Environmental policy and innovation: A sectoral analysis*

Elena Verdolini[1]

Abstract

This paper provides preliminary and suggestive evidence regarding the relation between environmental policy and innovation using sectoral-level data on 39 major economies over the years 1995-2009. First, we ask whether environmental policy stringency is associated with higher or lower sectoral innovation levels. Unlike most of the literature, we focus on overall innovation rather than low-carbon innovation, thus accounting for any substitution dynamics between green and general technologies. Second, we ask whether (increased) innovativeness impacts the ability of countries to implement more stringent climate policy, namely if our data supports to hypothesis of an "environmental policy multiplier". Our results suggest that increased environmental policy stringency does not hamper innovativeness in our sample, and also finds evidence that innovation acts as a springboard for further increases in policy stringency. We conclude by highlight fruitful research avenues to test the robustness of the preliminary results emerging from our base specification.

Keywords: Environmental policy, innovation, system estimation.

1. INTRODUCTION

In recent years the number of contributions investigating the inducement effect of environmental policy on innovation increased considerably. Most of these studies are focused on testing whether increasing the stringency of environmental policy induces more innovation in energy efficient and green technology. The general conclusions that can be drawn from this literature is that green innovation (generally proxies by patenting) is higher in those countries which implement stricter environmental policy (Popp, Newell and Jaffe, 2010).

* Acknowledgement: The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 308481 (ENTRACTE).

1 Fondazione Eni Enrico Mattei and CMCC. Email: elena.verdolini@feem.it

Three are the main research gaps that characterize this literature. First, there is only limited evidence of whether increased green innovation then translates into less pressure on the environment. To what extent the innovation induced by environmental policy stringency leads to a more efficient and less polluting way of using energy is still an open empirical question. Second, practically all studies in this respect consider environmental innovation alone, and don't explore the implications that directing investment specifically towards environmental innovation has on other types of innovation in the economy. Understanding whether increased green innovation crowds out innovation in other sectors or reduces overall innovation levels is an important step to assess the effects of environmental policy on countries' competitiveness as well as to fully understand and estimate the economic costs of environmental policy. Third, the evidence on whether increased innovation levels in turn act as an enabling factor to increase the stringency of environmental policies and meet challenging climate targets is limited to one paper, focused on the USA (Carrion-Flores and Innes, 2010).

This paper is a first, preliminary effort to partially address two of the three abovementioned questions using sector-level data from a panel of 39 countries over the years 1995-2009. Specifically, we focus on the relationship between (overall) innovation and environmental policy. First, we ask whether environmental policy stringency results in higher or lower sectoral innovation levels. Given the strong and well-accepted evidence that links environmental policy to higher level of innovation in energy efficient and green technologies, exploring the effects of environmental policy on overall innovation can help shed light on the net impact of any substitution dynamics between green and non-green innovation. Second, we explore whether (increased) innovativeness impacts the ability of countries to implement more stringent climate policy.

The paper is organized as follows. Section 2 briefly summarizes the relevant literature. Section 3 presents the data used in the paper, the empirical model and the results. Section 4 concludes, highlighting future avenues of research.

2. LITERATURE REVIEW AND RESEARCH QUESTION

The nexus between environmental regulation, innovativeness and competitiveness has been widely studied in recent years, with both a theoretical and empirical approach. From the traditional neoclassical economic perspective, (strict environmental) regulation represents an additional cost for firms, and is bound to result in lower overall competitiveness, with impacts also on trade dynamics and firms' relocations (Popp, Newell and Jaffe, 2010), at least in the short run.

The effects in the long run are less straightforward due to the inducement effect that environmental policy can have on innovation. Environmental policy makes dirty inputs comparatively more expensive by putting a price on pollution, thus internalizing the environmental externality. This in turn gives rise to induced innovation dynamics, as postulated by Hicks (1932). Firms and innovators in more regulated markets would find it profitable to invest in innovation aimed at increasing the efficiency of dirty inputs or at addressing pollution concerns. Greener and improved technologies would result in changes in the production structure. Moreover, as highlighted in Acemoglu *et al.* (2012), if governments capitalize on these changes through appropriate support policies, such dynamics can help direct economies towards greener and more sustainable economies.

