Innovation, Productivity and Environmental Performance of Technology Spillovers Effects: Evidence from European Patents within the Triad

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Abstract

The aim of this paper is that of investigating whether the integration process between environmental activities is important in the Spillovers flows analysis. For this reason, we explore the role of knowledge externalities for large international firms engaged both in environmental and in non-environmental activities. In particular, we develop a theoretical framework and an empirical analysis of the United States, Japan and Europe based upon a dataset composed of worldwide R&D-intensive firms. In order to deal with the firms' unobserved heterogeneity and the weak exogeneity of the regressors, we implement the Generalized Method of Moments (GMM) method. The results show a differentiated impact of environmental spillovers on firms' productivity and green performance, by suggesting some interesting policy implications in terms of actions to favor full sustainability of firms' production.

Keywords: technological innovation, environmental relatedness, environmental performance

1. Introduction

In order to assure long run sustainability, structural changes in each developed country economy are required (Cainelli et al. 2012; De Marchi, 2012; Harbach, 2008; Kemp and Pontoglio, 2011). Empirical literature on environmental issues has deeply explored the complementarity feature between dirty and environmental innovations (Hall et al. 2012; Mancinelli and Mazzanti, 2009; Mohnen and Roller, 2005; Aghion et al. 2016). However, there is a lack of studies focusing only on environmental activities. This is the main motivation of the manuscript.

In this paper, we analyze the environmental technology spillovers for large international firms within the Triad, on the basis of proximity computed through European patents data (as in Jaffe, 1986). Since Jaffe's proximity assumes externalities only occur within the same technology field, we use the Mahalanobis index (Bloom et al., 2013 and Aldieri, 2013), in such a way that we consider the co-location, that is the frequency that patents are taken out in different classes by the same firm (Lychagin et al., 2016).

The paper is structured as follows: Section 2 introduces a theoretical framework about firms' activity; Section 3 describes the data used in the empirical analysis; Section 4 presents the empirical analysis and Section 5 concludes.

2. Theoretical Framework

In order to better specify the relationships and sources of our empirical framework, this section presents a basic theoretical model, which is a set-up of a global economy with multiple sectors and countries. In each country, the production of a sector bases on three environmental targets, such as water pollution abatement, solid waste collection, and different types of green energy (wind, solar and geothermal energy, integrated emissions control, lightning to quote some). Each target combines varieties of technological classes, with physical, human and knowledge capital. The number of varieties in each sector and country is determined endogenously, and

investments in these technological classes may be assumed to depend on rational agents purposeful decisions (Bretschger et al. 2017). The final output of a sector i, country r, at time t $Y_t^{i,r}$ may be taken as the of two different outputs from two different production techniques: green ($Y_{Nt}^{i,r}$) and not ($Y_{gt}^{i,r}$), and written as:

$$Y_t^{i,r} = \theta Y_{Nt}^{i,r} + (1-\theta)Y_{g,t}^{i,r} \quad (1) \text{ with: } \quad 0 < \theta < 1,$$

where:

$$Y_{Nt}^{i,r} = Y_N\left(C_N, K_N, H_N\right) \quad (2)$$

$$Y_{gt}^{i,r} = Y_g\left(C_g, K_g, H_g\right) \quad (3)$$

$$K_N = K_N(K_g) \quad (4)$$
$$K_g = K_g(B_g; B_g^R) \quad (5)$$
$$B_g = B_g(\chi) \quad (6)$$
$$B_g^R = B_g^R(\chi^R) \quad (7)$$

$$\chi = \alpha x_1 + \beta x_2 + (1-\alpha-\beta)x_3 \quad (8) \quad \text{with: } \quad 0 < \alpha, \beta < 1$$

$$\chi^R = a x_1^R + b x_2^R + (1-a-b)x_3^R \quad (9) \quad \text{with: } \quad 0 < a, b < 1.$$

Parameters C_g and C_N, H_g and H_N measure respectively physical and human capital, green and not, the innovation effects on the technology are embodied by the impact of knowledge capital levels denoted K_g and K_N, and patents denoted B_g, depends on χ, a variable capturing the effects of the three different technological fields x_1, x_2 and x_3. Finally B_g^R, χ^R stand respectively for patents, and the variable catching the special effects of the three different technological fields x_1^R, x_2^R and x_3^R from other countries. After some simple substitutions we may write what follows:

$$Y_t^{i,r} = \theta Y_N\left\{C_N, H_N, K_N\left[K_g\left(B_g(\alpha x_1 + \beta x_2 + (1-\alpha-\beta)x_3), B_g^R(a x_1^R + b x_2^R + (1-a-b)x_3^R)\right)\right]\right\} + (1-$$

$$\theta)Y_g\left\{C_g, H_g, K_g\left(B_g(\alpha x_1 + \beta x_2 + (1-\alpha-\beta)x_3), B_g^R(a x_1^R + b x_2^R + (1-a-b)x_3^R)\right)\right\} \quad (10)$$

