.

with data on education levels would be interesting, but this is matter for micro-based studies. The aforementioned factors are also probably more robustly tested at that level of analyses. We here use them given their availability, as controls and tools for mitigating problems of omission of relevant variables. Some of these socio economic variables capture more than one of the structural/institutional elements characterising a country.

Third, we include in our analysis two types of 'policy proxies'. The first is related to the European Landfill and Incinerations Directives and their effective implementation in the member states. These proxies are built as dummy variables that take the value 1 in a given year between 1995-2005 if the country has transposed these directives into national law. We expect that implementation correlates positively with delinking performances.

The second group of policy indexes is more country specific.

We first exploit a 'decentralised waste management index' that reflects the degree of waste policy decentralisation across countries[19]. Decentralisation may be beneficial to waste performances though higher flexibility and specificity in policy implementation, that may account for local idiosyncratic costs and benefits elements related to waste policies (Pearce, 2004)[20]. Though decentralisation may thus improve the efficiency of policy implementation in the EU, it may also lead to drawbacks in case factors related to local rents exploitation by public and private agents emerge. Rents are neither good nor bad in principle in environmental realms. It depend son their effects on both static and dynamic elements like value creation and innovation. Waste 'markets' like landfilling and even recycling may be associated to rents that could lock in a local system in less than optimal equilibrium (Mazzanti and Zoboli, 2006). This open hypothesis calls for further research in the future.

Finally, an environmental policy index is considered. This last is a proxy for national policies over the time period examined. It captures all possible information regarding national implementation of waste related policies (MSW, biodegradable solid waste, packaging waste, end of life vehicles, other), even independently of the Landfill Directive. We used the country studies available on EIONET as our information source. This index is both extremely comprehensive with regard to landfill directive related variables[21], and also may capture some of the waste prevention features of national policies[22]. It is noteworthy that, besides the decentralised policy index, all other proxies vary across countries and over time.

The importance of introducing policy proxies is crucial in the waste arena, and a main contribution of our work. Their role is very relevant because many European policies were enacted quite recently, and their inclusion in a WKC framework could be a sort of ex-post effectiveness evaluation. Both structural indicators and policy variables may be important drivers of WKC shapes; their omission could overestimate the 'pure' economic effect.

The specification we test in this case is then:

(2) $$\text{Log(MSW generation per capita)} = \beta_{0i} + \alpha_t + \beta_1 \text{Log}(C)_{it} + \beta_2 \text{Log}(C)^2_{it} + \beta_3 (Xi)_{it} + \beta_4 (Zi)_{it} + e_{it}$$

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[19] This discrete index variable captures the extent to which a country is decentralised in (waste) policies, and more in general, is structured as a federal state. Actually, 4 countries are associated to value one: Italy, Germany, Austria, Spain (main federal states), two have value 0.5 (UK and Belgium), all others are associated to 0.

[20] Fredriksson (2000) studies the pros and cons of decentralisation vs centralised management options regarding the siting of waste facilities. Decentralised systems are in first place theoretically preferable, though drawback may emerge.

[21] Thus, in any given year each country is associated with an index value, assigning 1 to the maximum potential value (all considered policies present). We have differentiated between the presence of only a "strategy" (low value) and that of an effective regulatory policy (high value). The latter has been assigned a stronger weight (0 for no policy, 1 only strategy, 2 policy). Prominent examples of overall environmental policy performance indexes setup for many countries based on a synthesis of diverse policy performances can be found in Eliste and Fredrikkson (1998) and Dasgupta et al. (1994). Cagatay and Michi (2006, 2003) provide an index of environmental sensitivity performance for 1990-1995, for acidification, climate change, water and even waste management.

[22] Though specific waste prevention targets actions do not exist, (landfill related) policy variables can be included even at this level of analysis. We may hypothesise that the backward effects of landfill policies and waste management actions on the MSW generated are not significant. Nevertheless, since out synthetic policy index also captures the variety of measures a country has implemented on waste, not only landfill diversion actions, some effects may emerge.

where X contains the above discussed socio-economic / structural factors (DENS or URBPOP, SIZE, SINGLE, OLDNESS, VAMAN) and Z the policy levers (DECPOLIND, INCDIR, LANDIR, POLIND). We again refer the reader to table 2 for a synthetic summary of covariates related to the level of waste generation.

3.3 Landfill diversion

The second level of the empirical model then, focuses on the disposal stage of the waste chain, landfilling.

The economic driver is here hypothesising to impact landfilled waste following a bell shape. In fact, on average, even if some countries are still increasing their landfill share and heterogeneity is striking across Europe, shares of landfilled waste and also landfilled per capita have been constantly decreasing over the last decade. We may also expect to find a negative relationship, not a bell shape. From an average Eu viewpoint, the period 1995-2005 may be already at the 'right' descending side of the inverted U shape relationship concerning the landfill-economic growth relationship. In the future testing N shape tests may become relevant. As an example, a major country like Italy has witnessed, following a decade of strong landfill diversion, a slight increase in waste landfilled per capita in 2006 with regard 2005.