However, these long-term benefits likely come at a cost. Environmental regulation forces firms to invest in R&D in cleaner technology, displacing R&D expenditure in other, more profitable areas, such as the firm's core business, given that investment budgets are limited (see Gray and Shadbegian, 1995). Whether investment in green innovation crowds out innovation in other sectors, due for example to the inelastic supply of skilled labor or to switching of R&D funding from other areas, is an important empirical question. The evidence in this respect is scarce. This in turn implies uncertainty regarding all foregone benefits, and affects the ability to fully understand and quantify the trade-offs and the economic costs of environmental policy. Popp and Newell (2012), for instance, provide some insights on this issue by focusing on the USA, but their results are limited due to data availability constraints.

This traditional view postulating that environmental policy simply translates into additional costs for firms has been challenged by the so-called Porter Hypothesis (PH).

Porter (1991) argued that well-established environmental policy is a "win-win"' situation, that benefits both the environment and the firm. According to the PH, firms have to face with market imperfections, such as imperfect information, organizational inertia or control problems. Environmental regulation forces the firm to overcome such market failures. Regulation-induced innovation helps to increase resource efficiency and enhance productivity, offsetting compliance costs.

Specifically, the PH has been translated as three possible and distinct research statements (Jaffe and Palmer, 1997). First, the "narrow" version of the PH postulates that flexible environmental regulation, such as market-based instruments, increases firms' incentives to innovate compared to prescriptive regulation, such as performance-based or technology-based standards. Second, the "weak" version of the PH postulates the positive effect of well-crafted environmental regulations on environmental innovations (even when environmental innovation comes at an opportunity cost that exceeds its benefits for a firm). Finally, the "strong" PH states that innovation induced by well-crafted environmental regulation could more than offset additional regulatory costs, and, consequently, increase firms competitiveness and productivity. From an empirical point of view, there is much evidence in support of the statement that environmental regulation induced innovation in greener and less polluting technologies (hence, the "narrow" and the "weak" PH), both for the USA and for EU countries (Popp *et al.,* 2010). Conversely, evidence on the impact of environmental policy on "competitiveness" generally defined, among which general innovation, is often contradictory.

Two key questions still remain unanswered to the best of our knowledge. First, does environmental innovation come at the cost of innovation of other kind in the economy? Understanding whether green innovation crowds out other kinds of innovation is crucial to fully understand the economic impacts and opportunity costs of environmental policy.

Second, does innovation simply respond to changes in environmental policy, or does it also help in further increasing the stringency of environmental policy? As argued in Carrion-Flores and Innes (2010), three could be the mechanisms at play in this respect. To begin with, innovation may also spur at least temporary over-compliance with government pollution, especially if the regulation is based on a market-based approach. This could result in innovation-induced tightening of government standards. Moreover, in principle innovation and policy are jointly determined. Hence, accounting for both directions of the effect is crucial in empirical estimations to get unbiased results. Finally, the presence of a long-run environmental policy multiplier would help mitigate the perceived short-term costs of environmental regulation. Carrion-Flores and Innes (2010) provide in fact some evidence of the bidirectional link of environmental policy and innovation in the case of productive sectors in the USA.

Rubashkina, Galeotti and Verdolini (2015) takes a first step in this direction by exploring the impact of environmental regulation stringency as proxied by Pollution Abatement Costs and Expenditures (PACE) on the overall innovativeness and competitiveness of European Manufacturing sectors. The paper finds that, accounting for the endogeneity of policy in the empirical framework, more stringent regulation is not associated with higher R&D investment levels,but is associated with higher patenting. Moreover, stringent environmental regulation fails to have an impact (be it positive or negative) on sectoral TFP. These results are somewhat in contrast with other previously found in the few empirical analyses addressing this issue, and suggest that such questions should be further explored.

This paper builds on this analysis and studies the dynamics of environmental regulation and innovation at the sectoral level in 39 major economies over the years 1995-2009. The analysis improves on and complements that of Rubashkina, Galeotti and Verdolini (2015) by extending the sample beyond European countries, by considering a different proxy for environmental policy stringency and by jointly studying the determinants of innovation and environmental policy stringency. This allows to take into account the possible feedbacks between these two phenomena.

