

Theoretical and Empirical Foundations of Energy Production Efficiency Activity

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Abstract

The objective of this paper is to explore the energy production efficiency activity of large R&D-intensive firms. Research methodology follows two steps: first, we describe the theoretical background through a firm level model and, second, we develop econometric techniques that explore spatial spillovers and deal with the endogeneity of the explanatory variables. The findings show a significant effect of energy innovation externalities on firms' environmental performance.

Keywords: innovation; energy technology spillovers; environmental proximity

JEL codes: O32; O33; Q5

1. Introduction

The transition to a low-carbon competitive economy is a central challenge of our time. The success of this aim would assure new economic opportunities, prosperity, welfare and growth, while the eventual failure may put our well being at stake. All countries need to step up their investments in energy efficiency and renewable technologies. According to Porter (1991), strict environmental regulations could enhance the competitive advantage against rivals.

The existence of energy spillovers as a market failure provides support to the Porter hypothesis (Ambec et al. 2013). Indeed, Mohr (2002) finds that firms may switch to equilibrium with higher R&D investments, when there are technology spillovers to competitors, while Gans (2012) explains that more rigid climate policies will not produce necessarily more innovation. Also Greiner (2003) identifies technological spillovers as a theoretical prediction of Porter hypothesis. Hence, knowledge spillovers play a potentially important role for innovation and productivity in environmental technologies. However, we lack empirical studies about knowledge spillovers in such technologies at the firm level, as discussed in Hoppmann (2016).

To close this gap, in this article we investigate the effects of spillovers from innovation in energy production efficiency activities on environmental performance for American, Japanese and European firms. In particular, we distinguish the intra-industry spillovers (Marshall, 1890; Arrow, 1962; Romer, 1986) and inter-industry externalities (Jacobs, 1969).

The paper is structured as follows. Section 2 explores the spatial energetic spillovers of firms. Section 3 illustrates the theoretical core of the paper. Data and empirical framework are presented in the section 4. Section 5 evidences the results and final section discusses the findings and concludes.

2. Energy Innovation and Spatial Analysis within the Triad

In order to investigate energetic innovation and its distribution, we use particular econometric tools (Pisati, 2008; Crow, 2015; Kondo, 2015 and 2016).

In Table 1, we illustrate energy patents with IPC selected by the OECD or the World Intellectual Property Organization (WIPO), as in Marin and Lotti (2016).

Table 1. Energy patent classes

Macro category	Sub-category	IPC
Energy	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

Our aim is to test for the presence of both global and local spatial autocorrelation through the use of Moran index and Moran scatterplot, respectively.

Moran’s I test has the following form (Moran, 1950; Anselin, 1995): $I = \frac{z'Wz}{z'z}$, where z is an N – vector of standardized energy patents, W is an N x N row-standardized spatial weight matrix¹ and N is the number of observations. This study also presents Moran scatterplots, which depict how the geographical units depend on each other (Anselin, 1995).

As we may observe in Tables 2 and 4, the positive value of Moran-I indicates positive spatial autocorrelation across the American and European regions, that is, regions neighboring a region with high energy patents also show high energetic innovation rates, while in Japan (Table 3) we do not find a significant autocorrelation across regions.

