Endogenous Green Technology and Induced Policy Effects: Testing Direct and Indirect Impacts[*]

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Abstract

Higher environmental efficiency of economic processes is achieved by reducing the use of resources and enhancing reuse and recovery of materials. Green Innovations are commonly regarded as the most effective response to sustaining current standards of living while overcoming serious environmental concerns. Despite that, a broad and dynamic picture of the integrated innovation and policy effects is still lacking. The paper analyses the effects of policies on environmental performances through innovation. We primarily add to the literature by testing direct and indirect effects, namely (i) the impact of environmental policy and innovation on environmental performances and (ii) that of innovation on environmental performances through the inducement effect of policies. Preliminary results show that environmental policies are a relevant driver of increasing recycling trends. Innovation activities, as measured by patents, also play a role showing a positive and significant effect. Finally, also the effect of policy mediated by induced innovations is relevant and statistically significant, though more moderate, due to a more limited impact of policies on inventions over time in the EU.

1 Introduction

Environmental inventions and innovations (EI), are crucial to creating synergies between sustainability and competitiveness towards a greener economy (Jaffe et al., 2003; EEA, 2014). Researchers have focused on the drivers of environmental innovation and invention, with interest on market and policy factors

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[*] Provisional version. Please do not cite without authors' permission. This draft: January, 2016.

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(Dechezlepretre et al., 2011, Horbach et al. 2012, among others). While environmental policies have been shown to produce effects (Mazzanti and Zoboli, 2009), the role of innovation has been so far overlooked, especially in the field of resource efficiency (Cainelli et al., 2015). On the other hand, as underlined, among others, by Kinnaman (2009), technological improvements are a crucial factor in addressing the increasing impact of waste, one of the most critical aspects related to resource use. Specifically, a full understanding of environmental policy impacts implies the need to disentangle, theoretically and empirically, direct and indirect effects, the latter potentially driven by relevant innovation efforts. Our paper contributes to the literature by applying new techniques that identify the effect of innovation and policy on environmental performances (adopting an empirical strategy inspired by Franco and Marin, 2015), through a detailed analysis of direct and indirect, namely induced, policy effects on innovation. We investigate as case study the realm of resource efficiency and the circular economy (EC, 2015), with a focus on inventions for enhancing recycling capabilities.

In the first part of the paper we model a policy setting where an agent (e.g. a firm) is subject to regulation (e.g. a waste related tax) and has to choose the resource efficiency related effort, together with the investment to be devoted to invention in material resource saving technologies. This theoretical setting is aimed at obtaining testable implications on the role played by the strictness of environmental policies in boosting recycling oriented technological choices. Theoretical results lead to two testable implications. Testable implication 1 states that, as expected, 'abatement', namely resource saving effort, is larger in the presence of invention than in its absence. Testable implication 2 suggests that when invention investments are explicitly accounted for, resource efficiency is affected by an increase in the policy stringency both directly, through its impact on marginal resource use costs, and indirectly, through induced eco-innovation. Results are then tested through the construction of an original dataset for EU countries and years 1995-2009, containing time-varying information on recycled waste per capita, the latter being a function of patent production in recycling technologies, EU countries time variant environmental policies and other socio-economic factors. The paper is structured as follows. Section 2 presents the theoretical background and relevant literature. Section 3 comments on the data and presents the empirical model. Section 4 elaborates main econometric results. Section 5 concludes.

2 Theoretical framework

Our theoretical framework rests on the literature investigating the role of policies in boosting R&D and adoption, very well surveyed by Requate (2005) and Jaffe et al. (2003), among others. Specifically, we model a substantially simplified setting featuring a firm which chooses first the amount of investment in a cleaner technology and, then, the level of abatement (e.g. reduction of resource related inefficiencies) according to the related costs, which are in part driven by the effort performed in improving the available technology[1]. We compare a benchmark case where no investment takes place with a "full" model where both the technology related effort and the abatement effort are accounted for.