As far as socio-economic and structural factors are concerned, we note that population density and urbanisation should be negatively related to landfilled waste. Both opportunity costs linked to the higher value of land in densely populated and urban areas (value of land, of commercial activities a crowded out by landfill sites, and other public investments), and the higher externality costs which arise where more people live, ceteris paribus, should drive down the use of landfills as disposal option and a real 'investment' opportunity linked to rents that are compared to other market rents (Andrè and Cerda, 2000). Nevertheless, since opportunity costs and environmental costs may vary across regions (e.g. EU15 vs EU10) this hypothesis is to be carefully scrutinised case by case. We do not see any other factors relevantly impacting landfill trends from a socio-economic point of view. The role of R&D investments of a country is expected to correlate negatively with landfill diversion. The reason is nevertheless related to the expected role of R&D as driver of incineration dynamics. Relatively speaking, the technological content and innovation dynamics associated to incineration options are stronger than in landfill site management.

The core factors we test at such a level are instead policy levers. This is a crucial test in the analysis. By exploiting both binary indexes and the continuous synthetic index – it is worth noting that both vary over time and across country[23] - and we verify the extent to which the policy experiences that have characterised Europe in the last decade, primarily the pivotal role of the 1999 Landfill Directive, have affected the waste-income relationship. Since the synthetic policy index also captures the general commitment of a country over the period, some early actions occurred before 1999 and the effective ratification of the Directive are taken into account in the econometric investigation.

The tested specification is then:

(3) $\text{Log(MSW Landfilled per capita}^{24}) = \beta_{0i} + \alpha_t + \beta_1 \text{Log}(C)_{it} + \beta_2 \text{Log}(C)^2_{it} + \beta_3 (Xi)_{it} + \beta_4 (Zi)_{it} + e_{it}$

X (DENS or URBPOP) and Z (DECPOLIND, INCDIR, LANDIR, POLIND) usually refer to the socio-economic and policy variables linked to this stage of the investigation, as summarised in table 2[25].

3.4 Incinerated waste

The WKC-like relationship assumes here a different flavour. In fact, we may surely expect that incineration, at least in EU15 (the analysis is carried out only for EU15 given lack of data – most EU countries show incineration level close to zero nevertheless), is positively related to economic growth over the recent years.

[23] This is not always the case when using policy indexes. We thus can exploit both fixed effects and random effects specifications.

[24] We decide to exploit data in per capita terms instead than in share terms (% of landfilled waste over total waste), given policy targets are fixed in per capita terms, data are available, and finally for the difficulty of coping with fractional variable defined over shares. This could have been an option in case no data in tonnes per capita terms or too deficient data were available.

[25] For landfill diversion and incineration we test two stage regressions, including as covariate the predicted values of waste generation in specifications (3) and (4), replacing the economic driver. This is to account for the unchained and consequential nature of waste flows from generation to disposal. Results do not change; predicted values significance reflects the significance of consumption in the model (2), with elasticities around unity or even higher.

This is evident from descriptive analysis and is obviously linked to the landfill diversion trend. Nevertheless, the non-linearity of the relationship could assume either an exponential dynamics or a bell shape dynamics. The latter case, that we deem more plausible given that incineration is associated to some extent to diminishing marginal returns and increasing external costs. The interpretation is then different with respect to the usual EKC shape for waste generation and landfilling. It is related to the fact that we face other possible 'residual' options, like recycling and composting. An increasing role of such strategies, common in most countries, should lead to and make compatible scenarios of landfill diversion and increasing, but not exponentially-incineration, been independently on the at source delinking dynamics of waste generation. As quantified by many applied studies, in the waste arena corner solutions are seldom (never) optimal strategies, given the increasing marginal costs – merely financial and social- of both landfilling, incineration and recycling.

Liked to the above comment on the role of density, we here state that a clear hypothesis cannot be formulated. The resulting sign is unambiguous, depending on the chosen alternative to landfill disposal, if any. If we assume that densely populated areas move away from landfilling, the opportunity costs and environmental costs of incineration can represent a relatively better scenario. If instead the country moves away from landfilling primarily using recycling options, incineration and population density / urbanisation degree may be linked negatively.

A crucial factor we here test is R&D intensity, exploited as a country specific effect. Though some outliers may exist, that is countries showing high R&D/GDP shares and low incineration, eventually because they pursue recycling strategies more heavily, on average we expect to find a dynamic string correlation between the technological intensity of a country and its incineration started. The example of Germany may represent a paradigmatic case in Europe. We test whether this anecdotic fact may represent a general statistical regularity. Given the potential correlation with the economic driver, R&D is tested both in alternative to consumption. Eventual non-linearity is tested to account for diminishing marginal effects of R&D on incineration technological strategies.

The reasoning around policy levers is similar, with an opposite expected sign, to what commented on for landfill diversion. At this stage we maybe expect a robust specific link between the implementation of the incineration directive and incinerated waste dynamics. The inclusion of both an endogenous driver such as R&D and a policy lever allows a compelling assessment on the relative strengths of endogenous and exogenous drivers.