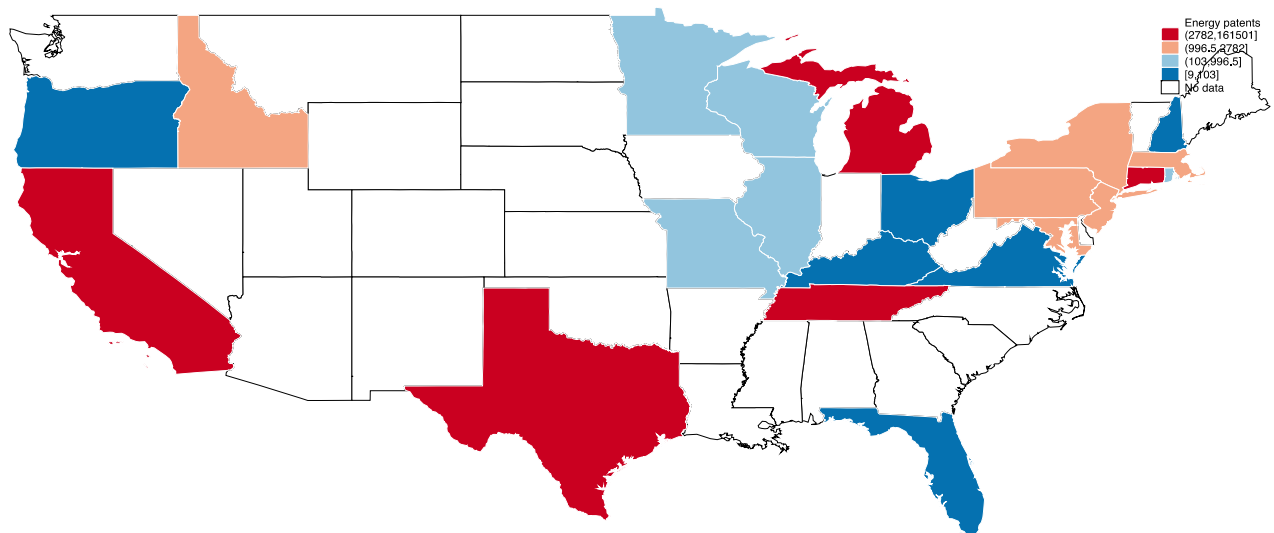
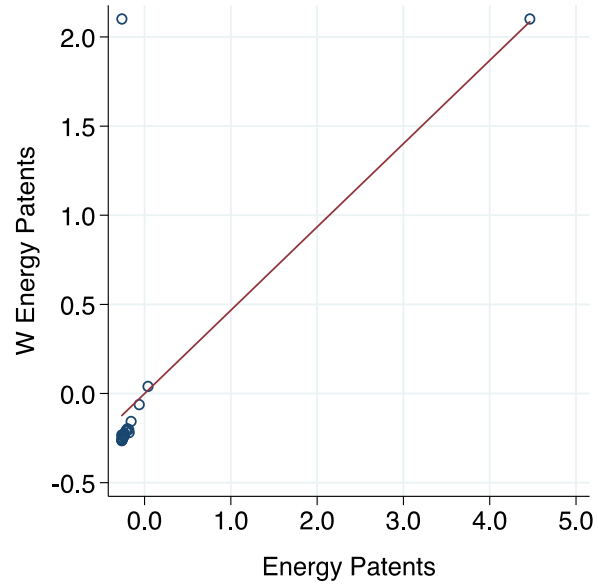


Figure 1. Energy patents in the USA

In Figure 1, where the USA country is clustered into 51 states (see Appendix), we may observe that New Jersey, Connecticut, Michigan, California and Tennessee exhibit the hot spots, while New Hampshire, Ohio, Kentucky, Virginia, Oregon and Florida display the cold spots.

¹We assume that spatial spillovers exists only within a distance of 300 km (Bottazzi and Peri, 2003).