Hence in order to determine the short run impacts of innovation on the green and total technology we may easily derive:

$$dY_g = \frac{\partial Y_g}{\partial C_g}dC_g + \frac{\partial Y_g}{\partial H_g}dH_g + \frac{\partial Y_g}{\partial K_g}\left\{\frac{\partial K_g}{\partial B_g}\frac{\partial B_g}{\partial \chi}[\alpha x_1 + \beta x_2 + (1-\alpha-\beta)x_3] + \frac{\partial K_g}{\partial B_g^R}\frac{\partial B_g^R}{\partial \chi^R}[a x_1^R + b x_2^R + (1-a-b)x_3^R]\right\} \quad (11)$$

$$dY_t^{i,r} = (1-\theta)\left\{\frac{\partial Y_g}{\partial C_g}dC_g + \frac{\partial Y_g}{\partial H_g}dH_g + \frac{\partial Y_g}{\partial K_g}\left\{\frac{\partial K_g}{\partial B_g}\frac{\partial B_g}{\partial \chi}[\alpha dx_1 + \beta dx_2 + (1-\alpha-\beta)dx_3] + \frac{\partial K_g}{\partial B_g^R}\frac{\partial B_g^R}{\partial \chi^R}[a dx_1^R + b dx_2^R + (1-a-b)dx_3^R]\right\}\right\} + \theta\left\{\frac{\partial Y_N}{\partial C_N}dC_N + \frac{\partial Y_N}{\partial H_N}dH_N + \frac{\partial Y_N}{\partial K_N}\frac{\partial K_N}{\partial K_g}\left\{\frac{\partial K_g}{\partial B_g}\frac{\partial B_g}{\partial \chi}[\alpha dx_1 + \beta dx_2 + (1-\alpha-\beta)dx_3] + \right.\right.$$

$$\left. \frac{\partial K_g}{\partial B_g^R} \frac{\partial B_g^R}{\partial \chi^R} [a d x_1^R + b d x_2^R + (1 - a - b) d x_3^R] \right\} \right\} \tag{12}$$

From the previous model we can identify two main research hypotheses:

[H1] : *The integration process between environmental technology fields is relevant in the computation of Spillover components of firms*

[H2] : *The effect of Spillovers stemmed from diversified environmental technology fields on firms' productivity is positive.*

3. Data

We use three sources of data. First, we use information from OECD, REGPAT database, February 2016 (Note 1), as in Aldieri and Vinci (2017). Second, we match the name of the same firms to applicant's name from European Commission (2013), as in Aldieri (2013). The third source of data is the World Input Output Database (WIOD), which is made up of four different accounts (World Tables, National Tables, Socio Economic Accounts and Environmental Accounts). For purposes of this paper, we use the Environmental Accounts providing CO_2 emissions variable by country and by year.

In Table 1, we report those patents with IPC code belonging to the groups selected by the OECD or the World Intellectual Property Organization (WIPO), as in Marin and Lotti (2016).

Table 1. Environmental patent classes

Sub-category	IPC
Water pollution abatement	C02F, E03F, E02B, C09K, C05F, B63J, E03C, E03B
Solid waste collection	E01H, B65F
Material recovery, recycling, and reuse	A23K, A43B, B03B, B22F, B29B, B30B, B62D, B65H, B65D, C03B, C03C, C04B, C08J, C09K, C10M, C22B, D01G, D21B, D21C, D21H, H01B, H01J, H01M
Waste management n. e. c.	B09B, C10G, A61L
Waste disposal	F03G, B60K, B60L, B09B, B65F
Treatment of waste	A61L, A62D, B03B, B09C, D21B
Consuming waste by combustion	F23G
Reuse of waste materials	A43B, B22F, C04B, C05F, C08J, C09K, C11B, C14C, C21B, C25C, D21F, B29B, B62D, C08J, C10G, C10L, C22B, D01G, D21C, H01J, H01M
Integrated emissions control	F02B, F02M, F01N, F02D, G01M, F02P
Post-combustion emissions control	F01M, F01N, F02B, F02D, F02M, G01M, B01D, B01J, B60, B62D
Technologies specific to propulsion using electric motor	B60K, B60L, B60R, B60S, B60W
Technologies specific to hybrid propulsion	B60K, B60W
Fuel efficiency-improving vehicle	B62D, B60C, B60T, B60G, B60K, B60W
Insulation	F04B, E06B
Heating	F24D
Lighting	H01J, H05B
Wind energy	F03D, H02K, B63B, E04H, B60K, B60L, B63H

