Energy innovation at the country level:
The role of cross-country knowledge spillovers

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Abstract

Energy innovation plays a crucial role in the reduction of carbon emissions. This paper focuses on the impact of cross-border knowledge spillovers on technological innovation in renewable energies. Evidence of the relationship between the patenting activities of industrialized countries and the intensity of international knowledge spillovers has been obtained for 26 countries over the 1974-2008 period. Our preliminary findings show that the greater the linkages between countries the greater the effect of international energy R&D. In addition, knowledge spillovers that stem from countries that are technological leaders in renewable energy technologies have been found to significantly improve the patenting performance of countries.

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1. Introduction

This paper deals with the effect of cross-border knowledge spillovers on technological innovation in renewable energy sector. Namely, the main objective is to provide empirical evidence and a preliminary econometric analysis on the relationship between the patenting activities of industrialized countries in renewable energies and knowledge spillovers stemming from countries that are technological leaders over the 1974-2008 period.

Energy innovation plays a crucial role in the reduction of carbon emissions (e.g. IPCC, 2007; Popp et al., 2009a). Recent aggregate models have increasingly represented technological change as endogenous to the energy sector, and have assumed that it can arise not only from knowledge creation by R&D, but also from learning-by-doing dynamics (e.g., Popp, 2004, 2006a; van der Zwaan et al., 2002). While this approach illustrates quite well the most advanced energy innovation systems, it seems to be less appropriate to represent laggard countries, which are more likely to exploit the new energy technologies that other countries have developed (Bosetti et al. 2008, OECD 2008). In particular, both new energy technologies and new knowledge originating from energy R&D could flow from foreign countries to domestic players via international trade, multinationals and international knowledge spillovers. Therefore, we argue that public energy R&D carried out in other countries positively affects the home country patenting activity in renewable energies, the greater the linkages among countries and that these knowledge spillovers are greater whenever they stem from countries that are technological leaders in renewable energy technologies considered.

In order to design climate and energy policies, policy makers not only require a theoretical understanding of the energy innovation system, but also empirical evidence of the factors that hamper the development and deployment of new energy technologies. At the same time firms a better understanding of national energy innovation systems in order to benefit from the development and commercialization of new climate-friendly products. To this purpose, this paper examines the role of cross-border knowledge spillovers on technological innovation in renewable energy sector. The analysis is conducted using patent data on a panel of 26 countries over the period 1974-2008. Three indicators that represent cross-country knowledge spillovers are constructed. We find that public energy R&D carried out in other countries is more likely to positively affect the home country patenting activity, the greater the linkages among countries. Also, we find that knowledge spillovers have a greater impact whenever they stem from countries that are technological leaders in renewable energy technologies.

The paper is organized as follows. First, after reviewing the main empirical studies on the effects of environmental and climate policies on energy innovation and findings of literature on knowledge spillovers and cross-country linkages, the paper proceeds by formulating the research hypotheses (Section 2). Second, the empirical methodology followed in the investigation is illustrated (Section 3), and empirical results are then illustrated and discussed (Section 4).

2. Conceptual model and research hypotheses

This Section will review the main findings obtained by empirical analyses that have investigated the determinants of energy innovation. Among the antecedents, energy and environmental policies are recognized to play a crucial role. In particular, technology-push policy actions (e.g. public R&D budgets) have been recognized to foster energy innovation in combination with market-creation and interface actions (Taylor 2008; Garrone and Grilli 2010; Popp 2010; Johnstone et al., 2010; Dechezlepretre et al. 2010). After investigating the effects of environmental and climate policy in energy innovation domestically, we examine the effect that domestic environmental regulation may have in spurring innovation in foreign countries, as well as the role knowledge spillovers and cross-country linkages.

2.1. The role of environmental and climate policy on energy innovation

Several theoretical works have examined been done to examine the inducement effects of environmental and climate policies in the innovation activities within a country. There are few empirical studies that analyse the role played by policy instruments on environmental and energy innovation.