Table 2. Moran scatterplot for the USA



Note: Moran-I test: 0.467, p-value: 0.000

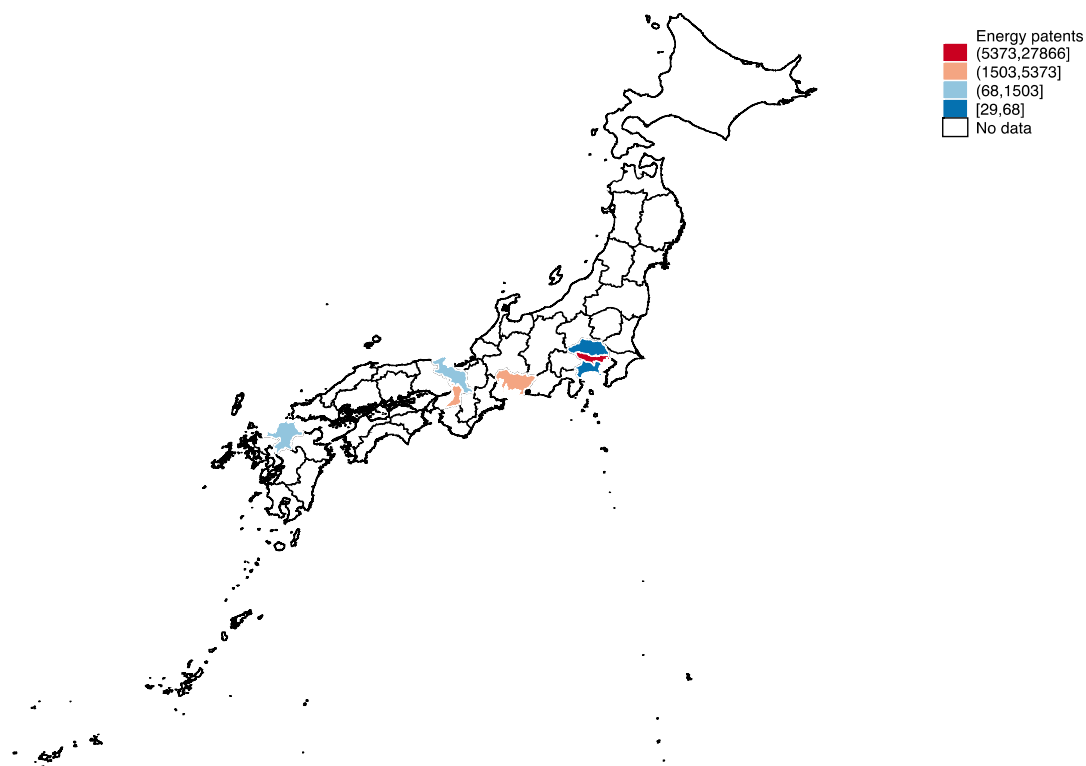
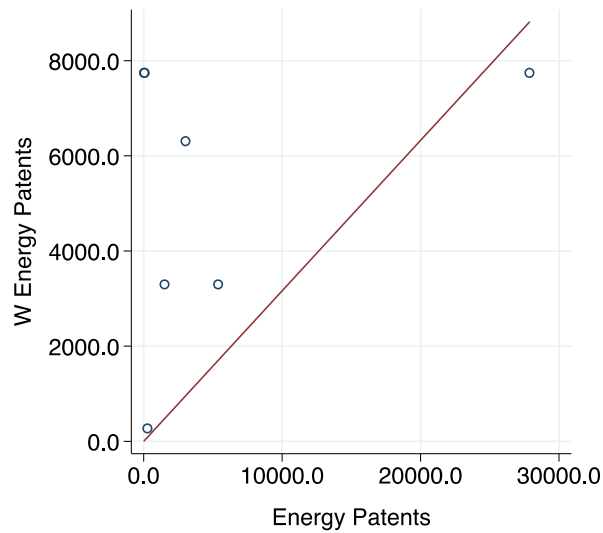


Figure 2. Energy patents in Japan

In Figure 2, where Japan country is clustered into 47 prefectures (see Appendix), we observe that Tokyo exhibits hot spots, while Kanagawa and Saitama display cold spots.

