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Abstract

This paper aims to shed light on the role of environmental policies, technological change and their interaction, on CO2 emissions in Europe. Building on the literature, which studies the relationship between environmental performances and technological change, as well as the literature related to the effects of environmental policy, two hypothesis are framed: the first one is that both environmental policy and technological change have a negative effect on CO2 emissions level. The second one is that technological change and environmental policy are complementary determinants of a reduced CO2 level. Both a fixed effects model and IV model are applied. Results offer support to these hypothesis and highlight sectorial differences in policy and technology effects toward lower emissions levels.

JEL Classification: L60, O33, Q53

Keywords: technological change, environmental policy, pollution emissions

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1. Introduction

Several authors have highlighted the positive effects of technology and science improvements on climate change (Abbott, 2009). Concerning emissions reduction, Jaffe et al. (2002) and Popp et al. (2009) underline that the process of technological change has an effect on both economic performance and environmental impact and that "potentially, emission reduction is associated with faster diffusion of existing technologies" (Jaffe et al., 2002, p. 48).

There is another literature stream that investigates the role of environmental policies in spurring innovation. Following Porter and Van der Linde (1995), regulation may have the effect of signaling to firms profitable opportunities which otherwise might be overlooked; thus, policies can push firms to search for less costly ways of production. This assumption has been evaluated in several empirical studies, which have produced mixed evidence. For a survey see Ambec et al. (2013).

The aim of this paper is to investigate the effects of technological change and environmental policy on CO2 emissions. We predict that : i) both environmental policy and technological change have a positive effect on CO2 emission levels reductions, and ii) the size of the effect of technological change on CO2 emissions is larger in presence of sectoral environmental policy, which might allow firms to capitalize on their existing knowledge base, thereby reducing uncertainties and providing an incentive to innovate.

2. Methodology

Table 1 summarizes the variables of interest. Data on CO2 and value added by sector for 14 manufacturing sectors and 13 European countries[1] are taken from the World Input Output Database (WIOD). Patent applications from the OECD REGPAT database are used as an indicator of technological change, and counted by applicant country of residence[2]. The environmental policy index is computed using information from the OECD database on environmental policy instruments. The time span considered is 1995-2009.

Patents is used as an indicator of technological change and computed following Popp et al. (2011).

Policy is computed following the methodology proposed in Nesta et al. (2014); six dummy variables were computed for policies which take the value 1 if the policy was in force in a certain year and in a certain sector and country and 0 otherwise. A policy variable ranging from 0 (no regulations) to 6 (all instruments implemented) was created as the sum of all the policies in force in a given year and in a given sector and country.

[1] Countries (Austria, Belgium, Germany, Denmark, Spain, Finland, France, Great Britain, Greece, Ireland, Italy, Luxembourg, Netherland, Portugal, Sweden) selected based on data availability.
[2] International Patent Code-NACE in line with Schmoch et al. (2003).

Table 1 - Description of the variables

Variable	Description	Obs.	Mean	Std. Dev.
CO2 (dependent variable)	Sectoral CO2 emission in tons sector	3018	4401.80	8825.02
Patents	Stock of total patents applications to the EPO~	3150	640.79	2346.17
Policy	Includes: deposit-refund schemes; taxes; ETS~~; voluntary approaches; environmental subsidies (by sector). Standardized in the analysis	3150	0	1
VA	Yearly sectoral value added, deflated at 1995 prices (control variable)	3150	8155.25	13746.33
Interaction	Policy*Patents	3150		

~ is European Patent Office; ~~ is Emissions Trading Scheme

We first specify a fixed effects model as follows:

$$CO2_{i,s,t} = \beta_1 patents_{i,s,t-1} + \beta_3 policy_{i,s,t-1} + \beta_2 value\ added_{i,s,t} + \beta_4 (patents_{i,s,t-2} * policy_{i,s,t-1}) + \alpha_s + \gamma_t + \varepsilon_{i,s,t}$$

where α_s are sectoral fixed effects, γ_t are time fixed effects and $\varepsilon_{i,s,t}$ is the idiosyncratic error component[3].