Solar energy	H01L, H01G, H02N, C01B, C23C, C30B, G05F, F21L, F21S, H02J, H01H, H01M, F24J, E04D, F22B, F25B, F26B, G02B
Geothermal energy	F01K, F24F, F24J, H02N, F25B, F03G

In particular, we analyze the integration process degree between environmental technology classes presented in Table 1, as discussed in the previous sections.
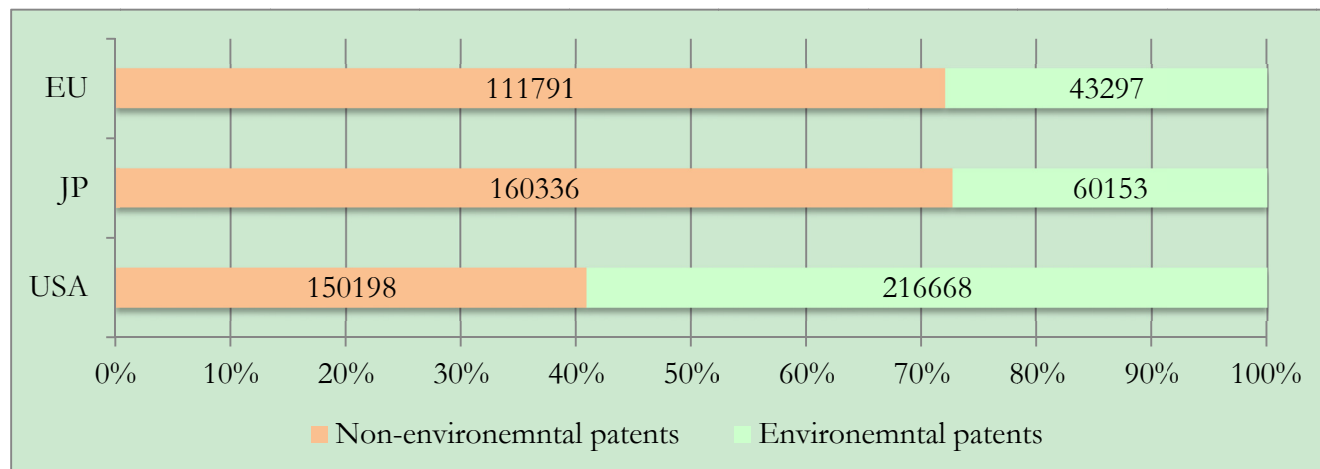

Figure 1. Distribution of Non-environmental/Environmental patents by economic area

As we may observe in Figure 1, European and Japanese firms in our sample are engaged mainly in non-environmental innovations, while American firms are more advanced towards green activities.

The aim of this paper is to investigate the integration degree between technology classes of environmental patents. To this end, we distinguish the spillovers originated within the same technology class or specialized externalities, and the spillovers derived from different classes or diversified externalities, on the basis of the Mahalanobis approach (Aldieri, Kotsemir and Vinci, 2017).

4. Empirical Framework

a.   Model specification

In order measure the impact of environmental spillovers on firms' productivity, we consider the following specification model:

$$\ln S_{it} = \alpha_i + \lambda_t + \beta_1 \ln L_{it} + \beta_2 \ln C_{it} + \beta_3 \ln K_{it} + \gamma_1 \ln SPEC_{it} + \gamma_2 \ln DIV_{it} + \varepsilon_{it} \tag{13}$$

where ln = natural logarithm;

S_{it} = Productivity measured by net sales for firm i and year t;

C_{it} = physical capital stock for firm i and year t;

L_{it} = number of employees for firm i and year t;

K_{it} = R&D capital stock of firm i and year t;

α_i = firm's fixed effects;

λ_t = set of time dummies;

$SPEC_{it}$ = vector of specialized spillovers for firm i and year t;

DIV_{it} = vector of diversified spillovers for firm i and year t;

β, γ = vectors of parameters;

ε_{it} = disturbance term.

Moreover, in order to identify the environmental performance of technology spillovers, we estimate also another model with ratio between productivity and CO2 (SCO2) as dependent variable (Repetto, 1990) and regressors like in (13). In Table 2, we show the summary statistics of our sample.

Table 2. Summary statistics

Variable	Mean[a]	Std. Dev.
lnS	8.50	1.450
lnSCO2	21.68	4.021
lnC	7.49	1.584
lnL	9.97	1.360
LnK	7.15	1.426
lnSPEC	3.86	6.490
lnDIV	4.31	7.023

Note: a) 1837 observations;

b.   GMM estimation procedure

In order to handle both firms' unobserved heterogeneity and the weak exogeneity of the explanatory variables, we estimate equation (13) using a one-stage generalized method of moments (GMM) (Note 2) estimator, as in Aldieri and Cincera (2009).