Specifically, the paper tests whether environmental regulation resulted in overall higher (general) innovation at the sectoral level. If this is indeed the case, there would be evidence that environmental innovation does not crowd out other innovation activities. At the same time, it explores whether innovation has an impact on the level of environmental policy stringency. This would provide evidence of the potential environmental policy multiplier. We detail our empirical approach in the next section.

3. EMPIRICAL APPROACH AND DATA SOURCES

We rely on the framework set up in Carrion-Flores and Innes (2010) to analyze the bidirectional link between innovation and environmental policy for the USA, which specifies a structural model with four outcomes. Sectoral level emissions and patenting are two observable variables which are determined, respectively, by industry pollution targets and investment in R&D, which are unobservable due to data constraints. The system of equations they propose is as follows:

$$P_{jit} = a_{pjit} + b_p RD_{jit\text{-}1} + c_p X_{jit} + \mu_j + \mu_i + \mu_t + \varepsilon_{pjit} \qquad [1]$$

$$Q_{jit} = a_{qjit} + b_q S_{jit} + \mu_j + \mu_i + \mu_t + \varepsilon_{qjit} \qquad [2]$$

$$S_{jit} = a_{sjit} + b_s P_{jit} + c_s X_{sjit} + d_s S_{jit\text{-}1} + \mu_j + \mu_i + \mu_t + \varepsilon_{sjit} \qquad [3]$$

$$R_{jit} = arjit + b_s E(S_{jit+1}) + c_r X_{rjit} + d_r S_{jit} + \mu_j + \mu_i + \mu_t + \varepsilon_{rjit} \qquad [4]$$

Where *j* indicates the sector, *i* indicates the country and *t* indicates time. P_{jit} are patents, RD_{jit} is investment in Research and Development, Q_{jit} is the level of emissions, S_{jit} is the aggregate pollution target and X_{jit} are exogenous covariates. In all four equations, ε represent disturbances and μ the fixed effects. This system of equation suggests that:

- Sector-level patenting (*P*) is determined by past R&D investment;
- Emission respond to changes in the stringency of environmental policies as proxied by industry-level standards;
- Sector-level environmental standards are influenced by the availability of (more efficient) innovations;
- Sector-level R&D investment is influenced by both current and expected environmental standards.

These four equations allow to derive the relationship between emissions and patents by substitution (see Carrion-Flores and Innes, 2010 for details). Specifically, the level of emissions is a function of past emissions levels, patents and exogenous variables; while patenting is a function of current and past emissions levels and exogenous variables. Furthermore, we modify the original equations in Carrion-Flores and Innes (2010) by substituting lagged emissions with a proxy for energy intensity (EI) as a way to mimic the dynamics of sectoral emissions, without having to necessarily estimate a dynamic model. As a result, our equations become:

$$Q_{jit} = v_{qjit} + m_q EI_{jit-1} + n_q P_{jit} + r_q X_{qjit} + \mu_j + \mu_i + \mu_t + \varepsilon_{qjit} \quad [5]$$

$$P_{jit} = v_{pjit} + m_p Q_{ijt} + n_p EI_{jit-1} + r_p X_{pjit} + \mu_j + \mu_i + \mu_t + \varepsilon_{pjit} \quad [6]$$

We then estimate equations [5] and [6] accounting for the fact that innovation and policy stringency are jointly determined and may influence each other. Specifically, our system of equations is estimated via a three-stage least squares method. To account for the panel nature of our data, we include fixed effects controlling for sector and country heterogeneity, alongside time fixed effects.

Our estimates are conditional on the vectors X_{qjit} and X_{pjit}, which include variables likely to affect emission levels and patenting: sector value added *(VA),* the skill of the labour force and trade dynamics. Specifically, the higher the production in a given sector, proxied by *VA,* the higher the use of all inputs, including the polluting ones. Hence, we expect the coefficient associated with *VA* in the emissions equation to be positive. We also postulate that low-skill employment is associated with higher emissions (Carraro and De Cian, 2012). We thus expect a positive coefficient associated with the the share of low skilled employment *(LS).* Finally, trade patterns have been widely studied as determinants of sectoral emission intensities (Levinson and Taylor, 2008). Evidence in this respect is somewhat contradictory. Many postulate that trade patterns are among the adjustment mechanisms that firms have to face following an increase in regulatory costs. Hence, firms suddenly faced with more stringent environmental regulation may resort to importing emission-intensive goods.