Patents and *policy* are lagged since a non-instantaneous effect is assumed. Lagged values of these variables are used also to compute the interaction variable; especially, to account for the direction of technological change the second lag of the patent stock is included.

Following Downing and White (1986), if the current policies are successful for reducing CO2 levels, stakeholders are induced to demand more stringent regulation in the future. This may introduce endogeneity problems because of the autocorrelation between $\varepsilon_{i,s,t}$ and $policy_{i,s,t-1}$.

An instrumental variable model is also set up. Instrumented variables are *policy* and *interaction*. Following Reed (2015), the second lag of *policy* has been selected as instrument together with the first and the second lag of *outpolicy*[4] (a variable which captures the mean value of the *policy* in all countries except the i^{th} one). As in

[3] A specification of the model using sectoral trend ($\varphi_{s,t}$) was run as a robustness check.
[4] See Franco and Marin (2015) for use of a similar instrument.

Wooldridge (2002, p. 68), *interaction* is instrumented using a new variable created as the product of the second lag of *patents* and the fitted values of the following regression:

$$Policy_{i,s,t} = \alpha + \beta_1 * policy_{i,s,t-2} + \beta_2 outpolicy_{j,s,t-1} + \beta_3 * oupolicy_{j,s,t-2} + \varepsilon_{i,s,t}$$

3. Results and Discussion

Columns FE(a) and FE(b) in Table 2 presents the results of the fixed effects model, FE(a) showing a specification with sector and year fixed effects and FE(b) presenting a specification with a sectoral trend. On average, lagged *patents, policy* and *interaction* have a negative and significant effect.

Figure 1 quantifies the results in FE(a). For values of *policy* below or equal to the median, a unit increase in *patents* decreases CO2 emissions by 0.004 tons. However, increasing *policy* turns the effects negative: a unit increase in *patents* decreases emissions by 0.19 tons at the 75^{th} percentile and by 0.57 tons when *policy* is at its maximum. The coefficient of *patents* in the absence of policy, suggests a unit increase in knowledge reduces *CO2* by 0.105 tons (column FE(a)).

Columns IV(a) and IV(b) present the results of the instrumental variables model, IV(a) in a specification with sector and country fixed effects and IV(a) in a specification with a sectoral trend. Figure 2 quantifies the results in IV(a) suggesting a similar situation to Figure 1, except that the overall effect of *patents* is negative for the smallest values of *policy* (50^{th} percentile or lower), with an overall effect of -0.012 tons of *CO2* per unit increase *patents*. In the absence of policy, the effect of a unit increase in *patents* causes CO2 emissions to decrease by 0.095 tons, (column IV(a)).

The results show that increasing environmental regulation allows sectors to exploit their knowledge base in order to comply with environmental regulation. Both the weak instruments test and the Hausman tests suggest IV is the preferred model.

Table 3 presents the estimate by sector of the equation in Table 2 column IV(a). The majority of sectors in which *policy* is significant and negative correspond to the highly polluting sectors identified by the ETS regulation (e.g., coke and petroleum, paper, basic metals). The role of environmental policy in relation to these sectors is vital for achieving lower CO2 emissions.

In contrast, *patents* has an ambiguous effect on *CO2*: for example, for the coke and petroleum sector, the effect of a unit increase in *patent* in the absence of policy is an increase in CO2 emissions of at least 24.68 tons. A quantification similar to the previous one, shows that in this sector the overall effect of technology is negative only for values of *policy* equal to or above the 99^{th} percentile (-14.16 tons of CO2 per unit of *patents*).

For other emissions-intensive manufacturing sectors such as non-metallic mineral metals, the average negative effect of technological change is higher than the corresponding value in Table 3, pointing to the existence of differences between sectors in the effect of technology in promoting emissions reductions.

The interaction between *policy* and *patents* does not always have the expected sign (e.g. in the chemical sector) which result is probably driven by the fact that patenting in the chemical sector is related mostly to products and chemical substances rather than processes.

