The impact of R&D offshoring on the home knowledge production of OECD investing regions

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Abstract

This paper investigates the complementarity between home and offshore R&D activities in the home knowledge creation of the investing regions. In the light of increasing offshoring of innovative activities to emerging countries we focus explicitly on Brazil, Russia, India, China, Korea, Singapore and Taiwan. Debate is ongoing on whether R&D offshoring replaces or complements the R&D performed at home. Drawing on the regional system of innovation perspective and the open innovation approach, we estimated a knowledge production function on a sample of 221 regions of 21 OECD countries. Our test confirms the complementarity between the two activities.

Introduction

Within the trend of an increasing internationalization of economic activities, available statistics report a recent change in the location of overseas activities (UNCTAD 2005; UNCTAD 2006) with significant proportions of R&D moved to countries of developing Asia (Beausang 2004), which have emerged as new technology producers (Athreye and Cantwell 2007). Von Zedwitz and Gassman (2002) provide empirical evidence that, although research activity exhibits a strong concentration in the Triad regions as well as in major centres in South Korea, Singapore and other emerging economies of the Pacific Rim, development is more evenly distributed. In particular, the re-location of R&D activity abroad has increasingly targeted fast-growing emerging economies, with Brazil, Russia, India, China, Korea, Singapore and Taiwan (hereafter BRICKST) receiving the bulk of R&D activities (UNCTAD 2005; Piscitello and Rabbiosi 2006; Belderbos and Sleuwaegen 2007).

Existing literature has mainly focused on the US and has been primarily concentrated with the determinants of offshoring, while a long-lasting debate is ongoing about the consequences on both home and recipient countries (e.g. Doh 2005; Levy 2005). On the one hand, it is argued that offshoring will stifle innovative activity at home (e.g. Teece 1987). On the other, a complementary hypothesis between home and offshore activities has been advanced (e.g. Kotabe 1990). Despite recent analyses at country-level (Piscitello and Santangelo 2010) supporting the former viewpoint, no consensus has yet been reached. This paper contributes to this debate by investigating whether and how R&D offshoring to fast-growing emerging economies affects the knowledge creation of the OECD regions from which the investment initially departed. In particular, we ask whether R&D offshoring complements R&D conducted at home in the home knowledge production of the investing region.

To answer this question, we rely on a sample of 221 large OECD regions for which we collected data on their patenting activity, socio-economic indicators, and information on R&D

offshoring investments towards BRICKST countries. Our regional focus is suggested theoretically by the regional system of innovation (RSI) literature (Cooke, Uranga et al. 1997; Cooke 2004; Asheim and Gertler 2005) and the open innovation approach (Von Hippel 1988; Chesbrough 2003), and empirically by prior studies on knowledge spillovers documenting the highly localised and spatially bounded nature of the phenomenon (Jaffe 1986; Audretsch and Feldman 1996). This *meso* level of analysis has indeed the advantage to overcome the limitations of a country-level investigation, which is a far too aggregate unit of analysis, and to capture the systemic and "open" aspect of knowledge creation (Braczyk, Cooke et al. 1998). The study seeks therefore to contribute to the literature on systemic and open innovation as well as to the studies on offshoring.

The paper is organised as follows. Section 2 provides the theoretical background of the study. In section 3, the theoretical framework is outlined. The sample and the variables are described in Section 4. Section 5 discusses the methodology, while the results of the econometric analysis are presented in section 6. A few conclusions are drawn in section 7.

Theoretical background

Studies in the innovation tradition have recognized the systemic and "open" nature of innovation (Lundvall 1988; Von Hipple 1988; Chesbrough 2003). Firms indeed do not act in isolation, but their innovation activity is influenced by and embedded in the external geographical environment. Due to the tacit component of knowledge (Nelson and Winter 1982; Rosenberg 1982), knowledge is hard to codify and costly to transfer. Therefore, it is best conveyed via face-to-face interactions and frequent contacts (Von Hipple 1994) which can be easily developed and established in geographically bounded systems. Spatially-bounded factors are explicitly taken into consideration by the regional innovation system approach (Braczyk, Cooke et al. 1998), which has been developed within the literature on national system of innovation (Freeman 1987; Lundvall 1992; Nelson 1993). In particular, the RSI approach is based on the idea that regional borders (rather than national) better define the ways innovation is created by strongly interrelated local actors (Braczyk, Cooke et al. 1998; Cooke 2004; Cooke 2005). Firms interact with other firms, research institutes, financial and public institutions, and their interactions are encouraged by face-to-face and continuous contacts. Local actors share common values, norms and standards that have a marked regional dimension. Differences among regions within the same country can be recognised in terms of regional governance of innovation, regional specialisation and evolution, and core/periphery differences (Howells 1999). The significance of geographical proximity has been confirmed in studies of knowledge spillovers (Jaffe, Trajtenberg et al. 1993; Feldman 1994; Audretsch and Feldman 1996) as well as by the literature on clusters (Porter 1990; 2000; Beaudry and Breschi 2003; Iammarino and McCann 2006). According to Porter (1990; 2000), in clusters there are some forces at work (e.g. factor input conditions, legal system, university quality, suppliers' competences, etc.) that, through mechanism of cooperation and competition, foster innovative firms and the diffusion of knowledge. The external environment of firms can also be understood in the sense of external boundaries of firms. In particular the open innovation paradigm (Chesbrough 2003) has pointed out that interactive learning is central to the innovation process, suggesting that innovators rely on external sources of knowledge, ideas, and practices within an innovation system that includes lead users, suppliers, universities (Von Hippel 1988; Lundvall 1992; Brown and Eisenhardt 1995; Szulanski 1996), and also competitors (Arora, Fosfuri et al. 2001). Thus, innovation is an open process that involves searching for new knowledge outside the boundaries of firms.