We further postulate that innovation levels are affected by value added *(VA),* the share of high-skill employment in the sector as well as trade dynamics. We expect the coefficient associated with the *VA* variable to be positive: the more productive a given sector, the more likely are investments in innovative activity. The higher the skilled labour employed in a given sector *(HS),* the higher the innovative output. Finally, trade dynamics affect innovation levels since trade is among the channels of foreign technology diffusion.

The data used in this paper were collected from two sources. For each NACE rev.1.1 sector, EUROSTAT provides the number of patents applied for at the European Patent Office. Patent data is assigned to a given NACE sector using the methodology of fractional counting. The WIOD Database provided data on emissions by sectors, imports and exports, value added and labor inputs. The emission variable, which proxies for (the inverse of) environmental policy stringency, is calculated as CO_2-equivalent sum of all emissions (including CO_2, SOx, NOx, NH_3, N_2O, CH_4). Energy Intensity is defined as energy use over value added. Gross value added at current basic prices (in millions of national currency) has been deflated. Import and export intensities are calculated as a share of value added at the sector level. Finally, our proxy for high-skilled and low-skilled labor measure the share of compensation to each of these types of workers in total labor compensation.

Table 1

Classification of Industrial Sectors

#	Sector	NACE Rev.1.1
1	Food products, beverages and tobacco	15-16
2	Textiles and textile products; leather and leather products	17-19
3	Wood and wood products	20
4	Pulp, paper and paper products; publishing and printing	21-22
5	Coke, refined petroleum products and nuclear fuel	23
6	Chemicals, rubber and plastic products	24-25
7	Other non-metallic mineral products	26
8	Basic metals	27
9	Fabricated metal, machinery and equipment, electrical and optical equipment, transport equipment, manufacturing n.e.c.	28-36

Source: International Standard Industrial Classification of all economic activities.

Table 2
Descriptive Statistics

Variable	Obs	Mean	Std. Dev	Min	Max
Log Patents	4,881	2.419	2.310	0.000	9.943
Log Emissions	4,881	7.443	2.656	-2.432	13.501
Log Value Added	4,881	12.564	2.158	2.523	17.980
Energy Intensity (t-1)	4,881	-1.603	1.759	-6.281	5.442
Export Intensity	4,881	0.008	0.011	0.000	0.233
Import Intensity	4,881	0.011	0.027	0.000	0.515

Source: Produced by the author.

Due to the different way in which sectors are reported in the two sources of data, we focus on 9 manufacturing sectors as described in Table 1. The final sample is unbalanced due to data availability and is composed of 39 countries: Austria, Australia, Belgium, Bulgaria, Brazil, Canada, China, Cyprus, The Czech Republic, Germany, Denmark, Estonia, Spain, Finland, France, Great Britain, Greece, Hungary, Ireland, India, Italy, Japan, Korea, Lithuania, Luxembourg, Latvia, Malta, Mexico, Netherlands, Poland, Portugal, Romania, Russia, Sweden, Slovenia, Slovak Republic, Turkey, Taiwan, and the United States. Table 2 reports the descriptive statistics of the main variables of interest.

4. RESULTS

Table 3 reports the result of the estimation of the system of equations, as explained in the previous section, alongside with the results from the estimation of the two equations separately, for comparison.

Focusing on the innovation equation, results are in line with our expectations and confirm what presented in Rubashkina, Galeotti and Verdolini (2015). Overall innovation levels are positively affected by lower emission levels (hence, in our framework, by higher policy stringency). Those sectors which are subject to more stringent regulation are also characterized by higher patenting levels, arguably as a result of regulatory pressure. This is preliminary and suggestive evidence that environmental policies do not hamper overall innovation in this sample; on the

