Waste performances, waste technology and policy effects

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1. Introduction

European environmental policies are aimed primarily at reducing the amount of waste that goes to landfill and reduce the overall amount of waste generated. The effectiveness of these policies in managing the generation and disposal of waste depends on the efficiency of their implementation. Efforts to reduce landfill are a priority in the European waste management policies, and one of the pillars of the EU's waste strategy is the 1999 Landfill Directive, which is being implemented at member state level in association with national efforts to manage waste, such as separate collection, recycling, incineration, disposal and handling of waste. Over the last few years the European Commission has also implemented policies aimed at reducing waste generated at source (to achieve a decoupling of different stages of the waste production chain), through the implementation of the European Directive 2008/98/CE, which identifies a specific waste hierarchy, defining waste prevention and material recovery as the most important objectives in waste management, followed by recycling, incineration and landfilling as the last preferred choices.

Moreover, since late 90s Italy has devoted several efforts to promote cleaner ways of disposing waste, thanks to specific political and legislative tools (for a comprehensive study of the effectiveness of waste management policies see Mazzanti et. al, 2009). As a result, Italy has reduced in some cases its dependence on landfills, increasing the adoption of incineration plants and recycling. However, on the other hand landfilling activity still remains overall the main method of managing waste, and alternative processes such as incineration and separate collection have not become well established across Italy. There is indeed a high heterogeneity in waste management policies in Italy due also to the reform under article 5 of the Italian Constitution. The national context is thus highly decentralized, with different regions that show different strategies and implement diverse policies with regard to waste management. Landfill is indeed the most cost-effective technology, whereas incineration plants and recycling are more expensive alternative processes.

Starting from these premises, the present paper seeks to shed a light on the determinants of the adoption of more advanced technologies for waste management and disposal, namely recycling and incineration, focusing the attention on the role of technical change and environmental policies. The rationale of the present paper lies in the idea that the implementation of better technologies (captured by patents) can improve cost-effectiveness in waste management processes and can therefore spur both incineration and recycling, which are environmentally-friendly disposal choices, w.r.t. the business as usual (according to the EU Waste hierarchy). Similarly, environmental policies, altering the relative price of different disposal technologies, can provide incentive for the adoption of more advanced disposal choices. Finally, we believe that a complementarity exists between these two effects. In particular, environmental policies tend to be more effective in provinces that have a more developed knowledge base and can absorb more easily the external shock provided by the policy.

Once we have explained the general aim of the paper and the intuition on which it is based on, we can state the following research hypotheses:

1. Technological change exerts an effect on good waste management performances reducing the cost of less cost-effective waste management strategies – like recycling and incineration – and making them more attractive with respect to landfilling, which is the traditional preferred choice.
2. Environmental policies are more effective in those provinces with higher amounts of patent stocks, which have therefore advanced knowledge to capitalize the positive effects of a rigorous environmental regulation. This hypothesis in other terms can be seen as a complementary effect of these two factors, where the presence of higher innovative activities (measured through a patent count) increases the returns from the adoption of environmental policies.

This study could therefore offer relevant insights on the pivotal role played by environmental and innovation policies in making waste disposal a more sustainable process.

The paper is organized as follows: section 2 provides a comprehensive description of the database used for carrying out the empirical analysis, section 3 explores in more depth the concept of complementarity and its role played by in this study, section 4 displays the main results deriving from the econometric analysis and section 5 draws conclusions.

2. Description of database

The above hypotheses are tested using a large panel dataset for the 103 Italian Provinces for the 1999-2010 period, which merges environmental, economic and demographic data, such as value added, population density, separate collection, waste generation, landfilled and incinerated waste. Environmental data has been taken from the Italian Environmental Agency (ISPRA), while economic and demographic data derives from the Italian National Institute for Statistics (ISTAT). We use two main environmental policies: Italian landfill tax, which represents the main environmental tax in Italy and generated around €185 million in revenue in 2010. Italy implemented the landfill tax in 1996 before the UK; it is defined by the 20 Italian Regions and the tax revenues are also managed by these regions under the general guidelines provided by the Italian Treasury. On the other hand, we use the former Italian *Tariffa di Igiene Ambientale* (captured by two specific proxies), a tariff that should have been partially calibrated on the actual amount of waste generated by every user, according to the polluter-pays-principle.