De Vires and Withagen (2005) found evidence that stricter environmental policies lead to more innovation. Johnstone et al. (2010) focused on renewable energies, and examined the effects of climate policies on the patenting activities of 25 advanced countries over the 1978-2003 period. They found that public energy R&D and the signing of Kyoto Protocol had a very significant influence on the development of new technologies. Estimates revealed that policy instruments have different impacts on different technological fields in the broad area of renewable energies (for instance, investment incentives spurred patenting efforts in biomass and waste and in overall renewable sources, but did not have a significant impact on wind, solar, geothermal and ocean technologies). As far as the diffusion of renewable technologies is concerned, Popp et al. (2009b) assessed the impact of technological advancements on the installed capacity in four technological fields: wind, solar photovoltaic, geothermal and biomass and waste. The sample included 26 OECD countries, and covers the 1990-2004 period. They used technology-specific patent counts to construct “knowledge stock” indicators that represent the world technological frontiers for each renewable energy. The knowledge stock was found to have a significant impact on technology diffusion but climate change policies, which are described by the signing of Kyoto Protocol, played a more relevant role.

Other few works explore the cross-border effects of environmental and climate policies on innovation activities, and test whether regulations in one country can spur innovation in other countries. Lanjouw and Mody (1996) used patent data from the US, Japan, Germany, and 14 low and middle-income countries. They found that the majority of vehicle air emission patents granted in the US has been obtained by foreign countries, while the US was the first country to adopt strict emission standards. Instead Popp (2006b) examined both innovation and diffusion of air pollution control equipment in the US, Japan, and Germany. He found that inventors respond primarily to policy incentives in their home country, and there is little increase in patents filed abroad in response to domestic regulation. Finally, Popp et al.

(2007) found that the inventors of chlorine-free technologies in the pulp and paper industry respond both to domestic and foreign environmental regulatory pressure.

2.2 Cross-country knowledge spillovers

The analyses that have been surveyed so far implicitly assumed that the borders of energy innovation systems coincide with national borders. This does not necessarily hold true: in fact, a country might exploit new energy technologies that other countries have developed. The lack of appropriate international linkages can prove to be a relevant barrier to energy innovation, particularly for those countries that are less advanced in the creation and deployment of climate-friendly technologies. For instance, as far as the climate mitigation technologies are concerned, Dechezlepretre et al. (2010) have found that three European Union countries have top positions in the ranking of inventors (i.e. Germany, UK, France), while other EU countries lag behind in the energy innovation race, as represented by the patenting activity.

Cross-country knowledge spillovers have been already recognized to have a significant impact on the innovation activity of countries (e.g. Branstetter, 1998), also in the energy sector (e.g. OECD 2008; Dechezlepretre et al., 2010; Bosetti et al., 2008). Specifically, international trade is a significant channel for knowledge flows and R&D spillovers (Rivera-Batiz and Romer, 1991), because countries can import intermediate goods that embody technology that is developed by foreign R&D. Lanjouw and Mody (1996) showed that imported equipment is a major source of technological knowledge in environmental sectors for some countries. Additionally, the presence of foreign multinational enterprises also fosters cross-country linkages.

Multinationals can generate local spillovers through labor turnover, if local employees of the subsidiary take up employment in domestic firms (e.g., Fosfuri et al. 2001). Several scholars found evidence that multinational enterprises transfer firm-specific technology to their foreign affiliates (e.g. Lee and Mansfield, 1996; Branstetter et al., 2006). Local firms may also increase their productivity by observing nearby foreign firms or becoming their supplier or customers (e.g., Ivarsson and Alvstam 2005; Girma et al., 2009). The last channel of cross-country linkages could be cross-border licensing and international filing of patents. Focusing specifically on thirteen climate mitigation technologies, Dechelepretre et al. (2010) found that in the period 2000-2005, 73% of climate inventions have been transferred by filing patents abroad between industrialized countries. By contrast, knowledge exchanges among developing countries are almost non-exsitent. Using patent citation data for pollution control patents granted in the US, Popp (2006b) finds that although foreign innovative activities do not substitute for domestic innovation, there are indirect knowledge spillovers across countries, that is, laggard countries benefit from earlier innovations of technology leader countries by adapting foreign innovation to local conditions. For the same technologies, Lovely and Popp (2008) find that countries that are more open to international trade are more likely to adopt environmental regulations, and to provide access to environmental technologies developed in other countries.