2.1 No investment

When no investment in innovation (e.g. R&D) is possible, the firm minimizes the sum of convex abatement (a) costs and tax payments:

$$\min_{a} c\left(a\right) + t(e - a)$$

where $c\left(.\right)$ are convex abatement costs, t is the unit emission tax, which is intended as a measure of the strictness of environmental policy, and e is unregulated impact on resources (i.e. $e - a$ can be intended as regulated resources use). First order conditions require:

$$c_a - t = 0 \tag{1}$$

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[1] For a more realistic model where an upstream (innovating) and a downstream (regulated) firm are two separate entities, with the resulting possibility of strategic interaction, see, among others, Perino (2010).

which are clearly sufficient for an optimum under convex abatement costs. Differentiating (1) we can conclude that:

$$\frac{da}{dt} = \frac{1}{c_{aa}} > 0.$$

Clearly, abatement increases with the strictness of environmental policy, as it is standard in the literature.

2.2 Possibility of investment

We model investment in technological improvements in the simplest possible way: we label the corresponding level as k, and the related, increasing and convex, costs as $\phi\left(k\right)$. The latter is therefore the investment cost born by the regulated firm. This investment reduces marginal abatement costs, so that such costs can be rewritten as :

$$\widehat{c}\left(a\right) = c\left(a\right) - ka$$

i.e. a larger k implies a downward parallel shift in marginal abatement costs. We model the regulated firm decision in two stages, to keep the abatement decision apart from the investment decision. In the second stage, the firm chooses abatement taking k as given, solving therefore:

$$\min_{a} c\left(a\right) - ka + t(e - a) + \phi(k)$$

where the term $\phi(k)$ are convex (and in the second stage sunk) investment costs.

First order conditions (necessary and sufficient under our assumption that $c_{aa} > 0$) require:

$$c_a - k - t = 0 \tag{2}$$

leading to the following straightforward comparative statics result:

$$\frac{da}{dt} = \frac{da}{dk} = \frac{1}{c_{aa}} > 0.$$

Clearly, for strictly positive k, and as $c_{aa} > 0$, the comparison of (1) and (2) implies our first testable implication:

Testable implication 1: *Abatement is larger in the presence of R&D effort than in its absence.*

In the investment stage, the firm solves:

$$\min_k c\left(a\left(t,k\right)\right) - ka\left(t,k\right) + t(e - a\left(t,k\right)) + \phi(k)$$

so that first order conditions require:

$$c_a \frac{da}{dk} - a\left(t,k\right) - k\frac{da}{dk} - t\frac{da}{dk} + \phi_k = 0$$

which, by the envelope theorem, can be rewritten as follows:

$$-a\left(t,k\right) + \phi_k = 0 \tag{3}$$

second order conditions require in this case $-\frac{1}{c_{aa}} + \phi_{kk} > 0$, i.e. the investment cost function must be "sufficiently convex". We assume this to be the case.

Totally differentiating (3), we get:

$$-\frac{\partial a}{\partial t}dt - \frac{\partial a}{\partial k}dk + \phi_{kk}dk = 0$$

that is:

$$\frac{dk}{dt} = \frac{\frac{1}{c_{aa}}}{\phi_{kk} - \frac{1}{c_{aa}}} > 0 \tag{4}$$

under second order conditions.

As a result, we can conclude that t has a both a direct and an indirect (through k) impact on a. More specifically, accounting for (2) and (4) we get:

$$\frac{da}{dt} = \left.\frac{da}{dt}\right|_{k=cost} + \frac{\partial a}{\partial k}\frac{\partial k}{\partial t} = \frac{\frac{\phi_{kk}}{c_{aa}}}{\phi_{kk} - \frac{1}{c_{aa}}} > 0$$

Assuming constant second derivatives, we can also conclude that:

$$\left.\frac{da}{dt}\right|_{inv} - \left.\frac{da}{dt}\right|_{noinv} = \frac{1}{c_{aa}^2\left(\phi_{kk} - \frac{1}{c_{aa}}\right)} > 0,$$

where *inv* and *noinv* label the invesntment and no investment case, respectively. We get therefore the second testable implication of our paper.