Finally, we construct a large database with data patents and use two main variables:

- "green stock", which captures innovation regarding general environmental management (such as air, waste and water);
- total patents, which represents a sum of all available types of patents, such as: a) energy generation from renewable and non-fossil sources; b) combustion technologies with

mitigation potential; c) energy effects in buildings and lighting; d) technologies specific to climate change mitigation.

We therefore construct a specific knowledge stock for both variables using 1977 as a base year. Following previous work on patent data (Popp et. Al, 2011; Lovely and Popp 2011), we measure the knowledge capital of province i at time t for each technology k based on the following equation: $K\ Stock_{i,k,t} = \sum_{s=0}^{\infty} e^{-\beta 1(s)}\left(1 - e^{-\beta 2(s+1)}\right) PAT_{i,j,t-s}$. We set the rate of knowledge obsolescence to 0.1 (β_1=0.1) and the rate of knowledge diffusion to 0.25 (β_2=0.25). As a result, we obtain a knowledge stock that varies by country, year and technology.

The following table describes the specific variables used in this paper:

Table 1: Description of the variables used in the empirical analysis.

Variable Name	Variable Descritpion	Observations	Max	Min	Mean
Recycling	Separate Collection per capita (kg/inhabitant)	1236	390	0.1	127.4956
Incinerated	Waste incinerated per capita (kg/inhabitant)	1236	123.7216	0	65.79416
Landfilled Waste	Waste landfilled per capita (kg/inhabitant)	1236	1898.47	0	307.5977
Popdens	Population Density	1236	2646.92	31.04	248.2135
Va	Value added (€)	1236	199475.9	8788.463	19309.07
Green_stock	Stock of patents on general environmental management (air, water, waste)	1236	102.1265	0	3.683285
Total_stock	Stock of patents on different environmental innovations (energy, combustion technologies etc.)	1236	5909.997	0	184.1278
Landfilltax	Landfill tax	1236	0.02583	0.00517	0.0158256
Copcomtar	Share of municipalities in a Province that have adopted the *Tariffa di Igiene Ambientale*	1236	102.3	0	9.3089
Copoptar	Share of population in a Province that are subject to *Tariffa di Igiene Ambientale*	1236	104.24	0	15.8551

3. Empirical Strategy

As we have previously seen, we are mainly interested in filling the gap regarding the effects exerted by innovation and environmental policies upon the choices of adopting cleaner technologies in waste disposal. We therefore scrutinize whether innovation and environmental integrated strategies can foster the adoption of recycling or incineration. The problem is thus to choose a combination of these policies that can maximize the amount of recycled or incinerated waste.[1] More precisely, our main research focus is to examine if a relationship of complementarity exists among these practices when the adoption of recycling (or, alternatively, incineration) is the objective. Thus, we investigate the extent to which more environmentally-friendly technologies in waste disposal are associated to innovation and environmental policies, by assessing their impact through the lens of complementarity theory.

To this end, it is worth explaining the concept of complementarity and the theoretical framework on which our analysis is based.

A relationship of complementarity between two activities (or, in this specific case, two policies) implemented exists when the "doing more" of "one of them" increases the attractiveness of "doing more" on the part of the other. Systemic effects arise, "with the whole being more than the sum of the parts" (Roberts, 2006). Expressed in mathematical terms and following Topkis (1995, 1998), Milgrom and Roberts (1990, 1995), Milgrom and Shannon (1994), we state that two variables x' and x'' in a lattice X are complements if a real-valued function $F(x', x'')$ on the lattice X is supermodular in its arguments. That is, if and only if:

$$F(x' \vee x'') + F(x' \wedge x'') \geq F(x') + F(x'') \qquad \forall\ x', x'' \in X \qquad (1)$$

or, expressed differently:

$$F(x' \vee x'') - F(x') \geq F(x'') - F(x' \wedge x'') \qquad \forall\ x', x'' \in X \qquad (2)$$

that is, the change in F from x' (or x'') to the maximum $(x' \vee x'')$ is greater than the change in F from the minimum $(x' \wedge x'')$ to x'' (or x'): raising one of the variables raises the value of increase in the second variable as well. Supermodularity gives an analytical structure to the idea that "increasing the value of some variables never prevents one from increasing the others as well" (Milgrom and Roberts, 1995).