Table 3. Moran Scatterplot for Japan



Note: Moran-I test: 0.099, p-value: 0.460

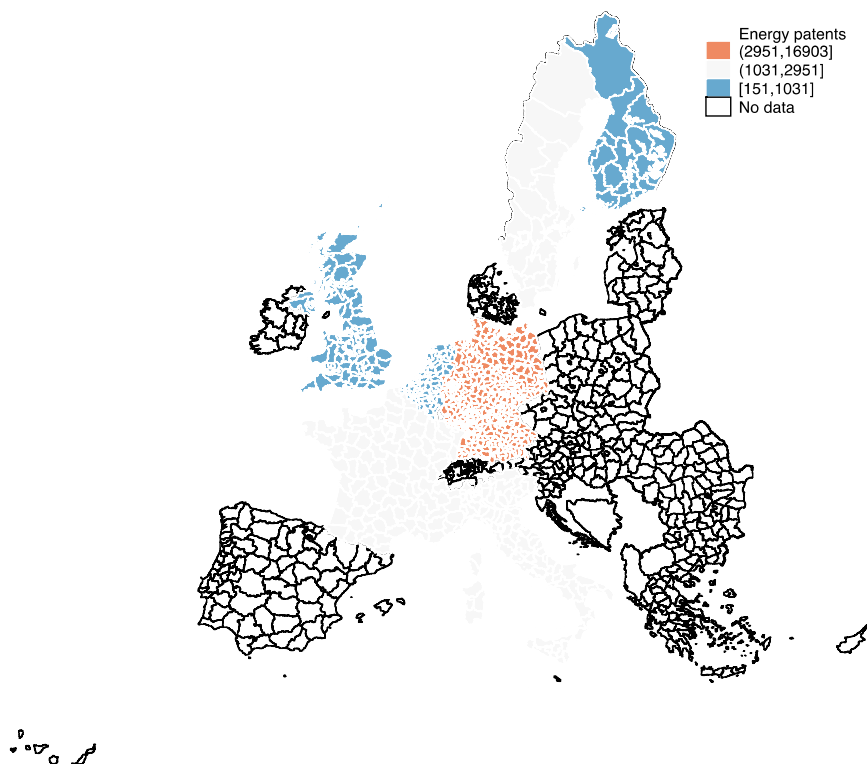
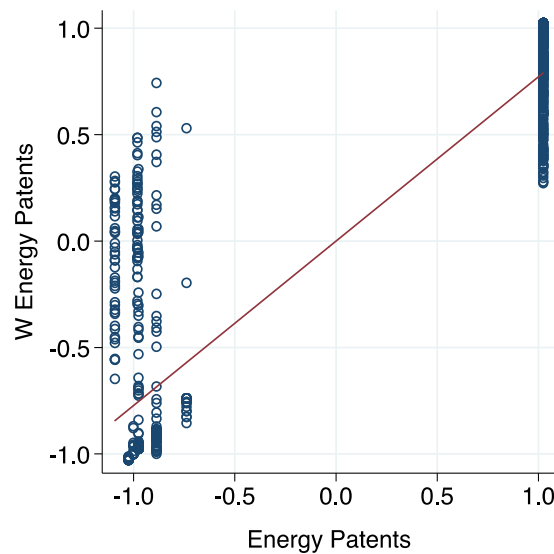


Figure 3. Energy patents in Europe

In Figure 3, where Europe is clustered into 42 countries (see Appendix), we observe that Germany exhibits hot spots, while Belgium displays cold spots.

Table 4. Moran Scatterplot for Europe



Note: Moran-I test: 0.772, p-value: 0.000

3. Theoretical Framework

In order to better specify the relationships and sources of our empirical framework, this section develops a multi-region multi-sector theoretical model, and focuses on aspects related to different types of green energy (wind, solar and geothermal energy, integrated emissions control, lightning to quote some) knowledge diffusion and accumulation. Following Bretschger et al. (2017), in each region at time t final production Y_{ir} in sector i may be taken as the combination of two different outputs from two different production techniques: a first Y_{igrt} where knowledge diffusion leads to a “greening” of economies improving the different types of green energy (wind, solar and geothermal energy, integrated emissions control, lightning to quote some), a second one Y_{inrt} where companies’ green investments are quite irrelevant. Knowledge diffusion, together with other targets such as water pollution abatement and solid waste collection, may have an important role for a drop of global climate policies cost in most of emerging countries. The final production Y_{ir} may be written as follows:

$$Y_{irt} = Y[\theta Y_{igrt}; (1 - \theta)Y_{inrt}] \quad \text{with } \theta \in [0,1]. \quad (1)$$