Testable implication 2: *In the presence of investment in technology improvements, abatement is positively affected by an increase in t both directly* *and indirectly (through k). Assuming constant second derivatives also implies that the overall impact of t on abatement is stronger when investment in k is possible.*

3 Empirical protocol and data description

In December 2015, the European Commission launched its action plan for the Circular Economy (EC, 2015) with the objective of unlocking the growth and jobs potential of the circular economy (CE). The action plan also seeks to boost the EU's competitiveness through new business opportunities and innovative means of production and consumption. Higher resource efficiency of economic processes is achieved by reducing the use of resources along the various production chain steps, their initial extraction and the disposal into the environment. The transition to a Circular Economy (CE) is highly influenced by the economic composition and innovation intensity of the economy, as well as by the environmental and industrial policy settings. Innovation is commonly regarded as the most effective response to sustaining current standards of living while overcoming serious environmental concerns (EEA, 2014). The (innovation) in material recycling is a fundamental component towards the achievement of a competitive and circular economy.

In order to quantify the relationship relationship between resource efficiency, policy and innovation, we focus on the case of recycling and estimate the following model:

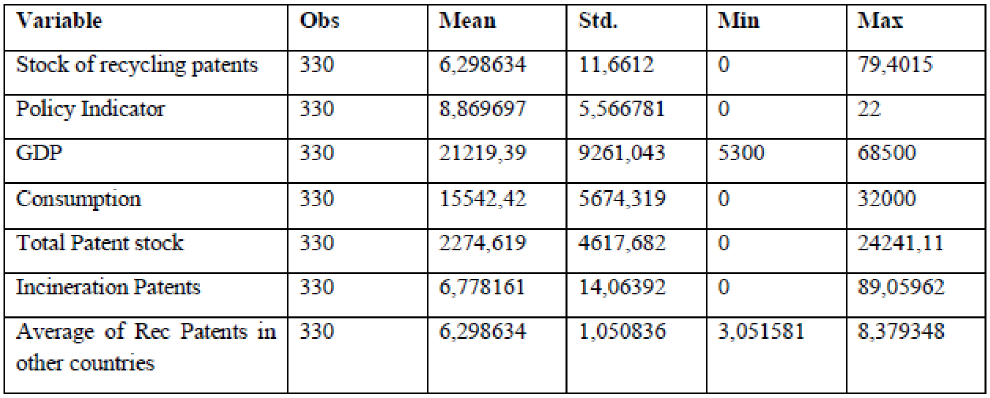
$$Recycling_{it} = \alpha_i + \mu_t + \beta_1(policy_{it}) + \beta_2(innovation_{it}) + \beta_3(popdens_{it}) + \beta_4(consumption_{it}) + \varepsilon_{it}, \tag{5}$$

where $i = 1, ..., 25$ indexes the cross-sectional unit (country) and $t = 1995, ..., 2009$ indexes time and α_i is a constant term that controls for country fixed effect. The dependent variable is measured as Kg per capita. $policy_{it}$ refers to a policy index that varies across country and through time and $consumption_{it}$ is the household consumption per capita in PPP. $innovation_{it}$ is a technology specific knowledge stock, which vary across countries and through time. It represent the national technological frontier and it is constructed following Popp et. al. (2011). Finally, we controlled for time fixed effect, by the inclusion of year dummies (μ_t).

As we are also interested in testing the effect of environmental policy on innovation, we also test the following equation:

$$Patent_{it} = \alpha_i + \mu_t + \beta_5(policy_{it}) + \beta_6(totpatent_{it}) + \beta_7(GDP_{it}) + \varepsilon_{it} \qquad (6)$$

where $patent_{it}$ is the log number of patents in recycling technology. Moreover, being environmental quality a normal good, we expect environmental innovation to increase with income, and for this reason we control here for the GDP level expressed in PPP. Finally, we included the total patent count ($totpatent_{it}$) in order to control for the different propensity to patent across countries, which could create bias in a regression model (see Johnstone et. al, 2010). The presence of these two equations allow us to compute the (total) induced innovation policy effect as $\beta_2 * \beta_5$, as well as the direct policy effect (β_1). Summary statistics of the variables used are reported in Table 1; the stock of recycling patents and the policy indicator will be explained shortly, while incineration patents (the stock of patents related to incineration technolgies), and the average recycling patents in other countries will be used as instruments, as will be clarified below.