In Table 3 and Table 4, we present the empirical estimates for the GMM-SYS estimator. In particular, we show the effects of specialized activities spillovers (SPEC) and diversified technology fields spillovers (DIV) on firms' productivity in Table 3 and environmental performance effects of spillovers in Table 4. We lag environmental spillover components by a year to reflect delayed response and also mitigate contemporaneous feedback effects.

Table 3. Productivity of Environmental Spillovers effects: GMM estimates

Dependent variable: $\Delta \ln LS_t$		
	Estimate	S.E.[a]
$\Delta \ln S(t-1)$	0.77***	(0.060)
$\Delta \ln L$	0.20***	(0.044)
$\Delta \ln C$	0.01	(0.031)
$\Delta \ln K$	0.06**	(0.031)
$\Delta \ln SPEC(t-1)$	-0.05**	(0.027)
$\Delta \ln DIV(t-1)$	0.05**	(0.025)
AR(1)[c] test	z=-5.14	p>z=0.000
AR(2) test	z= 0.41	p>z=0.682
Hansen[b]:$\chi^2(129)$=149.44		[0.105]

Notes: a: heteroskedastic-consistent standard errors; b: Hansen test of over-identifying restrictions, p-value in squared brackets; c: AR(1) and AR(2) are tests for first- and second-order serial correlation; ***, **, coefficient significant at the 1%, 5% level respectively. Country, time and industry dummies included. Endogenous variables are physical capital, labor, R&D capital stock and spillovers. Instruments are lagged values (2-9) of all explanatory variables.

Table 4. Environmental Performance of Spillovers effects: GMM estimates

Dependent variable: $\Delta \ln SCO2_t$		
	Estimate	S.E.[a]
$\Delta\ln SCO2(t-1)$	0.82***	(0.047)
$\Delta\ln L$	0.48***	(0.097)
$\Delta\ln C$	-0.01	(0.078)
$\Delta\ln K$	0.15**	(0.074)
$\Delta\ln SPEC(t-1)$	-0.14**	(0.069)
$\Delta\ln DIV(t-1)$	0.13**	(0.064)
AR(1)[c] test	z=-5.71	p>z=0.000
AR(2) test	z= 0.24	p>z=0.813
Hansen[b]:$\chi^2 (129)=151.52$		[0.086]

Notes: a: heteroskedastic-consistent standard errors; b: Hansen test of over-identifying restrictions, p-value in squared brackets; c: AR(1) and AR(2) are tests for first- and second-order serial correlation; ***, **, coefficient significant at the 1%, 5% level respectively. Country, time and industry dummies included. Endogenous variables are physical capital, labor, R&D capital stock and spillovers. Instruments are lagged values (2-9) of all explanatory variables.

Country, time, and industry dummies are added in the model to capture the effect of factors that change over time but not over the cross-sectional dimension of the sample. The results of the AR (1) tests is consistent with the assumption of no serial correlation in the residuals in levels and the Hansen tests do not reject the null hypothesis of valid instruments, indicating that the instruments are not correlated with the error term.

In particular, specialized environmental spillovers (SPEC) have a negative impact, while the diversified ones (DIV) have a positive one, by confirming the theoretical predictions: more integrated environmental activities lead to higher diversified spillovers which determine a positive impact both on productivity and environmental efficiency. This finding is extremely important for policy implications. Also the integration process between the environmental technology fields is crucial for a full sustainable achievement of firms and then fiscal incentives to this end are required.

5. Conclusions

In this paper we investigate the role of spillovers derived from different technological sectors for international firms engaged both in environmental and in non-environmental activities. We can identify a lack of integrated innovation adoption behind environmental productivity performance. In order to compute the technological proximity between the firms, we construct an Environmental industry weight matrix, based on the construction of technological vectors for each firm. In order to deal with the endogeneity of the explanatory variables, a Linear Generalized method of Moments (GMM) is implemented.

The interesting results are relative to causal effects of environmental spillovers on productivity and environmental performance. In particular, specialized environmental spillovers have a negative impact, while the diversified environmental activities have a positive one. This finding is extremely useful for policy implications: more fiscal incentives are necessary to assure the integration between the environmental technology fields for a full sustainable achievement of firms.

Further research to investigate this topic is needed. In particular, the analysis relative to single environmental target (such as water pollution abatement or energy production efficiency) could be very important to learn the extent to which our results may be generalized.

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Notes

Note 1. See Maraut et al. (2008) for the methodology used for the construction of REGPAT. Please contact Helene.DERNIS@oecd.org to download REGPAT database.

Note 2. See Arellano and Bover (1995) and Blundell and Bond (1998).

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