Theoretical framework

R&D offshoring, on the one hand, has been recognized to erode the innovation capacities of investing firms (Teece 1987) and, on the other, to enhance the capacities to integrate and coordinate distant activities (Kotabe 1990).

Traditionally, multinational enterprises (MNE) source new complementary knowledge by sitting their subsidiaries in "centres of excellence" in developed countries (Kuemmerle 1999;

Cantwell and Mudambi 2005) with the ultimate aim of benefiting from the reverse knowledge transfer from their foreign subsidiaries (Ambos, Ambos et al. 2006; Piscitello and Rabbiosi 2006). Recently, this phenomenon has involved emerging economies such as China, India, and South Korea (UNCTAD 2005) singling the rising of innovation clusters and the going up of the value chain by these recipient countries (Bardhan and Jaffee 2005). Mostly motivated by the search of savings in labour and skilled human capital (Bardhan and Jaffee 2005; Lewin and Couto 2006), offshoring of innovation activities in emerging economies is perceived as a threat to technological leaderships of developed countries because it implies a shift of most knowledge-intensive activities to fast-growing economies (Doh 2005). As long as emerging countries become an option to locate services at lower costs than in developed countries (Dossani and Kenney 2007), MNEs are hiring workers with science and technology skills outside the home countries, while in the past they concentrated R&D-related functions at home (Manning, Massini et al. 2008). These considerations have led to the fear that R&D offshoring might erode the traditional technological advantage of investing economies because of knowledge creation and skill-upgrading in the recipient countries (e.g. Teece 1987; Lieberman 2004). As the manufacturing offshoring prompted the reallocation of jobs from developed countries to emerging economies, the R&D offshoring might bear jobs losses in developed countries. More worrying than the loss of blue collars, the R&D-related jobs involve white collars and skilled people with science and engineering competences (Manning, Massini et al. 2008). However, this perspective is questioned by the view that managing distant activities reinforce MNEs' capabilities (as discussed in Kotabe 1990). In particular, with reference to US firms, it is suggested the increased significance of complementary between R&D activities by foreign affiliates and their reverse knowledge transfer back to the parents (Mansfield and Romeo 1984). Thus, this perspective contends that Western firms investing in emerging economies are likely to continue to remain at the forefront of innovation activities at least in the near future (Ernst 2006; Manning, Massini et al. 2008; Lewin, Massini et al. 2009). These different views on the phenomenon lead to different forecast of the effects of offshoring on the innovative activities at home of investing firms, with the former view forecasting negative effects and the latter positive ones. However, very little empirical evidence on such the effects is available, as far as our knowledge is concerned.

In tune with the theoretical background sketched above, in addressing the debate on the complementarity between offshoring and home R&D activities in the home knowledge production of the investors we take a regional approach that captures the systemic and open aspect of innovation. To further clarify our analysis, in the above discussion it is implicit the definition of R&D offshoring as the practice of placing activities at offshore locations outside the investing home country. Such re-location abroad may well co-exists with the persistence of the same type of activities at home. Therefore, the term offshoring is here used interchangeably with internationalization.

Sample and variables

Our sample refers to 221 TL2 regions of 21 OECD countries[i] from which R&D investment projects departed to BRICKST (Goldman Sachs 2003; Sauvant 2005; Armijo 2007; OECD 2007). For these regions, data were drawn from three main sources: the OECD REGPAT database (version January 2009), the fDi Market database, and the OECD Regional Database (RDB).