The green output Y_{igrt} may be taken as a sector-specific output Q_{igrt} and a composite input from other sector B_t^2 :

$$Y_{igrt} = Y_g[\alpha Q_{igrt}; (1 - \alpha)B_t] \quad (2)$$

where $\alpha \in [0,1]$ is a share parameter. Output Q_{igrt} is produced by combining varieties of intermediate composite goods x_{igj} according to:

$$Q_{igrt} = Q\left(\int_{j=0}^{J_{irt}} x_{igjrt} dj\right) \quad (3)$$

where J_{irt} measures the total number of intermediate varieties in sector i region r at time t . If we assume symmetric production of intermediate composite goods: $x_{igjrt} = x_{igrt}$ we will have: $\chi_{igt} = J_{irt}x_{igrt}$ and

² It’s only for simplicity that region and sector indices are omitted.

(2) may be written as:

$$Q_{igrt} = Q(\chi_{igt}) \tag{4}$$

from inspection of which we will observe that Q_{igrt} may grow either by yielding more quantity (x) per firm, given (J), or by increasing the whole number of intermediate varieties. In this light, as well emphasized in Bretschger et al. (2017) each single variety is produced by a precise company and every new firm requires additional knowledge capital to be active. Different interpretations may be attributed to J :

- a measure of knowledge *green* Capital,
- the number of intermediate varieties,
- total of intermediate Companies.

Let's now introduce a mechanism of knowledge accumulation and diffusion. We will assume that knowledge capital at time t in region r depends on investment at time $t-1$ I_{grt-1} , knowledge stock at time $t-1$, and knowledge increment at time $t-1$ ΔJ_{irt-1} :

$$J_{irt} = I_{grt-1} + (1 - \delta)(\Delta J_{irt-1} + J_{irt-1}) \tag{5}$$

with δ measuring a constant knowledge depreciation rate. In order to extend the knowledge diffusion to cover inter-sectorial domestic and foreign intra-sectorial knowledge spillovers, as in Bretschger et al. (2017) we can take assume:

$$\Delta J_{irt} = f(J_{irt}; J_{irt}^B; J_{irt}^C) \tag{6}$$

$$J_{irt}^B = \sum_{h \neq i} J_{hrt} \tag{7}$$

$$J_{irt}^C = \sum_{s \neq r} J_{ist} \tag{8}$$

where s and h are regional and sectorial indexes, while J_{irt}^B and J_{irt}^C stand for respectively domestic inter-sectorial and foreign intra-sectorial knowledge stocks. By combining the above conditions we may easily derive what follows:

$$J_{irt} = J(J_{irt-1}; J_{irt-1}^B; J_{irt-1}^C) \tag{9}$$

Since intermediate goods x_{igrt} are produced by combining labor L_{igrt} , energy E_{igrt} and physical capital C_{igrt} , and may be:

$$x_{igrt} = x(L_{igrt}, E_{igrt}, C_{igrt}) \tag{10}$$

condition (2) will be revised as:

$$Y_{igrt} = Y_g \{ \alpha Q [J(J_{irt-1}; J_{irt-1}^B; J_{irt-1}^C) x(L_{igrt}, E_{igrt}, C_{igrt})]; (1 - \alpha) B_t \} \tag{11}$$