The specification for incinerated waste is then:

(4a) $\text{Log (MSW incinerated per capita)} = \beta_{0i} + \alpha_t + \beta_1 \text{Log}(C)_{it} + \beta_2 \text{Log}(C)^2_{it} + \beta_3 (Xi)_{it} + \beta_4 (Zi)_{it} + e_{it}$

or

(4b) $\text{Log (incinerated waste per capita)} = \beta_{0i} + \alpha_t + \beta_1 \text{Log}(R\&D/GDP)_{it} + \beta_2 \text{Log}(R\&D/GDP)^2_{it} + \beta_3 (Xi)_{it} + \beta_4 (Zi)_{it} + e_{it}$

X (DENS or URBPOP) and Z (DECPOLIND, INCDIR, LANDIR, POLIND) usually refer to the socio-economic and policy variables.

4. Empirical evidence

4.1 Methodological issues and estimation procedures

We here present regression results for EU25, given their higher statistical robustness and generality. Eventual relevant specific outcomes for sub samples are commented on. Because of the large number of cases involved, we report in the table only the EU_{25} regressions. All analyses are available upon request.

All the analyses are conducted in three consequential steps: i) a traditional WKC specification, including only the main economic driver; ii) the specification with the structural and socio-economic drivers relevant in each waste issue; iii) the regression including the economic driver, the significant structural factors and the different policy indexes.

In all levels, variables included in vectors X and Z are inserted separately to mitigate collinearity flaws. Only more robust results are shown.

All regressions are first estimated by both fixed and random effects, and the best specification is selected following the Hausman test. We present specifications according to the Hausman test outcomes. We can see that the results of the fixed effects models (FEM) and the random effects models (REM) are quite similar.[26]

4.2 MSW generation

The analyses (Table 3) do not show overall WKC evidence for MSW generation. The linear term shows a significant and positive coefficient for consumption, with an elasticity ranging from 0.114 to 0.23 across specifications [27]. The EU15 and EU25 analyses are similar, but with a higher elasticity (around 0.70-0.80) in the case of the former. These elasticities are slightly lower compared to previous analyses of Europe using waste data for the 90's (Mazzanti, 2008), and seem also to imply a more active delinking process in the EU10 countries.[28] In general, we thus observe evidence of a 'relative delinking' in the relation. This result is interesting and partially confirms expectations of only a relative delinking, but with some positive signals in terms of currently lower elasticities.

The introduction of socio-economics controls does not alter previous results. The analysis shows an evidence of relative delinking, and elasticity equal to 0.72 in the sub-sample EU15. The most significant and robust control variables are population density, or alternatively the share of urban population, and the share of manufacturing[29] in the total economic activities. The share of manufacturing shows a negative sign coherent with our expectations: richer and services oriented economies produce more waste. This opens a question on the relatively better environmental performances we may at first sight attribute to services, if we think mainly at pollution-related issues: composition effects could show, for a theme like waste (e.g. MSW include some commercial & business derived waste), counterintuitive results. Population density or alternatively urban population instead impacts positively on waste generation: scale effects prevail over possible economies of scale in waste prevention and waste management / collection activities[30].

All other factors are never significant. Summing up, socio-economic structural factors add some useful hints and food for thought for waste management though they do not impact on the core relationship. Household related variables seem to not have a great influence. This may indicate that policy efforts are still weighting more post collection actions, such as recycling and landfilling operations. Household behaviour and characteristics, at least on average, are not correlated to the amount of waste collected, neither negatively nor positively.

We next exploit our policy proxies adding these variables to the set of explanatory factors. The effect of neither the Landfill Directive nor the environmental policy index is statistically significant[31]. This means that the efforts made so far have not promoted a stronger delinking between waste collection and domestic consumption.[32] The results are the same for the analyses of the smaller samples. Overall, policy levers appear to have a very marginal, if any, impact on waste generation. This reflects the lack of waste prevention oriented

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[26] We also estimated the relationship in first differences to take account of possible serial correlations in the data, but the results were very similar to those for the fixed effects estimation.

[27] Table 3 presents only linear specifications. Overall results do not change when running quadratic specifications that do not show EKC evidence but a linear term having a negative coefficient and the quadratic term a positive one. This is due to the nature of the data, and captures the effect of the low-income countries (e.g. Lithuania, Czech Republic, Slovakia, Poland and Slovenia), which registered a reduction in the total MSW collected in the period studied. This slight anomaly generates a downwardly sloped relationship between MSW collected and consumption in the first phase. This trend does not appear in sub samples EU10 and EU15.

[28] This may be interpreted in terms of the (observed even in other contexts) delinking occurring in some east European countries (Hungary among others), which may be driving the general empirical picture. Even the EU25 quadratic analysis shows a U shaped curve affected by the delinking occurring in low income eastern countries. Bluffstone and Deshazo (2003) present a case study on an eastern country process of coping with EU waste management challenges.