Variable	Obs	Mean	Std.	Min	Max
Stock of recycling patents	330	6,298634	11,6612	0	79,4015
Policy Indicator	330	8,869697	5,566781	0	22
GDP	330	21219,39	9261,043	5300	68500
Consumption	330	15542,42	5674,319	0	32000
Total Patent stock	330	2274,619	4617,682	0	24241,11
Incineration Patents	330	6,778161	14,06392	0	89,05962
Average of Rec Patents in other countries	330	6,298634	1,050836	3,051581	8,379348

Table 1. Descriptive statistics

Turning to the way in which patents data are included (namely, the variable $Patent_{it}$ in (6)), it is well known in the economics debate that a good indicator of a country innovative output is hard to be found. For this reason researchers used in previous works many different imperfect proxies, like R&D expenditure, number of scientific workers, patent counts (Johnstone et. al., 2010). Among these measures, patent applications are particularly appealing for researchers for many reasons. First of all, patent counts display an overall good availability both in terms of time and country coverage, and secondly they can be easily and efficiently divided in technological fields. Every single patent in fact is classified through an International Patent Classification (IPC) code, developed at the World Intellectual Property Organisation. This tree-like classification allows to create technological fields at different level of detail, in a manner similar to the NACE classification. For example, Section “D” contains all patents related to “textiles; papers”, while the subcategory “D 21” refers more specifically to “paper making and production of cellulose”, “D 21 F” refers to “Paper making machines; methods of producing paper thereon”, and, at the maximum level of detail, “D 21 F 11/06” refers to the very specific field of patents related to “Processes for making continuous lengths of paper, or of cardboard, or of wet web for fibreboard production, on paper-making machines of the cylinder type".

This coding allows creating very specific technological subcategories, able to identify specific fields of interest. For all these reasons, patent data have been for long considered as a useful proxy of innovation for economic research (Griliches, 1990). Moreover, as Dernis and Kahn (2004) suggest, generally all the economically relevant innovations are patented, and for this reason patents may be used as a valuable proxy for a country or firm level innovation. Nevertheless, patents also suffer of some well-known criticalities. First of all, it is difficult to discern the value of different patents. An indicator created as the sum of patent counts per year by country certainly includes patents with an high commercial and/or technological impact and patent with a lower value. Second, patent regimes and patent attitudes across countries may be different. This may be due in part to legislative differences across countries and in part to a different general propensity toward patenting.

For this specific analysis, however, we refer to a country knowledge stock, which we expect to be more likely to influence waste management performances with respect to a simple indicator based on patent counts. The main advantage of such procedure with respect to the simple patent count is that such measure does not only account for the level of invention in the current year but also for the previous years, providing us with a more suitable proxy of a country innovative performance.

In doing this we follow Popp et. al. (2011), which explain that such measure can be considered a valid proxy of a country technological frontier. Technically, we measure knowledge capital of country i at time t based on Popp (2002) as follows:

$$K_{it}^{POPP} = \sum_{s=0}^{\infty} e^{-\beta_1(s)} \left(1 - e^{-\beta_2(s+1)}\right) p_{it}$$

where β_1 is the rate of knowledge obsolescence, β_2 captures knowledge diffusion and p_{it} is the number of patents applied for by firm i in year t. According to previous work on patent data (Popp et. al., 2011), we set the rate of knowledge obsolescence to 0.1 ($\beta_1 = 0.1$), and the rate of knowledge diffusion to 0.25