2.3 Research hypotheses

Our paper is an attempt to continue along this line of analysis, by modelling international knowledge spillovers as a determinant of energy innovation at the country level. We focus on the invention stage, and test whether a country is more likely to innovate in the renewable energy sector if international knowledge spillovers are greater.

First of all, we claim that public renewable energy R&D carried out in other countries positively affects the home country patenting activity in renewable energies, the greater the linkages among countries. Secondly, we hypothesize that these knowledge spillovers are greater whenever they stem from countries that are technological leaders in renewable energy technologies.

3. Methodology

This paper is very much in the spirit of Johnstone et al. (2010), but it extends the analysis by considering the role of cross-country knowledge spillovers. The analysis is conducted using patent data on a panel of 26 industrialized countries over the 1974-2008 period. The sample includes 538 observations for the majority of variables du to missing data for certain years and countries, but at present the number of observations for public R&D budgets in renewable energies is more limited (i.e. 476 observations). Specifically, our dependent variable, i.e. energy innovation, has been proxied by patent counts in all the renewable energy sources (OECD patent database 2010). We are extending our analysis to individual energy sources (i.e. wind, solar, geothermal, ocean, biomass and waste), but this paper limits to report estimates for all the renewable sources.

Since the dependent variable is a count indicator, a negative binomial model is used to estimate the equation (Cameron and Trivedi, 1998). Additionally, we are attempting to control for heteroskedasticity in the data by the means of a bootstrapping correction of standard errors, but we regard the findings obtained with this technique as very preliminary and we do not report them in this version.

3.1 Explanatory variables

Cross-country knowledge spillovers

We follow the traditional approach to the modeling of international R&D spillovers (e.g. Klette et al., 2000; Garrone and Grilli, 2010). Three R&D pool measures represent cross-country knowledge spillovers in the field of renewable energies (CCKS). The first indicator has been obtained for each country in each year by summing the public R&D expenditures in renewable energies made by other industrialized countries:

$$CCKSRD_{i,t} = \sum_{j \neq i} PRERD_{j,t} \tag{3a}$$

where $PRERD_{j,t}$ represents the R&D expenditures in renewable energies in country j in year t. Public energy R&D budgets of each sample country have been collected from the IEA's Energy Technology Research and Development Database (IEA 2010a). R&D for renewable energy as a whole is calculated by subtracting hydro R&D expenditures from that of total renewable energy expenditures. The second indicator has been calculated for each country in each year by summing the public R&D expenditures in renewable energies made by other countries weighted by trade flows with the same countries. Trade flows are calculated as the sum of total imports and exports between country i and partner country j, as reported by the UN Comtrade database:

$$CCKSTF_{i,t} = \sum_{j \neq i} \left[PRERD_{j,t} \times \left(import_{i,t}^{j} + \exp ort_{i,t}^{j} \right) \right]. \qquad (3b)$$

Finally we added a third measure of cross-country knowledge spillovers by weighing the public R&D expenditures of country j by trade flows and an indicator of technological leadership. Specifically, the index of technological leadership has been calculated relying on the revealed technological advantage (RTA) index (Cantwell, 1995). RTA of country j in year t in the field of renewable energy technologies is set equal to the ration between the share of renewable energy patents obtained by country j in year t, relative to the world share in the same year:

$$CCKSRTA_{i,t} = \sum_{j \neq i} \left[PRERD_{j,t} \times RTA_{j,t} \times \left(import_{i,t}^{j} + \exp ort_{i,t}^{j} \right) \right]. \qquad (3c)$$

Public policy variables

Different policy indicators have been included, as in Johnstone et al. (2010). Three continuous variables are constructed to present policy stringency: renewable energy R&D expenditures (see the description of cross-country spillover indicators), feed-in tariffs and targets for renewable electricity. For feed-in tariffs, our indicator represents the average value of price levels guaranteed to each technology. For renewable energy targets, we use the percentage of electricity that must be generated by renewable or covered with a renewable energy certificate when emission trading measures have been adopted. Various reports, country-specific sources and articles were consulted to collect information for both indicators; the main sources are IEA (2004) and Eref (2007, 2009) (see also the reference list in Jonhnstone et al. 2010).