Table 2 - Estimation results.

	FE(a)	FE(b)	IV(a)	IV(b)
Patents	-0.0798**	-0.105***	-0.0952***	-0.108***
	(0.03)	(0.036)	(0.022)	(0.021)
Policy	-212.6**	-260.4***	-518.0***	-329.3***
	(106.0)	(98.00)	(144.6)	(70.56)
VA	0.0262**	0.0309**	0.0251***	0.0321***
	(0.012)	(0.012)	(0.009)	(0.009)
Interaction	-0.149**	-0.151**	-0.126*	-0.144**
	(0.07)	(0.072)	(0.066)	(0.06)
Observations	2602	2602		
*Country*Sector fixed effect*	Yes	Yes	Yes	Yes
Year fixed effect	Yes	No	Yes	No
Sectorial trend	No	Yes	No	Yes
F first step	-	-	148.4	2093.1
Hansen test(p-value)	-	-	0.684	0.1503

Robust standard errors (in parentheses). * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Figure 1 - Quantification of the results in FE(a).

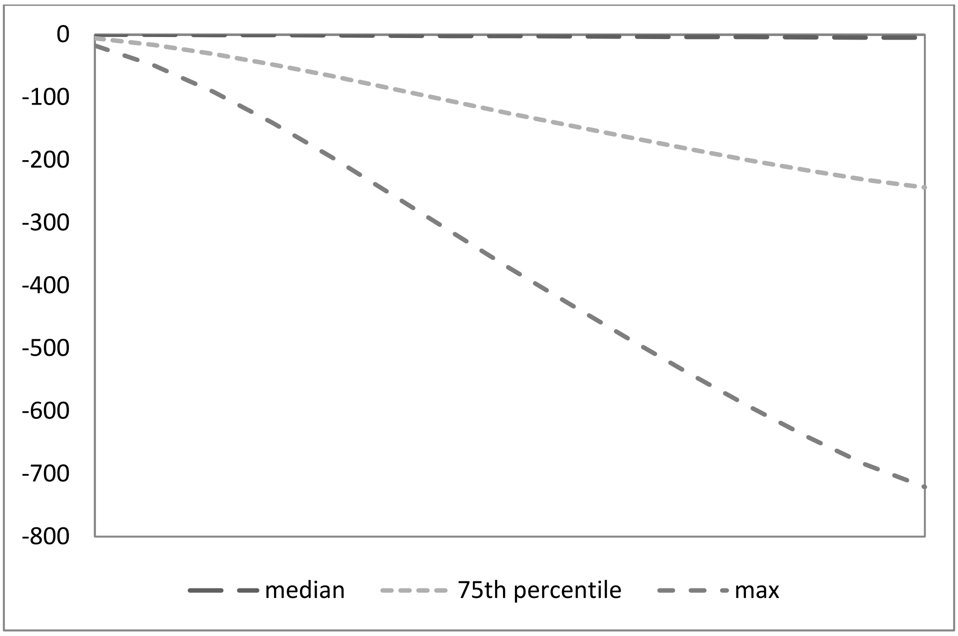

Figure 2 - Quantification of the results in IV(a).