[29] There are no data for Greece on manufacturing share.

[30] Following an hypothesis sometime tested in the EKC literature (Torras and Boyce, 1998), we verified whether income inequality is associated to waste generation. Since inequality is negatively related to income drivers (-0.39): its effect resembles that of income driver, the richer and more 'equal' a country is the more waste it generates..

[31] Though when implementing a two stages regression, estimating the fitted values of POLIND in the first stage (covariates URBPOP, C) for using those values as covariate in a second stage regression with MSW generation as dependent variable (without C), POLIND emerges with a positive sign. This signals the potential 'endogeneity' of policy commitment with regard to income levels. Where income is higher, and MSW is obviously higher as well, given no delinking is in place in the EU, waste policy actions are stronger / more extensive.

[32] The underlying correlation between the dummies for landfill and incineration directives is 0.66.

policies and the marginal or negative effects of landfill policies on waste generation. All of these points to the need for waste policies targeting waste reductions at source by stimulating more efforts by firms, that may change product characteristics and reduce product weight (Glachant, 2004) and households, that may affect production thorugh changing consumption and then reducing waste collection, and improving the quality of waste collection by separating materials. As trivial, behaviour may change through a shift towards more environmental preference, having in mind hat income matters since environmental quality of private and public goods is increasing more proportionally than income. In addition, policy can affect behaviour by influencing the relative prices of market and non market goods in favour of a partial or total internalisation of environmental diseconomies (Choe and Fraser, 1999[33]). Waste reduction at source efforts have been lacking so far; in the early stages, policies related to waste disposal were perceived as less costly. This may be true if we do not decide which policy is better following a quantification of net present value in the medium long run, that leads to clearer efficiency assessments (Pearce, 2004)

Table 3 here

4.3 Landfilled Waste

The analysis relative to landfilled waste reported in Table 4 below shows evidence in support of a WKC, which given the scenario in recent years is to be expected. The process of diverting waste from landfill in fact started, on average in the EU, around or even before 1995. Thus, our data register only the downward-sloped part of the relationship and the TP. This evidence connects to the aforementioned relatively better performance for the EU10 in waste generation. Further investigations are needed in the future to confirm this possible difference[34].

The introduction of socio economic / structural variables does not alter the previous results, and again shows a trend towards absolute delinking in relation to waste disposal in Europe. Other factors that are significant are density and degree of urbanisation (EU25/EU15, respectively positive and negative signs).[35] The latter shows a stronger statistical significance associated to a negative sign. It is in our eyes a structural factor that recalls economic rationales: the significance of density and urban population, above positively correlated to waste generation, is well expected, and shows that where opportunity costs are higher (in urban areas, densely populated areas) and disamenity / external effects influence more people, landfill diversion is stronger. As an example, landfill studies have flourished in situations where the value of land is especially high and population density reaches world peaks as in Asia (Lang, 2005, Ozawa, 2005)[36]. The size of the coefficient is high, as well its statistical significance. Such factors could explain the degree of delinking and landfill diversion in the endogenous scenario without policy interventions.

Finally, the analysis shows that the policy levers here tested, that is the policy indexes, the landfill directive and the incineration directive are highly significant and negatively correlated to landfill diversion. These results, are confirmed for both sub-samples. The main relationship persists in terms of type of specification and level of significance, and the TP becomes slightly higher. This is an important result because it underlines the high level of effectiveness achieved by European policy, as additional lever to the ones above commented on, in terms of diverting waste from landfill. Policies help 'tunnelling through' the endogenous delinking path driven by mere economic drivers.

In terms of the other environmental policy proxies analysed, the Decentralised Waste Management (DWM) index (taking three values, low/medium/high), is significant at 1% and has a positive coefficient. This seems to suggest that the more that waste management is decentralised within countries the more difficult is diversion

[33] Who show first and second best optimum solutions through the adoption of environmental taxes on firms and waste charges on households, also including the monitoring of illegal waste dumping.

[34] The evidence may be driven by an effective good performance of those countries that are experiencing a period of economic growth which began in the late 1990s associated with the implementation of environmental policies (a requirement for joining the EU) proposed by the richer EU countries. We could claim that, from a development point of view, the EU10 countries have more opportunities to be more efficient, at the same level of income, since their growth is embedded in a scenario characterised by a rich set of environmental policies that cannot be avoided as they (among other aspects) are prerequisites for entry in the EU by these incoming countries

[35] Those become both positive in EU10. This may imply for urbanisation degree a different influence or level of opportunity costs linked to the urbanisation. Urbanisation is in EU10 countries still in its infancy and strong opportunity costs in terms of eland and land prices do not emerge, prevailing scale effects with negative impacts on the environment through landfilling.

[36] We also refer to the 2008 march issue of the *Journal of Environment and Development*.

from landfill. The interpretations remain open, but the evidence is not strikingly counterintuitive: in DWM systems (Italy being one example) there are often incentives for the local waste management actors (municipalities) to increase waste disposal in terms of landfill or recycling, depending which option produces the higher rent in the local "market". Since landfill rents are often very high, DWM could favour "distort" dynamics. We are not suggesting negative effects from DWM overall. We would underline that this variable is time invariant capturing only cross country heterogeneity and may be lower compared to other policy proxies[37].