Table 3

Main results

	Three-stage least square system estimation		OLS	OLS
Variables	(1a) Log Patents	(1b) Log Emissions	(2) Log Patents	(3) Log Emissions
Log Emissions	-2.333*** [0.774]		-0.0491*** [0.0121]	
Log Patents		-0.632*** [0.216]		-0.0516 [0.0509]
Energy Intensity (t-1)	0.0136*** [0.00513]	0.00605*** [0.00140]	0.000585* [0.000340]	0.00542** [0.00238]
Export Intensity	46.36*** [13.83]	21.39*** [2.659]	-0.716 [1.127]	17.20** [7.505]
Import Intensity	-11.53*** [4.156]	-5.066*** [0.927]	0.622 [0.393]	-4.706 [3.430]
Log Value Added	1.749*** [0.499]	0.801*** [0.0582]	0.0669*** [0.0206]	0.655*** [0.0983]
High Skilled Labour (%)	-0.00173 [0.00161]		0.000340 [0.000378]	
Low Skilled Labour (%)		-0.000265 [0.000230]		0.000182 [0.000264]
Observations	4,881	4,881	4,881	4,881
R-squared	0.205	0.875	0.989	0.900

Note: Standard errors in brackets: *** p<0.01, ** p<0.05, * p<0.1.
Source: Produced by the author.

contrary, countries with higher stringency (and lower emissions) are also more innovative. Furthermore, more productive sectors (with higher value added) are also those where innovation is higher. Conversely, the sectoral share of skilled labor does not seem to impact sectoral innovation levels. With respect to trade dynamics, high import dependence is associated with lower innovativeness, while higher innovation levels characterize those sectors with large exports.

Considering that our patent variable measures overall innovation (as opposed to green innovation only) our result on the inducement effect of environmental policy stringency is consistent with two explanations. On the one hand, it could be due to the fact that energy innovation, spurred by an increase in environmental policy stringency, does not crowd out innovation of other kinds. On the other hand, this result could also arise if environmental policy spurs enough green innovation to compensate for any decrease in overall innovation. While our analysis is not able to discern the precise underlying dynamics, we provide evidence that overall innovativeness is not hampered by environmental policy.

Focusing on the determinants of emissions (hence, in our framework, on the determinants of environmental policy stringency), our analysis confirms the presence of an environmental policy multiplier. Indeed, the coefficient associated with patents is negative and significant, indicating that the higher the innovation level in a given sector, the lower the emissions (hence, the higher the environmental policy stringency). This should be considered as preliminary and suggestive evidence that in our sample innovation does act as an enabling factor for more stringent environmental policy. In line with expectations, value added is confirmed as having a positive impact on emissions. Looking at the impact of trade on our proxy of environmental policy stringency, sectors which are export-dependent tend to be characterized by lower policy stringency (higher emissions). The opposite is true for import-depending sectors.

Note that our system approach provides different insights when compared to a more basic, separate estimation of the innovation and emissions equations. The former finds evidence for both the inducement effect of environmental policy and the presence of an environmental policy multiplier. The latter confirms that higher environmental policy is associated with more innovation (albeit with a much smaller marginal effect), but fails to identify any environmental policy multiplier.

The evidence regarding the presence of an environmental policy multiplier emerging from our analysis is in line with the results presented in Carrion-Flores and Innes and with the insights emerging from the IV approach presented in Rubashkina, Galeotti and Verdolini (2015). However, Carrion-Flores and Innes (2010) focus on environmental innovation, while this paper focuses on innovativeness in general. Therefore, our results suggest that the environmental policy multiplier is present even after accounting for any substitution dynamics between green innovation and other types of innovation.

Similarly, our results are in line with the insights coming from the first stage of IV approach presented in Rubaskhina, Galeotti and Verdolini (2015), which shows that the coefficient of the knowledge stock in the first-stage, PACE equation is positive. In this respect, it is important to note that Rubaskhina, Galeotti and Verdolini (2015) use PACE as a proxy for environmental policy stringency, while here the focus is on emissions levels. The former informs on inputs into the process of emissions reductions, namely the amount of money spent. Conversely, the latter measure the actual outcome of the efforts to limit emissions.

5. CONCLUSIONS

This paper is a first step towards shedding light on two questions which have not been satisfactorily addressed by the empirical investigations focusing on the relationship between environmental policy and innovation. The first question relates to the relationship between environmental policy and overall inventiveness. The second question concerns the possible presence of an environmental multiplier effect by which innovation acts as a springboard towards more stringent environmental policy. Our analysis thus provides insights on the overall competitiveness of countries in terms of innovation potential as well as on the inducement effect of (overall) innovation on environmental policies.