Shifting our attention to Y_{inrt} , with irrelevant companies' *green* investments, we can assume that

production derive by the combination of labor L_{irt} , energy E_{irt} , physical capital C_{irt} , and finally knowledge capital K_{irt} depending on knowledge green Capital $K_{irt} = K_n(J_{irt})$ we may write that:

$$Y_{irt} = Y_n[L_{irt}, E_{irt}, C_{irt}, K_n(J_{irt})] \tag{12}$$

Lastly condition (1) will turn into:

$$Y_{irt} = Y \left\{ \theta Y_g \left[\alpha Q \left(J_{irt-1}; J_{irt-1}^B; J_{irt-1}^C \right) x \left(L_{igrt}, E_{igrt}, C_{igrt} \right) \right]; (1 - \alpha) B_t \right\}; (1 - \theta) Y_n \left[L_{irt}, E_{irt}, C_{irt}, K_n \left(J_{irt-1}; J_{irt-1}^B; J_{irt-1}^C \right) \right] \tag{13}$$

Inspection of condition (13), and the premise according to which each sector has a production structure as the one depicted in *Figure 4*, take us to suggest that Knowledge diffusion leading to a *greening* process of economies depends on accessibility and absorptive capacity, and conclude with the following testable result:

4. Result

[H]: The effect of spillovers due to diversified green technology fields concerning energy production efficiency activity (Jacobian externalities) on firms’ environmental performance is positive.