We would underline that from a statistical viewpoint policy dummies appear not to be affected by endogeneity issues, being positively but not highly correlated with income variables (below 0.10), but the policy index is. Early movers are likely to be wealthier countries, Germany as an example[38]. We note that here and above, as far as index POLIND is concerned, two stage instrumental variable regression using consumption as driver of the index in the first stage and then including the predicted values of POLIND in the specification analysing waste indicators confirm results. In this case, POLIND is highly and negatively related to Landfilled MSW per capita. This potential endogeneity, that characterises only this more comprehensive index capturing the overall waste policy commitment and action of a country, is not undermining our evidence and is dealt with.

4.4 Incinerated Waste

In this case we drop all the observations relative to countries with missing or zero value data for the analysed period[39].

The result is a sub-sample composed of the EU15 countries less Ireland and Greece.[40] Missing data are often due to no data because incineration is a relatively new disposal option, adopted largely by the EU15 countries. In the first regression of table 5 we observe the joint significance of the linear and quadratic terms for consumption (model 4a). This is due to the presence of an outlier, Luxembourg, which has very high income and a relative low level of incinerated waste. It is the only country with a consumption level in line with the TP, which appear coherently quite high. When this country is excluded from the dataset, the quadratic term loses its significance and the relation became linear and with an elasticity greater than one (1.67).[41] In conclusion, from that first step we can evince that in the analysed period the trend for the European country is towards incineration between the different waste disposal options. The meaning of the TP, though probably contingent as explained, is here different. Since incineration is neither a 'bad' or a 'good' thing (Diikgraaf and Vollebergh, 2004), we would expect that a decreasing trend may be explained by 'diminishing returns': in the end all waste recovery options, including recycling, are subject to non increasing returns to scale, and, for incineration, to a problem of land scarcity (e.g. incineration siting), similar to landfilling.

Other covariates are not relevant: both density and URBPOP show a positive but not significant coefficient.

The introduction in the regression of the environmental policy index and the incineration directive dummy gives very important results. Both indicators are statistically significant at 1% and 10% respectively, but in this case they are positively correlated with the amount of waste incinerated, as we expect following the analysis on

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[37] The fact that analyses show that the more a country is decentralised the more they use landfill as option may be driven by countries such as Italy, Spain, Belgium, UK, that present medium-low landfill diversion performances in comparison to other EU15 countries. As always, econometrics catches regularities, with exceptions being possible (Germany) within the average evidence.

[38] Recent studies have focused on analysing the drivers of environmental regulation, defining endogenous factors (Cole et al., 2006; Alpay et al., 2006). Efforts aimed at setting up environmental policy indexes for climate change, waste and other areas show that developed countries' environmental regulations are more stringent. Consistent with EKC reasoning, policies may result endogenous especially if correlated with income factors at both supply and demand levels (Cagatay and Mihci, 2006). Regarding (paper) waste, evidence is supporting higher demand for waste management and environmental policies in more developed richer countries (Berglund and Soderholm, 2003). At micro level Callan and Thomas (1999), who study the drivers of unit pricing adoption at municipal level, provide evidence for policy (economic instrument) endogeneity with regard demographics, fiscal capacity and socio-economci determinants.

[39] Some regressions are also carried out by using a semi log model to deal with the large amount of zero values. Unbalanced panels are used given missing values are present. The semi log specifications are not shown but results are commented on for comparison.

[40] The result is an unbalanced panel, since Portugal and Finland, for instance, have missing data in the years between 1995 and 1998.

[41] The somewhat high values of the coefficients in the incineration regression may be driven by the nature of the variable, which is not discrete and shows some substantial jumps from one year to another at least in this initial phase of expansion. In some countries, sudden changes and breaks in the total figure series occur when a big plant starts or closes operations

landfilling trends. It confirms what we have assumed in relation to European policies. This is a common trend among all the countries analysed. The index of decentralised policy actions, opposite to above, shows a negative effect on incineration dynamics. Then, on average, our regressions show that where waste policy is more decentralised, incineration undermined and landfilling is 'preferred'. The fact that landfill diversion is not favoured by decentralisation of policy is a result worth noting and food for thought; given the relevancy decentralisation has in many EU scenarios (e.g. Italy, Germany, and Spain).

Finally, we test the model (4b) including the share of R&D on GDP, the technological proxy, as alternative to consumption (the two are strongly correlated). R&D is significant and positively correlated with incinerated waste. This is an expected result that underlines the importance of R&D in this field, which is characterised by innovative technologies, rapid change and major economies of scale. In the analysis (excluding Luxemburg), as in the previous case, only the linear term is significant, and the R&D coefficient is significant and positively correlated with incinerated waste (30.24). The TP is smaller than before but also the only country with a consumption value bigger than the TP is Luxembourg. The inclusion of R&D in the regression, which is positive and highly significant, reduces the elasticity of the relationship (1.17).