First, we complement previous results on the inducement effect of environmental innovation by looking at the relationship between environmental policy and overall patenting activity by sector. The positive link between more stringent environmental policy and more environmental and green innovation has been widely studied both using aggregate and micro-level data. In line with the results presented in Rubashkina, Galeotti and Verdolini (2015) for European countries, we confirm that countries with more stringent environmental policies are characterized by higher innovation levels overall, and not just in green and environmentally-friendly technology. This is an important insight because it implies environmental policies do not only improve green innovation in a given economy, but they do not come at the expense of overall activity within the economy.

Second, our paper however suggests that indeed there is an environmental policy multiplier effect, whereby higher levels of innovation as springboards to further tightening environmental standards. Overall, this is suggestive of a virtuous cycle whereby more stringent regulation increases innovativeness, which in turn makes a further tightening of environmental standards easier to implement.

However, the robustness of our results, and the breadth of their implications, clearly need to be further tested. Indeed, this preliminary analysis suffers from several shortcomings, which should be the focus of further research. First, the analysis should be extended by including information regarding sectoral low-carbon innovation. When such data becomes available, it will be possible to fully explore the inducement effect of environmental policy and the presence of an environmental policy multiplier while accounting for substitution dynamics between green and non-green innovation. Therefore, a first important future effort should be to improve data availability regarding low-carbon innovation at the sector level.

Second, the robustness of our findings should be tested by using different proxies for environmental regulation other than carbon emissions, as in our framework. Possible candidates in this respect include information on PACE, or indexes of environmental policy stringency such as the OECD EPS. These, however, are currently not widely available: PACE is limited to a few, mostly European, countries, while there is currently no widespread index of sectoral level environmental policy stringency.

Lastly, an important extension would be to estimate a system of simultaneous, dynamics equation, in which emissions and patents are allowed to depend on past emissions and the available knowledge stock, respectively.

In these directions we are currently focusing our research endeavors.

REFERENCES

Acemoglu, D.; Aghion, P.; Bursztyn, L., and D. Hemous (2012), "The Environment and Directed Technical Change," *American Economic Review,* 102: 131-166.

Carraro C., and E. De Cian (2012), Factor-augmenting technical change: an empirical assessment, *Environmental Modeling & Assessment*, http://dx.doi.org/10.1007/s10666-012-9319-1

Carrion-Flores, C.E., and R. Innes (2010), "Environmental Innovation and Environmental Performance", *Journal of Environmental Economics and Management,* 59: 27-42.

Eurostat, http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database

Gray, W. B., and R. Shadbegian (1995), "Pollution Abatement Costs, Regulation, and Plant-Level Productivity," *NBER Working Paper,* 4994, January.

— (2003), "Plant Vintage, Technology and Environmental Regulation," *Journal of Environmental Economics and Management,* 46: 384-402.

Hicks (1932), *The Theory of Wages*, MacMillan.

Jaffe, A. B., and K. Palmer (1997), "Environmental Regulation and Innovation: A Panel Data Study," *The Review of Economics and Statistics,* 79: 610-619.

Levinson, A., and M. S. Taylor (2008), Unmasking the Pollution Haven Effect, *International Economic Review,* 49: 223–254, doi: 10.1111/j.1468-2354.2008.00478.x

Popp, D., and R. Newell (2012), Where Does Energy R&D Come From? Examining Crowding out from energy R&D," *Energy Economics,* 34(4): 980-991.

Popp, D.; Newell, R., and A. Jaffe (2010), "Energy, the Environment, and Technological Change," Handbook of the Economics of Innovation: vol. 2, Bronwyn Hall and Nathan Rosenberg, eds., *Academic Press/Elsevier,* 2010: 873-937.

Porter M. (1991), "America's Green Strategy", *Scientific American*, 264: 168.

Rubashkina, Y.; Galeotti, M., and E. Verdolini (2015), “Environmental Regulation and Competitiveness: Empirical Evidence on the Porter Hypothesis from European Manufacturing Sectors”, *Energy Policy,* 83: 288–300.

WIOD Database, available at www.wiod.org (version 2012).