Five binary variables have also been constructed to capture the presence of climate policies that are intended to support the development and diffusion of renewable energy technologies: investment incentives (e.g. grants, preferential loans, rebates, third party financing); tax measures (e.g. taxes and tax incentives, tax credit, tax exemption, tax reduction); voluntary programs (e.g. green pricing, net metering); obligations (e.g. portfolio standards, quota systems), guaranteed prices. A policy indicator is set equal to 1 for an individual renewable energy source if country i is enacting the corresponding measure in year t, and it is set equal to 0 otherwise. The same policy indicators have been constructed for the overall renewable sector according to the following rule: the policy indicator is set equal to 1 for the overall sector if the measure is enacted for at least 3 individual energy technologies. The main reference source for these binary variables is IEA (2004) for the 1974-2002 period. For more recent years, we resort to IEA Policies and Measures Databases (2010b).

Control variables

We use the growth rate of electricity consumption to measure the expectations for future market growth, similarly to Johnstone et al. (2010). Total electricity consumption of country i in year t is defined as domestic generation, plus imports, minus exports, minus transmission and distribution losses. Data have been obtained from the International Energy Statistics of the US Energy Information Administration (2010). Similarly, to capture expectations about future policy, we construct a country-invariant binary variable that is set equal to one after the signing of Kyoto Protocol (December 1997).

Tables 1 and 2 illustrate the descriptive and correlation statistics of the variables, respectively.

Table 1 Descriptive statistics of explanatory variables (1974-2008)

Variable	Obs.	Mean	SD	Min	Max
ERC, Growth of electricity consumption (%),	502	2.47157	3.538737	-22.15274	38.1222
TPAT, Total EPO patent filings	538	3640.482	6209.902	5.7	33992
RDD, Total renewable R&D expenditures (Million USD, 2008 prices and PPP)	476	61.83715	142.5896	0.411	1528.981
Policy proxies (continuous)					
FIT, Feed-in tariff levels (€/MWh; mean level across renewable sources)	531	25.33534	56.64077	0	303.2
REC, REC targets (%)	538	0.24671	1.230049	0	12.6
Policy proxies (binary)					
II, Investment incentives	538	0.3884758	0.4878573	0	1
TM, Tax measures	538	0.3085502	0.4623248	0	1
GP, Guaranteed prices	538	0.3215613	0.4675103	0	1
VP, Voluntary programs	538	0.1784387	0.3832379	0	1
O, Obligations	538	0.204461	0.4036825	0	1
KY, Kyoto Protocol	538	0.3568773	0.479524	0	1
Cross-country knowledge spillover indicators					
RTA	538	3.15	8.2677	0.1	153.8
CCKSRD, R&D other countries	538	957.1287	430.9704	227.827	2324.101
CCKSTF, R&D mediated by trade flows	538	1.48e+07	1.91e+07	236027.4	1.30e+08
CCKSRTA, R&D mediated by trade flows and RTA	538	1.27e+07	1.48e+07	223010.3	1.18e+0

Table 2 Correlation matrix

	ELC	**TPAT**	**RDD**	**FIT**	**REC**	**KY**	**II**
ELC	1.0000						
TPAT	-0.1085	1.0000					
RDD	-0.0499	0.4781	1.0000				
FIT	-0.0329	0.0599	-0.0665	1.0000			
REC	-0.0856	0.1683	0.0494	-0.0557	1.0000		
KY	-0.0867	0.1904	-0.0579	0.2724	0.2314	1.0000	
II	-0.0895	0.0621	-0.1170	0.1637	0.1051	0.3353	1.0000
TM	-0.0441	0.2924	0.2154	0.1087	0.1017	0.3114	0.2954
GP	-0.0280	0.2211	0.1982	0.5434	-0.0682	0.2110	0.2034
VP	-0.0017	0.2717	0.0698	0.3781	-0.0113	0.2521	0.1790
O	0.0296	0.0027	-0.0800	0.0996	0.0645	0.4426	0.3019
CCKSRD	-0.1113	-0.2634	-0.0694	-0.1076	0.0069	-0.0967	-0.2332
CCKSTF	-0.1318	0.5517	0.2114	0.0685	0.2065	0.3629	0.1114
CCKSRTA	-0.1407	0.6369	0.2439	0.1627	0.2950	0.3827	0.0785