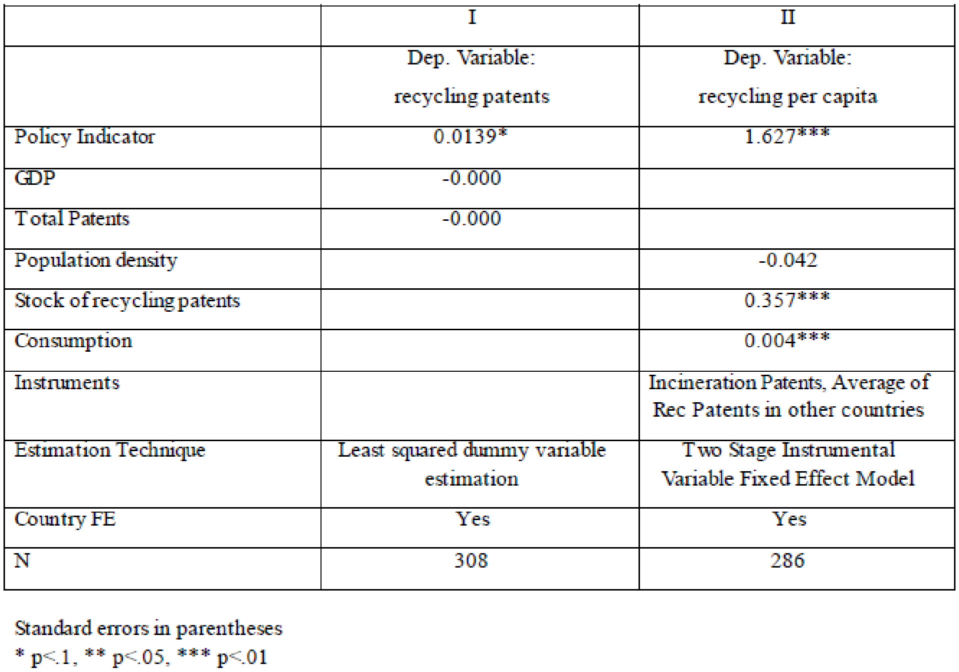
($\beta_2 = 0.25$).

Turning to the policy index, namely the variable $policy_{it}$ in (5) and (6), it is built to assess the role of policy stringency in the adoption of innovation and in waste performances. Such index is the result of a two-step process representing respectively: (1) the systemization and weighting of the different types of government directives to manage waste, and (2) their joint adoption per country per year. The first indicator (1) is based on the Countries' Fact Sheets on waste management available at Eionet, plus some additional information from the individual Government Departments of Environment web sites (especially for non EU countries). On the basis of this information, we created a series of ordinal variables ranging from 0 to 2 and representing the policies adopted for the different fields of waste and their impact. Specifically, the variable takes the value of 0 when the policy is not been adopted, 1 when the policy designed provided a scarce articulation of the waste management practice to apply (Low impact policy), and 2 when the policy designed provided a very articulated standardisation of the waste management practice to apply (High impact policy). We determined the impact of the policy (values equal to 1 or 2) according to a quantitative ranking based on the available policy information or the sampling distribution (preferably using the median as indicator of central tendency). For example, the simple adoption of an EU directive is coded as a Low impact policy. Conversely, effective regulation plans or policies setting a high threshold of waste management accomplishment are coded as High impact policies. In the case of the Landfill tax we used the level of the tax itself. Thus, countries associated with a tax level below the yearly median value were assigned with a weight equal to 1, and countries with a tax level bigger than the median value were associated with a weight equal to 2. After the creation of this new variable, we finalized the policy index by averaging all the policies adopted per country per year (hence, we averaged all the ordinal variables adopted per country per year).

Such an indicator can be a good proxy of the overall adoption of policy at country level, and thus a good candidate as main policy variable in the empirical analysis. Prominent examples of overall environmental policy performance indices set up, for several countries, based on a synthesis of diverse policy performances, can be found in Eliste and Fredrikkson (1998). Cagatay and Mihci (2006) provide an index of environmental sensitivity performance for 1990–5, for acidification, climate change, water and even waste management.