It should also be noted that if R&D and policy factors are inserted together R&D effects prevail, decreasing the importance of policy[42]. This is really interesting evidence. The interpretation could be that, overall, innovative dynamics (and landfill diversion), rather than policy levers have spurred incineration[43].

5. Conclusions

This paper sets out to establish a sound framework to analyse delinking for diverse waste related trends, within a WKC conceptual environment that encompasses the policy evaluation stage. This study has provided new evidence on waste generation and disposal delinking by exploiting a rich updated EU-based dataset that allows various analyses on the relative roles in driving the waste process played by: economic drivers, structural socio-economic and, policy factors. The core WKC hypothesis was tested and its robustness confirmed by the inclusion of explanatory variables.

First, the results show that regarding waste generation no WKC trend is present, though elasticity to income drivers appears lower than in the past, pointing to the presence of a current relative delinking. For the EU10, there are stronger delinking signals, although for a more robust validation this aspect should be further investigated. No landfill or other policy effects seem to provide backward incentives to waste prevention, a result that calls for the introduction of waste policies targeted at the level of the sources of the waste generated. It confirms the lack of policy emphasis, relatively to landfill diversion, at EU level so far.

Secondly, we provide evidence confirming that landfill and incineration are, as expected, significantly decreasing and increasing respectively, along the endogenous cycle of economic development, but with policy effects significantly driving these trends: both policy dummies linked to EU Directives and the comprehensive policy index we defined were negatively correlated to landfill waste across specifications. Some additional factors, such as urbanisation and density among others appear to be playing a role. In absence of policies, delinking for landfilling seems to be driven by the increasing opportunity and environmental costs associated to waste disposal. Interestingly, as far as incineration dynamics are concerned, they seem to be explained relatively more by R&D, an income-related country specific factor, rather than by policy levers.

We thus found that there are socio-economic and policy factors that are impacting on waste trends, confirming that EKC analyses cannot rely on a mere and somewhat rough environment-income relationship. It should also be noted that the effects of policy may in part be endogenous in terms of economic indicators, which is particularly relevant in the waste arena.

To sum up, although complete delinking is far from being achieved, especially for waste generation, some positive signals are emerging, with a quite significant role played by EU waste policies implemented in the late 1990s and early 2000s in diverting waste away from landfill and towards incineration and recycling. Nevertheless, the role played by other socio economic and technological factors (R&D) should not be

[42] Even in a two stages regression as implemented above the POLIND coefficient vanishes in terms of significance.

[43] As anticipated, semi log specifications covering the EU25 show the following evidence: consumption levers are associated to weak EKC evidence; a linear specification presents higher robustness. URBPOP driver's incineration: opposite to landfilling, urban and population density favour incineration options (e.g. Milan, that has recently closed its landfills moving to incinerators, and Lombardy as a Region, are a clear anecdotic example). R&D is significant, as far as the two policy factors POLIND and INCDIR.

overlooked. Policies interact with other socio-economic and economic factors within a scenario of endogenous development in which vicious or virtuous circles drive regions' and countries' performance in relation to waste.

Overall, our evidence gives support to the claim that in order to pursue a more sustainable dynamic of waste generation and disposal, the weight of policy actions should be rebalanced towards the former: although waste prevention at source is at the top of the EU waste hierarchy, policy efforts so far have been biased towards disposal and recycling. In addition, only a few countries (Hungary, Italy, and Flanders as Region) have implemented targets in physical per capita terms (e.g. tonnes per capita) or with respect to delinking benchmarks (e.g. waste cannot grow more than a share of GDP every year). Waste prevention targets and innovative benchmarking at policy implementation level are ways to shape waste policies in the future. In the EU framework, country and regional decentralised implementation plays a major role in achieving overall objectives.

Policies may have contributed to creating and sustaining markets and rents associated to those waste management and disposal options. There is a risk that EU waste policies and the dynamic of the waste system will become locked in some actions, assigning a lower weight to waste prevention activities that may receive mention within policy principles, but are never effectively implemented. The higher present costs of such a strategy may work to lower the targeted achievement costs, at all stages of the waste filiere, in the future.

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Table 1. Literature survey on waste-related studies

