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

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Received: June 28, 2017      Accepted: August 7, 2017      Online Published: September 29, 2017
doi:10.5539/jsd.v10n5px123                  URL: https://doi.org/10.5539/jsd.v10n5p123

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 \( t \) \( Y_{i,r}^{t} \) may be taken as the of two different outputs from two different production techniques: green \( (Y_{NI}^{t}) \) and not \( (Y_{g}^{t}) \), and written as:

\[
Y_{i,r}^{t} = \theta Y_{NI}^{t} + (1-\theta)Y_{g}^{t}, \quad (1) \text{ with: } 0 < \theta < 1,
\]

where:

\[
Y_{NI}^{t} = Y_{N} \left( C_{N}, K_{N}, H_{N} \right), \quad (2)
\]

\[
Y_{g}^{t} = Y_{g} \left( C_{g}, K_{g}, H_{g} \right), \quad (3)
\]

\[
K_{N} = K_{N} \left( K_{g} \right), \quad (4)
\]

\[
K_{g} = K_{g} \left( B_{g}; B_{g}^{f} \right), \quad (5)
\]

\[
B_{g} = B_{g} \left( \chi \right), \quad (6)
\]

\[
B_{g}^{f} = B_{g}^{f} \left( \chi^{f} \right), \quad (7)
\]

\[
\chi = ax_{1} + bx_{2} + (1 - \alpha - \beta)x_{3}, \quad (8) \text{ with: } 0 < \alpha, \beta < 1
\]

\[
\chi^{f} = ax_{1}^{f} + bx_{2}^{f} + (1 - \alpha - b)x_{3}^{f}, \quad (9) \text{ with: } 0 < a, b < 1.
\]

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 \( \chi \), a variable capturing the effects of the three different technological fields \( x_{1}, x_{2}, \) and \( x_{3} \). Finally \( B_{g}^{f}, \chi^{f} \) stand respectively for patents, and the variable catching the special effects of the three different technological fields \( x_{1}^{f}, x_{2}^{f} \) and \( x_{3}^{f} \) from other countries. After some simple substitutions we may write what follows:

\[
Y_{i,r}^{t} = \theta Y_{N} \left\{ C_{N}, H_{N}, K_{N} \left[ K_{g} \left( B_{g} (ax_{1} + bx_{2} + (1 - \alpha - \beta)x_{3}), B_{g}^{f} (ax_{1}^{f} + bx_{2}^{f} + (1 - \alpha - b)x_{3}^{f}) \right) \right] \right\} + (1 - \theta) Y_{g} \left\{ C_{g}, H_{g}, K_{g} \left( B_{g} (ax_{1} + bx_{2} + (1 - \alpha - \beta)x_{3}), B_{g}^{f} (ax_{1}^{f} + bx_{2}^{f} + (1 - \alpha - b)x_{3}^{f}) \right) \right\} \quad (10)
\]

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

\[
dY_{g} = \frac{\partial Y_{g}}{\partial C_{g}} dC_{g} + \frac{\partial Y_{g}}{\partial H_{g}} dH_{g} + \frac{\partial Y_{g}}{\partial K_{g}} \left[ \frac{\partial K_{g}}{\partial B_{g}} \frac{\partial B_{g}^{f}}{\partial \chi^{f}} \right] \left[ ax_{1} + bx_{2} + (1 - \alpha - \beta)x_{3} \right] + \frac{\partial K_{g}}{\partial B_{g}^{f}} \frac{\partial B_{g}^{f}}{\partial \chi^{f}} \left[ ax_{1}^{f} + bx_{2}^{f} + (1 - \alpha - b)x_{3}^{f} \right] \quad (11)
\]

\[
dY_{i,r}^{t} = (1 - \theta) \left\{ \frac{\partial Y_{g}}{\partial C_{g}} dC_{g} + \frac{\partial Y_{g}}{\partial H_{g}} dH_{g} + \frac{\partial Y_{g}}{\partial K_{g}} \left[ \frac{\partial K_{g}}{\partial B_{g}} \frac{\partial B_{g}^{f}}{\partial \chi^{f}} \right] \left[ ax_{1} + bx_{2} + (1 - \alpha - \beta)x_{3} \right] + \frac{\partial K_{g}}{\partial B_{g}^{f}} \frac{\partial B_{g}^{f}}{\partial \chi^{f}} \left[ ax_{1}^{f} + bx_{2}^{f} + (1 - \alpha - b)x_{3}^{f} \right] \right\} + \theta \left\{ \frac{\partial Y_{N}}{\partial C_{N}} dC_{N} + \frac{\partial Y_{N}}{\partial H_{N}} dH_{N} + \frac{\partial Y_{N}}{\partial K_{N}} \left[ \frac{\partial K_{N}}{\partial B_{g}} \frac{\partial B_{g}^{f}}{\partial \chi^{f}} \right] \left[ ax_{1} + bx_{2} + (1 - \alpha - \beta)x_{3} \right] + \frac{\partial K_{N}}{\partial B_{g}^{f}} \frac{\partial B_{g}^{f}}{\partial \chi^{f}} \left[ ax_{1}^{f} + bx_{2}^{f} + (1 - \alpha - b)x_{3}^{f} \right] \right\}
\]
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 CO2 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).

| 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 | 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.

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:

\[
\ln S_{it} = \alpha_i + \lambda_t + \beta_1 \ln L_{it} + \beta_2 \ln C_{it} + \beta_3 \ln K_{it} + \gamma_1 \ln SPEC_{it} + \gamma_2 \ln DIV_{it} + \epsilon_{it}
\]  

(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 \( t \);  
\( \alpha_i \) = firm’s fixed effects;  
\( \lambda_t \) = 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 \( t \);  
\( \beta, \gamma \) = vectors of parameters;  
\( \epsilon_{it} \) = 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.

| Variable | Mean | 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.

| Dependent variable: Δ ln LS_t | Estimate | S.E. | AR(1) test | AR(2) test | Hansen: χ² (129)=149.44 [0.105] |
|-------------------------------|----------|------|------------|------------|----------------------------------|
| ΔlnS(t-1)                     | 0.77***  | (0.060) | z=-5.14    | p>z=0.000  |
| ΔlnL                          | 0.20***  | (0.044) |             |            |
| ΔlnC                          | 0.01     | (0.031) |             |            |
| ΔlnK                          | 0.06**   | (0.031) |             |            |
| ΔlnSPEC(t-1)                  | -0.05**  | (0.027) |             |            |
| ΔlnDIV(t-1)                   | 0.05**   | (0.025) |             |            |

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.
Dependent variable: $\Delta \ln \text{SCO}_2$

| Estimate | S.E. $a$ |
|----------|----------|
| $\Delta \ln \text{SCO}_2(t-1)$ | 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) |
| $\Delta \ln \text{SPEC}(t-1)$ | -0.14** (0.069) |
| $\Delta \ln \text{DIV}(t-1)$ | 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. Endogeneous 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).