In our specific case, we consider recycling (or incinerated waste) as the objective function and we focus on the policies that can affect it:

$$Rec\_waste = Rec\_waste(h', h'', \sigma)$$

and

$$Incin\_waste = Incin\_waste(h', h'', \sigma)$$

[1] To do a more complete work, we also test this hypothesis with regard to the amount of landfilled waste, in such a way as to take into account the three main technologies currently used in waste management. However, it is clear that the most interesting results regard recycling and incineration, as landfill represents the most pollutant solution.

where h' and h'' represent the combination of the policies abovementioned and belonging to the set H, whereas σ defines all the exogenous parameters.

Complementarity between the two different policies may be analysed by testing whether Rec_waste = Rec_waste (h', h'', σ) or Incin_waste = Incin_waste (h', h'', σ) are supermodular in h' and h''.

Our aim is to find a set of inequalities, such as those previously expressed (1) and (2), which are tested in the empirical analysis.

More specifically, through the supermodularity approach we analyse whether the probability of adopting a cleaner technology in waste disposal is significantly influenced by the presence of complementarities between environmental and innovation policies.

At this point, we can define the "states of the world" used in this study.

If in this maximizing problem, neither of the two policies has been adopted, namely $h' = 0$, $h'' = 0$, the element of the set H is $h' \wedge h'' = \{00\}$. On the other hand, if both policies have been adopted, we have $h' = 1$, $h'' = 1$ and the element of the set H is $h' \vee h'' = \{11\}$. Including the mixed cases as well, we have four elements in the set H that form a lattice: H = {{00}, {01}, {10}, {11}}.[2]

From the above we can assert that h' and h'' are complements and hence that the function Rec_waste (or Incin_waste) is supermodular, if and only if:

$$\text{Rec\_waste}(11, \sigma) + \text{Rec\_waste}(00, \sigma) \geq \text{Rec\_waste}(10, \sigma) + \text{Rec\_waste}(01, \sigma) \tag{3}$$

or:

$$\text{Rec\_waste}(11, \sigma) - \text{Rec\_waste}(00, \sigma) \geq [\text{Rec\_waste}(10, \sigma) - \text{Rec\_waste}(00, \sigma)] + [\text{Rec\_waste}(01, \sigma) - \text{Rec\_waste}(00, \sigma)] \tag{4}$$

that is, changes in the adoption of cleaner technologies when both forms of policies are implemented together are more than the changes resulting from the sum of the separate implementation of the two types of strategies. In other words, increases in the objective function due to an increase of both h' and h'' from {00} to {11} are greater (or at least equal) than the sum of increases in the function due to separate increases of h' and h'' from {00} to {10} (or {01}).

[2] To determine whether a policy has been implemented, we have decided to assign "1" to those policies whose value is above the median, and 0 if the value is below the median.

4. Empirical evidence

Tables below present complementarity tests with reference to recycled, incinerated and landfilled waste. The null hypothesis that we have tested is the absence of complementarity between environmental and innovation policies in the adoption of cleaner technologies in waste disposal, namely it means that in this case coefficients are not statistically different from each other and inequalities (3) and (4) have not been found in the empirical work.

As we can see from results, complementarity relationships do not overall emerge in our study in a significant way [3].

First of all, we can observe that “copoptar” (and also “copcomtar”) and “green stock” are characterized by a substitutability effect when the objective function is represented by landfilled waste, which therefore shows the highest increase when these strategies are not implemented together.