Correlation matrix

	TM	GP	VP	O	CCKSRD	CCKSTF	CCKSRTA
ELC							
TPAT							
RDD							
FIT							
REC							
KY							
II							
TM	1						
GP	0.2039	1					
VP	0.2639	0.3412	1				
O	0.1832	0.0707	0.0248	1			
CCKSRD	-0.2386	-0.1938	-0.1896	-0.1142	1		
CCKSTF	0.1840	-0.0161	0.3016	0.0522	-0.0793	1	
CCKSRTA	0.2406	0.0821	0.2624	0.0498	-0.0820	0.9300	1

4. Discussion of empirical results

This Section illustrates the empirical findings. The obtained empirical evidence is then discussed with respect to our research hypotheses.

The model has been estimated by the means of negative binomial fixed effect (NBFE) estimator after having normalized each variable panel to the sample mean. Table 3 reports the NBFE estimates. The first column exposes the estimates for the baseline model (i.e. Model (1) does not include any cross-country knowledge spillover variables). Other columns report the estimates obtained by extending the set of explanatory variables to cross-country knowledge spillovers. While Models (2)-(4) include one-by-one the CCKS variables, Models (5) and (6) include CCKSTF and CCKSRTA, respectively, in addition to CCKSRD, in order to test whether the effect of international R&D spillovers is more significant if a country has more intense international linkages and more international linkages with technological leaders, respectively.

The estimated coefficients of baseline models (Model (1), Table 3) can be compared to the findings reported by Johnstone et al. (2010), even though there are differences between the two analyses. Our sample includes 26 countries over the 1974-2008 period, while their sample limits to the 1978-2003 period. However the sample sizes are comparable, because we were not able to complete the panel for several countries because of missing data in our reference sources. At the same time, we normalized the continuous variables before estimating the models and we did not include electricity price among explanatory variables. In spite of these differences, the sign of most coefficient estimates reported in Table 3 (NBFE Baseline model) is equal to the sign of coefficient estimates obtained by Johnstone et al. (2010). The significance levels are different for feed-in tariffs and for few binary policy variables.

Let us consider Model (2). It highlights a positive and significant effect of pooled international R&D on patenting activities of countries in renewable energy sources. CCKSRD coefficient results to be different from 0 at a 99% confidence level, other things being equal. Models (3) and (4) confirm that cross-country spillovers have a significant effect on the country capability to invent in renewable energy sector (i.e. CCKSTF and CCKSRTA coefficients are positive and significantly different from 0 at 99% confidence level). In addition, estimates of Models (3) and (4) show that the impact of international R&D is greater if international linkages as measured by trade flows and technological leadership of partner country in renewable energy sectors are taken into account (i.e. CCKSTF and CCKSRTA coefficients in Models (3) and (4) are greater than CCKSRD coefficient in Model (1)), other things being equal. Estimates of CCKS coefficients in models (5) and (6) provide a more complete picture of the role of international knowledge spillovers in renewable energy sector. Public energy R&D carried out by foreign countries have a positive effect per se on home country inventions in renewable energy sources (i.e. CCKSRD coefficient is positive and significant different from 0). At the same time, an additional effect emerges whenever the country has more intense linkages with foreign countries: the CCKSTF coefficient is positive and significantly different from 0, after having controlled for the autonomous impact of CCKSRD, other things being equal (Model (5)). In addition, our estimates show that international knowledge spillovers are greater if partner countries are technological leaders: the CCKSRTA coefficient is positive and significantly different from 0, after having controlled for the autonomous impact of CCKSRD, other things being equal (Model (6)).

In other words, our results reveal that the invention capacity of a country in renewable energy technologies is determined not only by the domestic energy R&D but it is positively affected by public R&D efforts conducted in all other countries, via cross-country knowledge spillovers. In addition, inventions in the renewable energy sectors are more likely if home countries have more intense international relations with the countries that are investing greater budgets in energy R&D and have acquired a technological leadership in the renewable fields.