Author(s), (publication year)	Countries / Geographical focus	Time period	Waste typology	Panel / Cross-section data	EKC Evidence	Turning Point (per capita)
Andersen et al., (2007)	EU15 and EU10 countries	past years before 2000	waste and material flows	model allowing for trendwise changing coefficients	waste generation is linked to economic activities by non-constant trend ratios, waste Kuznets curve reasoning	-
Beede and Bloom, (1995)	36 countries	various years (several case studies)	solid waste	cross-section and time-series	MSW generation is positively associated, but inelastic, with respect to per capita income	-
Berrens et al., (1998)	US, county level (3,141 counties)	1991	hazardous waste	cross-section	negative elasticity; inverted-U shape	20,253$ and 17,679$
Cole et al., (1997)	OECD countries	1975-1990	municipal waste	panel	no evidence of an inverted U-shape	no TP
Fischer-Kowalski and Amann, (2001)	OECD countries	1975-1995	landfilled waste and waste generated	panel	absolute decoupling for landfilled waste but not for waste generated	-
Johnstone and Labonne, (2004)	OECD countries	1980-2000	municipal solid waste	panel	positive elasticities, but lower than 1	-
Karousakis, (2006)	OECD countries	1980-2000 (four years)	municipal solid waste	panel	MSW increases monotonically with income, with an elasticity around 0.42-0.45	-
Mazzanti and Zoboli, (2005)	European countries	1995-2000	municipal and packaging waste	panel	neither absolute nor relative delinking (elasticity close to unity)	no TP
Mazzanti, Montini and Zoboli, (2008)	Italy	1999-2005	MSW	panel	Relative delinking; weak sign of absolute delinking (some richer provinces)	24,000-27,000€
Raymond, (2004)	international data	2001-2002	waste/consumption indicator	cross-section	evidence for EKC	
Seppala et al., (2001)	5 industrialised countries	1975-1994	direct material flows	panel	no evidence of delinking	no TP
Wang et al., (1998)	US, county level	1992	hazardous waste	cross-section	evidence for EKC	23,000 (1990 US$)

Tab.2a Descriptive statistics and a summary of Research hypotheses

	MIN	MAX	Mean	acronym	
DEPENDENT VARIABLES					Descriptive stats are calculated for EU 25 over 1995-2005
MSW Collected/generated (kg per capita)	239.00	753.00	484.70	MSW-GEN	
MSW Landfilled (kg per capita)	9.00	659.40	283.95	MSW-LAND	
MSW Incinerated (kg per capita)	0.00	396.60	73.47	MSW-INC	
INDEPENDENT VARIABLES					
1. ECONOMIC DRIVERS					HYPOTHESISED CORRELATION[44]
Final Consumption Expenditure of Households (Euro per inhabitant - at 1995 prices and exchange rates)	900.00	21000.00	8103.27	C	+ G eventual inverted U + I - L
Gross Domestic Expenditure on R&D (% of GDP)	0.19	4.25	1.37	RD	+ I - L
2. STRUCTURAL AND SOCIO-ECONOMIC VARIABLES					
Population Density	16.70	1276.00	174.80	DENS	+ G - L ? I
Urban Population (% of total)[45]	50.60	97.20	71.36	URBPOP	
Household Size	1.9	3.4	2.62	SIZE	- G
Single households (%)	10.12	38.30	25.04	SINGLE	+ G
Age index or 'elderly ratio' (population 60 and over to population 20 to 59 years)	0.3	0.5	0.358	OLDNESS	? G
Value added at factor cost, Share of Manufacturing	9.10	36.30	18.54	VAMAN	- G
3. POLICY VARIABLES					
Decentralised Waste Management Policy Drivers (dummy)	0	1	0.24	DECPOLIND	? G,L,I
Incineration Directive (dummy: years/country in which Directive is ratified)	0	1	0.24	INCDIR	- G + I - L
Landfill Directive (dummy: years/country in which Directive is ratified)	0	1	0.27	LANDIR	- G + I - L
Waste strategy Policy Index (range 0 - 1)	0.00	0.95	0.34	POLIND	
Landfill strategy policy index	0.00	0.25	0.09	LANDPOLIND	

All values in non log format

[44] The sign on the hypothesised correlation is shown, as well as the level at which this is most relevant (G for generation, L for landfilling, R for recycling, I for incineration). The element (?) means that the hypothesis is ambiguous either because opposing forces may be influencing the link or because economic theory and other scientific fields do not provide clear insights.

[45] Given high correlation, population density and urban population are used alternatively.

Table 2b- Main variables figures (1995 -2005 values)