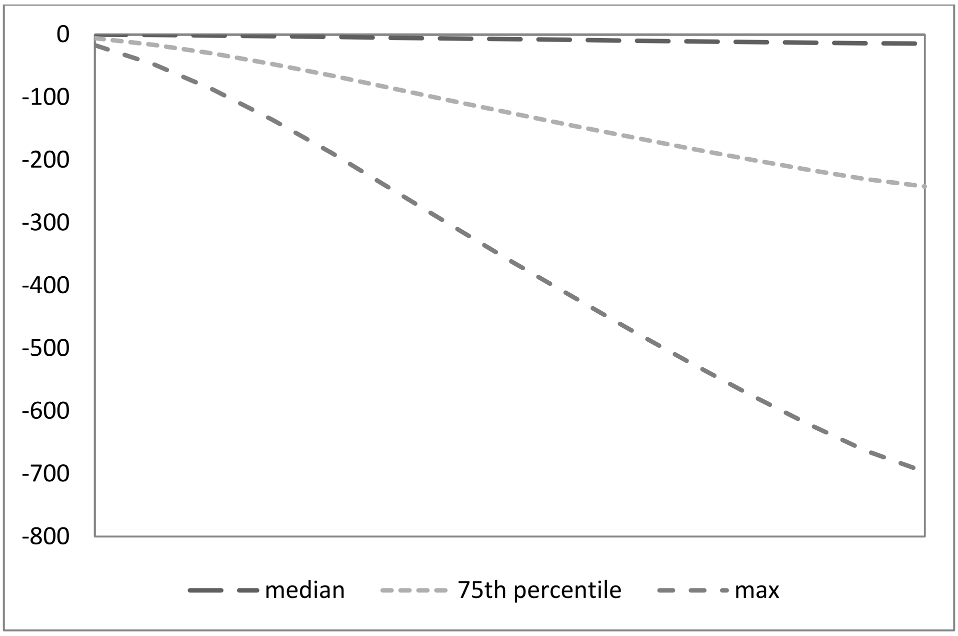

Table 3 – Estimation results.

	Leather	Wood	Coke & Petroleum	Chemical	Rubber & Plastic	Non-metallic minerals	Machinery
Patents	-3.018***	-0.859**	24.68**	-0.745***	-0.452**	-7.967***	-0.0457***
	(0.335)	(0.346)	(10.29)	(0.198)	(0.201)	(1.730)	(0.00996)
Policy	-8.881	-13.24	-1017.0*	-1074.7***	-109.9	-1246.0***	-294.1
	(17.14)	(45.21)	(543.3)	(299.1)	(150.7)	(446.6)	(240.5)
VA	-0.0279	0.0342**	0.138	-0.0460	0.0120	0.840***	0.0112**
	(0.0252)	(0.0154)	(0.112)	(0.0442)	(0.0153)	(0.187)	(0.00484)
Interaction	-0.289	-4.206	-14.20***	0.249**	0.188	1.182	-0.0112
	(1.592)	(4.621)	(4.132)	(0.101)	(0.133)	(0.837)	(0.0513)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
F first step	35.90	134.6	22.71	77.39	15.47	48.76	5.246
Hansen test (p-value)	0.317	0.631	0.0133	0.117	0.943	0.743	0.944

Robust standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4 – Estimation results.

	Food	Textile	Paper	Basic Metals	Electrical equipment	Transport equipment	Recycling
Patents	2.498	-8.237***	-1.737	-0.770	-0.0148**	-0.192***	-0.319*
	(3.055)	(0.912)	(3.352)	(1.409)	(0.00681)	(0.0654)	(0.183)
Policy	7.466	-228.6	251.6**	-2600.1***	13.67	-137.6	-2018.8
	(280.8)	(593.4)	(124.9)	(822.7)	(67.55)	(142.8)	(2328.4)
VA	-0.0320	-0.178	0.0230	0.328***	0.00388**	0.0105***	0.0295
	(0.0245)	(0.111)	(0.0344)	(0.0817)	(0.00155)	(0.00401)	(0.0302)
Interaction	-0.0279	-0.184*	0.0230	0.322***	0.00384**	0.00987**	0.0509
	(0.0270)	(0.108)	(0.0342)	(0.0798)	(0.00157)	(0.00395)	(0.0431)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
F first step	18.71	26.01	68.89	60.35	9.480	13.27	0.520
Hansen test(p-value)	0.104	0.0466	0.864	0.474	0.624	0.0893	0.0768

Robust standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

4. Concluding remarks

This analysis yields some interesting results. First, both policy and technology as well as their interaction, have a negative and significant impact on CO_2 emissions suggesting that environmental policy reinforces the effect of innovation on the environment. This result also imply that a low knowledge base at sector or country level may hinder the effects of environmental policy. Second, these effects show high sectorial variability, which calls for sector-specific policies.

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