Moreover, we can note that weak evidence in support of complementarity exists between “copcomtar” and “green stock” with regard to incineration, that is the increase in the amount of incinerated waste when we pass from a situation in which we implement neither environmental nor innovation policies (h’= h’’= 0) to a situation where we implement both policies (h’, h’’ = 1) is higher than the increase when we pass from h’, h’’ = 0 to a situation in which only one policy is implemented (10 or 01).

By observing the empirical analysis carried out with regard to the total amount of patents, we can firstly see that the two set of policies composed of “copoptar” and “total stock” on the one hand, and on other hand of “copcomtar” and “total stock” are complements with regard to recycling. This is maybe the most interesting result and it is shown in table 5, because we can assert that a combination of environmental and innovation policies can spur the adoption of separate collection, making this process more convenient and attractive. Nevertheless, we have also to note that we have used the variable “total stock”, which captures a large variety of patents that go beyond those relating to waste management, and therefore it represents a less precise indicator for our study.

By contrast, a substitute effect exists between “copoptar” and “total stock” when we define landfilled waste as the objective function and even “copcomtar” and “total stock” appear to be substitute policies with regard to landfilled waste[4].

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[3] Therefore, in most cases we have accepted the null hypothesis for which (b 00 + b 11) + (- b 10 - b 01) = 0.

[4] As a result, we can observe that both “copcomtar” and “copoptar” are complements with “green stock” and “total stock” when our objective function is represented by landfilled waste.

Table 2: Complementarity tests in a continuous setting. Recycled waste as the objective function.

	Wald Test	Adj. p-vlaue for: H_0: coeff. 11+00 >= coeff. 10+01	Sign of linear Combination (b1 + b4) + (-b2 – b3)[5]
copoptar and green_stock	0.52	0.2344194	< 0
landfilltax and green_stock	0.77	0.18965802	< 0
copcomtar and green_stock	0.57	0.22542301	< 0

Since we are testing one linear restriction at a time the F distribution has 1 degree of freedom as the number of the linear restrictions; H0: b1+b4-b2-b3=0; Critical values of F test (1) distribution: 6.63, 3.84, 2.71 (***1%, ** 5% and * 10% level of significance respectively);

Adjusted p-value for inequality tests when the Wald F test statistics has 1 degree of freedom

(b1+b4)+(-b2-b3)≥0 is index of supermodularity

(b1+b4)+(-b2-b3)<0 is index of submodularity

Note: Tests conducted on marginal effects

Table 3: Complementarity tests in a continuous setting. Incinerated waste as the objetive function.

	Wald Test	Adj.p-vlaue for: H_0: coeff. 11+00 >= coeff. 10+01	Sign of linear Combination (b1 + b4) + (-b2 – b3)
copoptar and green_stock	1.78	0.9087282	> 0
landfilltax and green_stock	0.69	0.20244121	< 0
copcomtar and green_stock	2.86*	0.95460774	> 0

Since we are testing one linear restriction at a time the F distribution has 1 degree of freedom as the number of the linear restrictions; H0: b1+b4-b2-b3=0; Critical values of F test (1) distribution: 6.63, 3.84, 2.71 (***1%, ** 5% and * 10% level of significance respectively);

Adjusted p-value for inequality tests when the Wald F test statistics has 1 degree of freedom

(b1+b4)+(-b2-b3)≥0 is index of supermodularity

(b1+b4)+(-b2-b3)<0 is index of submodularity

Note: Tests conducted on marginal effects

[5] Where "b" represents the different combinations of environmental and innovation policies used in the present work and for which we have tested for complementarity.

Table 4: Complementarity tests in a continuous setting. Landfilled waste as the objective function.

	Wald Test	Adj.p-vlaue for: H_0: coeff. 11+00 >= coeff. 10+01	Sign of linear Combination (b1 + b4) + (-b2 – b3)
copoptar and green_stock	19.44	0.000005199	< 0
landfilltax and green_stock	0.61	0.21751982	< 0
copcomtar and green_stock	21.09	0.000002196	< 0

§ Since we are testing one linear restriction at a time the F distribution has 1 degree of freedom as the number of the linear restrictions; H0: b1+b4-b2-b3=0; Critical values of F test (1) distribution: 6.63, 3.84, 2.71 (***1%, ** 5% and * 10% level of significance respectively);

Adjusted p-value for inequality tests when the Wald F test statistics has 1 degree of freedom

(b1+b4)+(-b2-b3)≥0 is index of supermodularity

(b1+b4)+(-b2-b3)<0 is index of submodularity

Note: Tests conducted on marginal effects

Table 5: Complementarity tests in a continuous setting. Recycled waste as the objetive function.