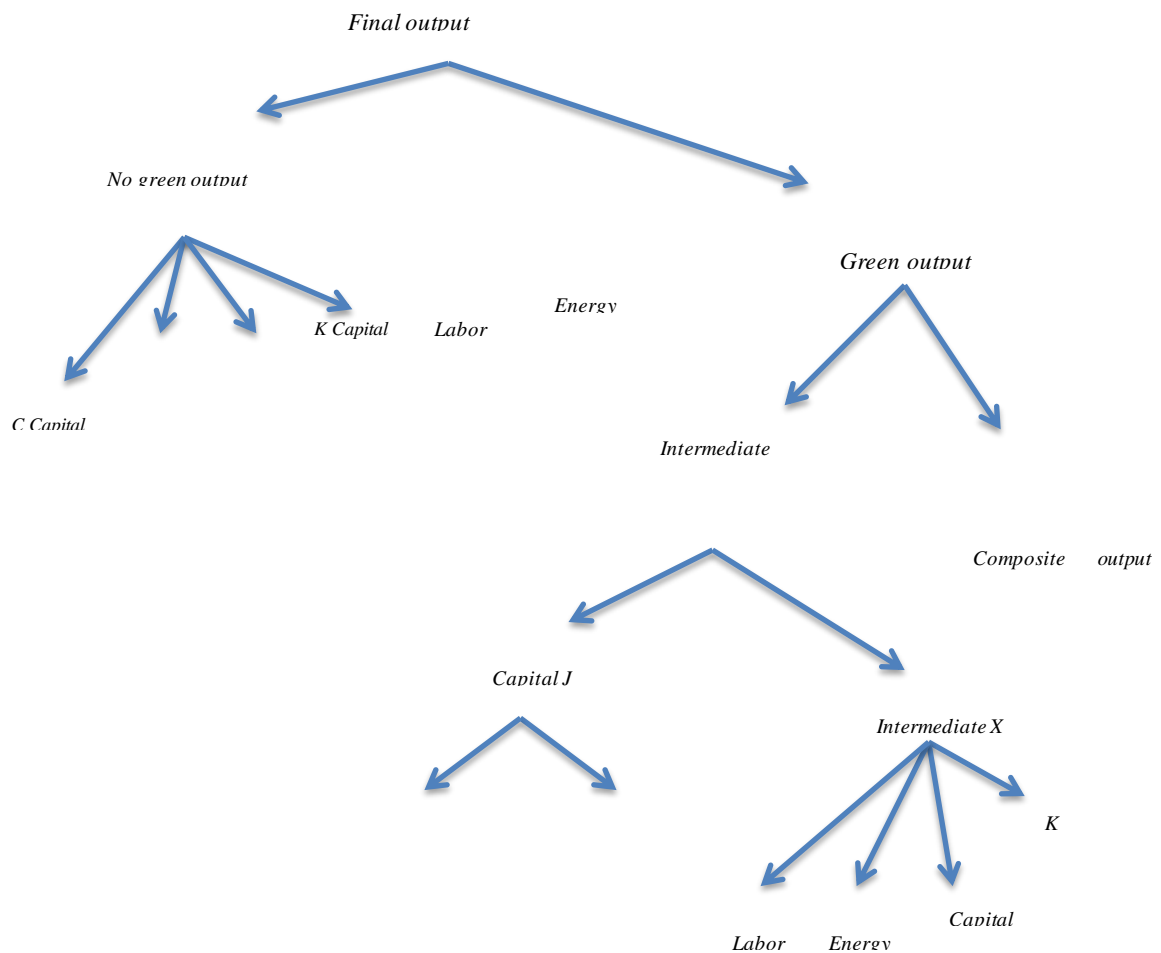


Figure 4. Firms’ Production structure

5. Data and Methodology

OECD, REGPAT database (2017) is employed. We match the name of the same 240 firms to applicant's name from European Commission (2013), as in Aldieri (2013). Another source is the Environmental Accounts providing CO2 emissions variable by country and by year in the World Input Output Database (WIOD).

In order to measure the effect of energy technology on firms' environmental performance, we develop the following extended Cobb-Douglas production function:

$$\ln SCO2 = \alpha_i + \lambda_t + \beta_1 \ln L_{it} + \beta_2 \ln C_{it} + \beta_3 \ln K_{it} + \gamma_1 \ln INTRA_{it} + \gamma_2 \ln INTER_{it} + \varepsilon_{it} \quad (14)$$

where \ln = natural logarithm;

$SCO2_{it}$ = Environmental performance measured as ratio between net sales and CO2 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;

$INTRA_{it}$ = vector of externalities relative to firms belonged to the same industry, computed on the basis of environmental proximity. This is the Jaffe's procedure (Aldieri and Cincera, 2009) with energy patents;

$INTER_{it}$ = vector of externalities relative to firms of different industries, as for the previous variable;

β, γ = vectors of parameters;

ε_{it} = disturbance term.

The previous extended version Cobb-Douglas production function to consider also the spillover components is in line with the relative empirical literature (as discussed in Aldieri and Cincera, 2009; Aldieri and Vinci, 2017a and 2017b).

In Table 5, we display the summary statistics of our sample.

Table 5. Summary statistics

Variable	Mean ^a	Std. Dev.
lnSCO2	21.68	4.021
lnC	7.49	1.584
lnL	9.97	1.360
LnK	7.15	1.426
lnINTRA	3.07	6.272
lnINTER	3.37	6.705

Note: a) 1837 observations;

6. Results and Discussion

In order to address the endogeneity of the explanatory variables, we estimate equation (14) using the Generalized Method of Moments (GMM) 3 estimator.

In Table 6, we show the effects of intra-industry spillovers (INTRA) and inter-industry spillovers (INTER) on firms' environmental performance. Moreover, we include lagged energy spillover components by a year to mitigate contemporaneous effects.

³See Arellano and Bover (1995) and Blundell and Bond (1998).

Table 6. Environmental Performance of Spillovers effects: GMM estimates

Dependent variable: $\Delta \ln \text{SCO}_2$		
	Estimate	S.E. ^a
$\Delta \ln \text{SCO}_2(t-1)$	1.03***	(0.068)
$\Delta \ln L$	0.93***	(0.145)
$\Delta \ln C$	-0.35	(0.153)
$\Delta \ln K$	-0.43	(0.154)
$\Delta \ln \text{INTRA}(t-1)$	-0.29*	(0.173)
$\Delta \ln \text{INTER}(t-1)$	0.25*	(0.152)
AR(1) ^c test	z=-5.42	p>z=0.000
AR(2) test	z= 0.41	p>z=0.679
Hansen ^b $\chi^2(83)=99.56$		[0.104]

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.