4 Empirical results and discussion

The results of our estimates are as reported in Table 2. Most of the literature on the link between environmental policy and innovation (see among others Carrion-Flores 2010; Rubashkina et al., 2015) suggest as the proxies for environmental policies are likely to be endogenous both for the presence of omitted variable bias, and reverse causality. For what concerns the first issue we control here for important drivers of recycling (see Mazzanti and Zoboli, 2009) as well as for country specific time invariant characteristics and year-specific shocks. On the other side we do not believe reverse causality to be an issue in this context as it was in other studies which adopted a similar policy indicator (Nesta et al., 2015) as environmental policy in the waste realm tends to follow European policy stimulus and directives, more than being reinforced by environmental performances, following the mechanism described by the standard neoclassical literature addressing the policy impact on innovation. The same consideration does not hold, on the contrary, in the relationship between innovation and environmental performances, as they tend to be simultaneously determined. It is reasonable to assume, in this instance, that succesfull innovation (in terms of increased recycling shares) may call for more innovative effort, reinforcing the investment in more innovation. For this reason, we follow here the approach by Franco and Marin (2015) and Lanoie et al. (2011) and use an instrumental variable approach to identify the effect of innovation on environmental performances. As a result we will instrument in the equation (5) innovation, measured as patent stock, with i) the log average number of patents in recycling technologies in other countries in the same year; ii) the log average number of patents in the same country but in other waste related technologies (namely incineration), the same year. The idea behind the choice of these two instruments (Franco and Marin, 2015), rests on the hypothesis that the patenting performance of a country or with reference to a certain technology is positively correlated with the two instruments: the propensity to patenting of a country as a whole (e.g. due to the availability of skilled labour force or to public support to research), and the features of a certain technological realm in terms of patenting intensity that is common across EU countries, which is expected to reflect general technological trends that are specific to the broad environmental problem at stake.



	I	II
	Dep. Variable: recycling patents	Dep. Variable: recycling per capita
Policy Indicator	0.0139*	1.627***
GDP	-0.000	
Total Patents	-0.000	
Population density		-0.042
Stock of recycling patents		0.357***
Consumption		0.004***
Instruments		Incineration Patents, Average of Rec Patents in other countries
Estimation Technique	Least squared dummy variable estimation	Two Stage Instrumental Variable Fixed Effect Model
Country FE	Yes	Yes
N	308	286

Standard errors in parentheses
* p<.1, ** p<.05, *** p<.01

Table 2. Econometric evidence: direct and indirect effects

Table 2 presents main results. The estimation of (6) above (first column) shows that environmental policy had a significant, but not very strong, role in sustaining green inventions development in the resource efficiency framework.

On the other hand, the estimation of (5) in the second column shows that both policies and innovation directly impact on recycling per capita in the expected way.

The estimated indirect effect, which can be thought of as ideally composed by the effects of policy on innovation and of innovation on recycling, (i.e. $\beta_2 * \beta_5$ taken from (6) and (5)), is positive and significant, though moderate. The testable implications of our theoretical model seem therefore not to be rejected: Testable implication 1 is coherent with the positive and significant impact of the stock of recycling patents on recycling per capita from column II in Table 2, while Testable implication 2 seems to match with the existence of both a direct and an indirect effect going in the same direction.

These conclusions also suggest potential policy implications. While recycling trends have benefited from both innovation and policy stimuli, the inducement of innovation by policies is not among the key factors. Environmental policies increased recycling through non technological mechanisms (e.g. changing behaviour, more infrastructures) and innovation enhanced recycling per capita due to non-policy technological levers (e.g. R&D, market spillover, market demand), which might be investigated in further research. This evidence poses serious concerns for the EU policies in the resource efficiency, waste and circular economy realm. The design of future policies towards recycling and resource efficiency should pay attention to the incentives for new inventions. Environmental policies that incorporate such incentives (e.g. well-designed economic instruments) are able to bring together environmental and economic performances in the long run by the action of technological development.

5 Concluding remarks

The paper contributes to the literature by disentangling the effects of innovation and policy on environmental performances through a detailed analysis of direct and indirect – induced - policy effects on innovation mechanisms. We investigate as case study the realm of resource efficiency and the circular economy with a focus on technologies for recycling. Firstly, we analyse the effect of environmental policies. Secondly, we assess the role played by innovation in supporting this process. Thirdly, we test these relationships also indirectly by verifying whether innovation is one of the channels through which higher recycling can be achieved by imposing more stringent environmental regulations. Preliminary results show that environmental policies are a relevant driver of increasing recycling trends. Innovation activities, as measured by patents, also play a role showing a positive and significant effect. Finally, also the effect of policy mediated by induced innovations is relevant and statistically significant, though more moderate, due to a more limited impact of policies on inventions over time in the EU. Further research should enhance and extend the development of policy indicators worldwide and focus on other areas of policy relevance within environmental economics and innovation economics.

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