	Wald Test	Adj.p-vlaue for: H_0: coeff. 11+00 >= coeff. 10+01	Sign of linear Combination (b1 + b4) + (-b2 – b3)
copoptar and total_stock	5.75**	0.99177192	> 0
landfilltax and total_stock	0.00	0.47792891	< 0
copcomtar and total_stock	5.49**	0.99045928	> 0

§ Since we are testing one linear restriction at a time the F distribution has 1 degree of freedom as the number of the linear restrictions; H0: b1+b4-b2-b3=0; Critical values of F test (1) distribution: 6.63, 3.84, 2.71 (***1%, ** 5% and * 10% level of significance respectively);

Adjusted p-value for inequality tests when the Wald F test statistics has 1 degree of freedom

(b1+b4)+(-b2-b3)≥0 is index of supermodularity

(b1+b4)+(-b2-b3)<0 is index of submodularity

Note: Tests conducted on marginal effects

Table 6: Complementarity tests in a continuous setting. Incinerated waste as the objetive function.

	Wald Test	Adj.p-vlaue for: H_0: coeff. 11+00 >= coeff. 10+01	Sign of linear Combination (b1 + b4) + (-b2 – b3)
copoptar and total_stock	0.75	0.80724065	> 0
landfilltax and total_stock	0.51	0.23666943	< 0
copcomtar and total_stock	1.33	0.87534937	> 0

§ Since we are testing one linear restriction at a time the F distribution has 1 degree of freedom as the number of the linear restrictions; H0: b1+b4-b2-b3=0; Critical values of F test (1) distribution: 6.63, 3.84, 2.71 (***1%, ** 5% and * 10% level of significance respectively);
Adjusted p-value for inequality tests when the Wald F test statistics has 1 degree of freedom
(b1+b4)+(-b2-b3)≥0 is index of supermodularity
(b1+b4)+(-b2-b3)<0 is index of submodularity
Note: Tests conducted on marginal effects

Table 7: Complementarity tests in a continuous setting. Landfilled waste as the objetive function.

	Wald Test	Adj.p-vlaue for: H_0: coeff. 11+00 >= coeff. 10+01	Sign of linear Combination (b1 + b4) + (-b2 – b3)
copoptar and total_stock	14.39	0.00007431	< 0
landfilltax and total_stock	2.18	0.06985777	< 0
copcomtar and total_stock	15.72	0.00003675	< 0

§ Since we are testing one linear restriction at a time the F distribution has 1 degree of freedom as the number of the linear restrictions; H0: b1+b4-b2-b3=0; Critical values of F test (1) distribution: 6.63, 3.84, 2.71 (***1%, ** 5% and * 10% level of significance respectively);
Adjusted p-value for inequality tests when the Wald F test statistics has 1 degree of freedom
(b1+b4)+(-b2-b3)≥0 is index of supermodularity
(b1+b4)+(-b2-b3)<0 is index of submodularity
Note: Tests conducted on marginal effects

5. Conclusion

The present paper takes a step forward in the current debate on the determinant of good waste management practises introducing a new mechanism derived from innovation literature. Namely, we hypothesize here that the effect of environmental policies is stronger in provinces with a strong knowledge base, measured via patent stock. In other terms, this means testing for complementarity between technological change and environmental policies in the realm of waste. Interestingly the evidence is mixed and the result is not reassuring. Complementarity exists but are limited to the specific case of recycling waste. The absence of strong complementarity stresses the need for more stringent and more targeted environmental policies in the realm of waste management, a result in line with previous waste Kuznets curves studies (Mazzanti et al., 2009).

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