In order to identify the elements that change over time but not over the cross-sectional dimension of the sample, we include also time, country and industry dummies. The results of Hansen tests do not reject the null hypothesis of valid instruments, supporting the no-correlation of the instruments with the error term.

As far as our findings are concerned, intra-industry externalities (INTRA) have a negative effect, while the inter-industry externalities has a positive one, in line with the expected sign of the variables included in the model. Indeed, the diversification process in green activities leads to important environmental performance improvements. This result could be interpreted as an important instrument of policy makers: more additional incentives are required to improve the complementarity between the energetic sectors.

7. Concluding Remarks

The objective of this paper is to explore the energy production efficiency activity of large R&D-intensive firms. An original Environmental proximity matrix is constructed, on the basis of technological vectors for each firm. Since there are few empirical studies about knowledge spillovers in such technologies at the firm level, as discussed in Hoppmann (2016), we close this gap by investigating the effects of spillovers from innovation in energy production efficiency activities on environmental performance for large international firms. In particular, we distinguish the intra-industry externalities and inter-industry externalities. To address the endogeneity of the explanatory variables, we run the Generalized Method of Moments (GMM) estimator. From the empirical results, we may observe that energy intra-industry spillovers (INTRA) have a negative impact on environmental performance, while the energy inter-industry components (INTER) have a positive effect. This finding is useful as a relevant policy maker instrument: the full sustainability achievement requires more incentives to complete the integration between energy technology fields.

However, further research on this topic is needed. The analysis should focus on factors that affect heterogeneity in technology spillovers effects both in spatial context and on the basis of industrial sectors.

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Appendix

Table A. Distribution of regions by economic area

The USA	States	Japan	Prefectures	Europe	Countries
	Alabama		Aichi		Andorra
	Alaska		Akita		Albania
	Arizona		Aomori		Austria
	Arkansas		Chiba		Bosnia
	California		Ehime		Belgium
	Colorado		Fukui		Bulgaria
	Connecticut		Fukuoka		Belarus
	Delaware		Fukushima		Switzerland
	District of Columbia		Gifu		Cyprus
	Florida		Gunma		Czech Republic
	Georgia		Hiroshima		Germany
	Hawaii		Hokkaido		Denmark
	Idaho		Hycgo		Estonia
	Illinois		Ibaraki		Spain
	Indiana		Ishikawa		Finland
	Iowa		Iwate		France
	Kansas		Kagawa		Gibraltar
	Kentucky		Kagoshima		Greece
	Louisiana		Kanagawa		Croatia
	Maine		Kochi		Hungary
	Maryland		Kumamoto		Ireland
	Massachusetts		Kyoto		Italy
	Michigan		Mie		Liechtenstein
	Minnesota		Miyagi		Lithuania
	Mississippi		Miyazaki		Luxembourg
	Missouri		Nagano		Latvia
	Montana		Naoasaki		Marocco
	Nebraska		Nara		Moldova
	Nevada		Niigata		Malta
	New Hampshire		Oita		Netherlands
	New Jersey		Okayama		Norway
	New Mexico		Okinawa		Poland
	New York		Osaka		Portugal
	North Carolina		Saga		Romania
	North Dakota		Saitama		Russian Federation
	Ohio		Shiga		Sweden
	Oklahoma		Shimane		Slovenia
	Oregon		Shizuoka		Slovakia
	Pennsylvania		Tochigi		San Marino
	Rhode Island		Tokushima		Turkey
	South Carolina		Tokyo		Ukraine
	South Dakota		Tottori		United Kingdom
	Tennessee		Toyama		
	Texas		Wakayama		
	Utah		Yamagata		
	Vermont		Yamaguchi		
	Virginia		Yamanashi		
	Washington				
	West Virginia				
	Wisconsin				
	Wyoming				

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