In conclusion the empirical results allow us to confirm the research hypotheses (2.3)

First, public renewable energy R&D carried out in other countries positively affects the home country patenting activity in renewable energies, the greater the linkages among countries. Second, knowledge spillovers are greater whenever they stem from countries that are technological leaders in renewable energy technologies.

This is only the preliminary results. We will estimate the effects of knowledge spillovers on different renewable energy source for future work and estimation techniques to control for heteroscedasticity will be performed. Measures of international knowledge spillovers will be refined and interactions between international R&D, technological leadership, trade flows will be modeled in different ways to reach more robust conclusions on our research hypotheses, also following empirical analyses aimed at exploring the role of international spillovers in other conventional sectors will be conducted.

Table 3 Estimated coefficients of NBFE models

	Baseline -Model (1)	*CCKSRD - Model (2)*	*CCKSRDTF - Model (3)*	*CCKSRDRTA - Model (4)*	*CCKS - Model (5)*	*CCKS -Model(6)*
Growth of electricity consumptions	-0.0142501 (0.670)	0.0061203 (0.854)	-0.0050379 (0.873)	-0.009435 (0.771)	0.0089091 (0.780)	0.0061666 (0.850)
Total EPO filings	0.1513674 (0.001)***	0.1670526 (0.000)***	-0.0353629 (0.49)	-0.0052688 (0.921)	-0.0016227 (0.975)	0.0307024 (0.562)
R&D expenditures	0.1446398 (0.000)***	0.1368396 (0.000)***	0.1373628 (0.000)***	0.1466442 (0.000)***	0.1332993 (0.000)***	0.1408249 (0.000)***
Feed-in tariff levels	0.1929777 (0.000)***	0.1963119 (0.000)***	0.1281142 (0.001)***	0.1319655 (0.001)***	0.1369296 (0.000)***	0.1425826 (0.000)***
REC targets	0.022188 (0.306)	0.0119741 (0.580)	-0.0307335 (0.186)	-0.0302684 (0.204)	-0.0319535 (0.167)	-0.03087 (0.193)
Kyoto protocol	0.820908 (0.000)***	0.8196032 (0.000)***	0.6891898 (0.000)***	0.7318463 (0.000)***	0.7008968 (0.000)***	0.7412959 (0.000)***
Investment incentives	-0.0824962 (0.207)	-0.0253401 (0.703)	-0.032053 (0.605)	-0.0102244 (0.874)	0.0034643 (0.957)	0.0240889 (0.715)
Tax measures	0.0274766 (0.753)	0.033474 (0.699)	0.0152558 (0.851)	0.0372139 (0.655)	0.0194658 (0.811)	0.0399503 (0.632)
Guaranteed price	-0.4254077 (0.000)***	-0.3938897 (0.000)***	-0.3745563 (0.000)***	-0.4348347 (0.000)***	-0.3609153 (0.000)***	-0.4137485 (0.000)***
Voluntary programs	-0.1737964 (0.086)	-0.1568212 (0.115)	0.0275594 (0.773)	0.0295569 (0.768)	0.0153232 (0.872)	0.0141448 (0.888)
Obligations	0.0399826 (0.602)	0.0586966 (0.438)	0.0691295 (0.340)	0.0803446 (0.283)	0.0779898 (0.282)	0.0900867 (0.228)
R&D other countries		0.1416873 (0.000)***			0.0947679 (0.002)**	0.1054067 (0.001)***
R&D mediated by trade flows			0.2764281 (0.000)***		0.2454473 (0.000)***	
R&D mediated by trade flows and RTA				0.1917274 (0.000)***		0.1644648 (0.000)***
N	436	436	436	436	436	436
Log-likelihood	-1061.3132	-1051.6565	-1039.379	-1045.8516	-1034.9971	-1040.6237
x^2	459.14	492.81	627.98	570.24	631.19	578.02
($p>x^2$)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Legend: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$, p values in parentheses. All the continuous variables have been standardized in the regression.

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