countries	C	MSW-GEN	MSW-LAND	MSW-INC
Austria	12700 - 14500	438 - 630	204.7 - 112.6	54.3 - 147
Belgium	11400 - 13000	456 - 464	218.4 - 43.4	162.8 - 154.9
Cyprus	6900 - 8800	600 - 739	599.6 - 653.1	0 - 0
Czech Republic	2100 - 2800	302 - 289	301.9 - 208.7	0 - 36.7
Denmark	13400 - 15600	567 - 737	96.4 - 38.3	294.1 - 396.6
Estonia	1100 - 2300	368 - 436	365.3 - 274.1	0 - 0.1
Finland	9700 - 13200	414 - 468	267.9 - 275.8	0 - 40.7
France	11200 - 13500	476 - 543	213.6 - 195.7	178.3 - 183.5
Germany	13300 - 14500	533 - 601	245.3 - 88.8	97.1 - 147.9
Greece	6100 - 8200	302 - 438	311 - 380.5	0 - 0
Hungary	1700 - 2800	460 - 459	346 - 361.8	31.9 - 29.1
Ireland	7300 - 11300	514 - 740	398.1 - 443.9	0 - 0
Italy	8800 - 9900	454 - 542	422.2 - 296.4	23.9 - 62
Latvia	1000 - 2000	263 - 310	246.7 - 243.2	0 - 3
Lithuania	900 - 1900	424 - 378	424.4 - 340.2	0 - 0.1
Luxembourg	16300 - 21000	592 - 705	160.6 - 126.7	312.2 - 252.5
Malta	4900 - 5100	338 - 611	311.2 - 542.8	0 - 0
Netherlands	10100 - 12300	549 - 624	157.5 - 9	138.5 - 207.5
Poland	1600 - 2500	285 - 245	279.5 - 225.9	0 - 1.2
Portugal	5500 - 6900	385 - 446	200.3 - 278.1	0 - 98.5
Slovakia	1400 - 2200	295 - 289	168 - 227.8	28.2 - 34
Slovenia	4600 - 6000	596 - 423	456.6 - 329.7	0 - 0.6
Spain	6900 - 9000	510 - 597	308.4 - 317.5	24.3 - 34.9
Sweden	10500 - 13000	386 - 482	136.1 - 23.3	148.6 - 242.1
United Kingdom	9200 - 12500	499 - 584	414 - 374.9	45 - 48.9

Tab. 3- MSW generation regression results (EU25)

Model	FEM	FEM	FEM	FEM	REM	FEM	FEM	FEM
C	0.230***	0.163***	0.117**	0.158***	0.188***	0.114*	0.118**	0.164***
Dens	0.629***	…	…	…	…	…	…	…
Urbpop	…	4.263***	1.760***	42.582***	0.290	1.760***	1.761***	1.777***
Vaman	…	…	-0.284***	…	-0.319***	-0.284***	-0.285***	-0.291***
Size	…	…	…	0.117	…	…	…	…
Oldness	…	…	…	0.120	…	…	…	…
Decpolind	…	…	…	…	-0.015	…	…	…
Polind	…	…	…	…	…	0.002	…	…
Landdir	…	…	…	…	…	…	-0.0005	…
Incdir	…	…	…	…	…	…	…	-0.022
	…	…	…	…	…	…	…	…
TP	/	/	/	/	/	/	/	/
N	275	275	264	275	264	264	264	264

(…) means not included. significance at 90%, 95% and 99% is denoted by *, ** and ***; TP (€, consumption per capita); F test show overall significance for all regressions at 1%, R squared present reasonably high value for panel settings

Tab.4 – Landfilled MSW (EU25)

Model	FEM	FEM	REM	REM
C	3.382**	3.658***	4.156***	3.390***
C^2	-0.242***	-0.248***	-0.260***	-0.236***
Urbpop°	-3.694**	-1.554**	-1.714**	-1.340**
Decpolind	…	0.576**	…	…
Landdir	…	…	-0.324***	…
Polind^	…	…	…	-0.632***
TP	1083	1595	3610	3951
N	275	275	275	275

(…) means not included; ° DENS is less significant; ^ if a specific index only related to landfill policy is included results do not change. The correlation between the two is 0.81. significance at 90%, 95% and 99% is denoted by *, ** and ***; TP (€, consumption per capita); F test show overall significance for all regressions at 1%, R squared present reasonably high value for panel settings

Table 5- Incinerated MSW (EU15^)

Model	REM	REM§	FEM	FEM	REM	FEM	FEM
C	20.293***	1.676***	22.450***	24.287***	19.328**	...	...
C^2	-1.014**	…	-1.143***	-1.269***	-0.965**	…	…
Urbpop	0.651	…	0.111	0.252	1.157	4.451***	1.192***
RD	…	…	…	…	…	1.414***	3.623***
Decpolind	…	…	…	…	-0.868***	...	...
Incdir	…	…	0.076*	…	…	...	...
Polind	…	…	…	0.380***	…	…	0.151*
TP	22168	/	18409	14319	22348	/	/
N	137	126	137	137	137	137	137

(…) means not included; significance at 90%, 95% and 99% is denoted by *, ** and ***; TP (€, consumption per capita), ^ Greece and Ireland are discarded since they show only 0 values over the period, the panel is unbalanced for some years where Portugal also shows 0 values; §exclud. Luxem; F test show overall significance for all regressions at 1%, R squared present reasonably high value for panel settings

Table 6 - MSW generation regression results (EU25); Swamy random-coefficients linear regression model and dynamic analysis

Model	Random-coefficient	GMM-Diff One Step	GMM-Diff One Step
C	0.7141717***	0.129397***	0.1586279***
MSW-GEN (-1)		.817157***	0.7839553***
POLIND01	-0.1162203	…	-0.14038***
Slope test	0.0000	…	…
Sargan test	…	0.000	0.000
N	275	250	250

(…) means not included; significance at 90%, 95% and 99% is denoted by *, ** and ***; TP (€, consumption per capita), ^ Greece and Ireland are discarded since they show only 0 values over the period, the panel is unbalanced for some years where Portugal also shows 0 values; F test show overall significance for all regressions at 1%

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