The OECD REGPAT collects patent applications filled at the Patent Cooperation Treaty (PCT) at the international phase that have been designated at the European Patent Office (EPO). The PCT procedure is an alternative route to the direct applications at national/regional patent offices. This procedure allows seeking for patent rights in multiple countries with a single application in a single language, but only the designated national (e.g. the USPTO) or regional (e.g. the EPO) patent office has the authority to grant a patent. The PCT procedure allows to have a standardised international procedure to seek patent protection (Khan and Dernis 2005). In the OECD REGPAT database, the PCT applications have undergone a procedure of “regionalisation”, which linked the address of both inventor and applicant to regional codes. The “regionalisation” process has involved 42 countries (Maraut, Dernis et al. 2008), of which 30 are OECD members[ii]. The sub-national units used are the Territorial Grids by OECD (2008). According to this system, the regions within the OECD member countries have been classified into two hierarchical levels: Territorial Level 2 (TL2), and Territorial Level 3 (TL3)[iii]. The TL2 is more aggregated and it consists of 335 regions. The TL3 is the lowest, with 1679 regions. For most of the European Union countries, the Territorial Levels corresponds to the Eurostat classification (NUTS)[iv]. By relying on media sources and company data, fDi Market collects detailed information on cross-border greenfield investments worldwide since 2003. In particular, information refer to the *investment* (e.g. the business activities of the investment, estimation of the invested capital and the number of jobs created), the home and host locations involved in terms of country, region and city, and information about the *investing company* (e.g. leading industry sector, location, turnover, and parent company). The RDB collects socio-economic indicators of the OECD regions (e.g. demographic statistics, regional accounts, regional labour market, innovation indicators, and social indicators). The reason for focusing on BRICKST relies on the fact that these countries are major recipients of R&D projects among the fast-growing emerging economies, as illustrated in Table 1.

TABLE 1 HERE

Variables

To build our depend variable we averaged the fractional count of PCT applications aggregated by the region *i* of residence[v] of the inventor over the period 2005-2006 and transformed it in logarithm (*PAT_LN*). The two explanatory variables are total R&D expenditures in region *i* (*RDhome*) and the number of R&D offshoring investments made by firms whose headquarter is located in region *i* (*RDoff*). Both calculated over the period 2003-2004.

Controls

By taking the region as unit of analysis we account for the regional systemic characteristics of knowledge creation which is not merely the result of firms that innovate in isolation, but it is affected by several elements spatially bounded, which Lundvall (1992) indentifies as: inter-firm relationships, role of the public sector, institutional set-up of the financial sector, R&D organisation.

We introduced a set of exogenous variables to control for such elements. Following prior studies (e.g. Sterlacchini 2008; Usai 2008), we controlled for population density of the region (*DEN*) to proxy for inter-firm relationship under the hypothesis that in agglomerations firms' interaction and collaboration are stronger, as underlined by the studies on knowledge spillovers (Jaffe 1986) and clusters (Porter 1990). The role of the public sector in the region where the country capital city is located was accounted for by a binary variable (*CAP*) (Feldman 2003). Lundvall (1992) also highlights the significance of R&D organisation. Unlike in the past where knowledge creation mainly relied on internal R&D labs, lately it is increasing the results of more "open" process (Chesbrough 2003) characterised by inter-firm collaborations, firm-university partnerships, start-ups, and scientists' networks. These collaborations in innovation have also a cross-border dimension, as shown by the rise of international technological alliances (e.g. Narula and Hagedoorn 1999). Therefore, we controlled for international inter-regional collaboration with the share of patents with multiple inventors where at least one inventor is located in another country (*INTERNAT*). In addition to Lundvall's elements (1992), we considered the role of education and training as suggested by Freeman (1987) and included the share of population with tertiary level of education (*HK*) as proxy for human capital. To control for the role of the financial sector we use the share of employment in financial intermediation (*EMPL_FIN*) as a proxy for the local presence of financial institutions. The more localised are the financial institutions, the closest they are to the needs of innovative firms (Cooke, Uranga et al. 1997). Moreover, an additional control at the country level is introduced, by considering the net value of FDI inward stock (*FDI*) - namely, FDI inward stock minus FDI outward stock – based on the (UNCTAD 2008) database.

Table A1 shows the variables included in the analysis.

TABLE A1 HERE

Methodology

Complementarity

We want to test whether R&D at home (*RDhome*) and R&D offshoring (*RDoff*) are complements in the home creation of knowledge in the investing region. The complementarity concept refers to the simultaneous presence of certain elements, which reinforce the importance of each other. Complementarity arises when the marginal return to one element (which can be any practice or activity of firm, industry or region) increases as the other element increases.

An empirical test to complementarity derives from the theory of supermodularity (Milgrom and Roberts 1990; 1995). Suppose that there are 2 activities, A and B. Each activity can be done (A=1) or not (A=0). The function F(A, B) is called *supermodular* and A and B are said *complements* only if:

$$F(1,1) - F(0,1) \geq F(1,0) - F(0,0) \tag{1}$$

The right-side of the equation defines the marginal increase of doing only activity A (F(1,0)) rather than neither of the two (F(0,0)). The left-side describes the marginal increase of doing both activities (F(1,1)) rather than only B (F(0,1)). Therefore, the whole equation states that the marginal increase of adding one activity (i.e. A) when already doing the other (left-side) is higher than the marginal increase of adding one activity solely (right-side). Empirically, we would observe positive correlation among the complements when the function F is *supermodular* in the complements and in a vector of exogenous variables (that control for other characteristics that might affect F) (Arora and Gambardella 1990; Arora 1996).

To look for the complementarity between R&D at home and R&D offshoring we estimated a knowledge production function in which the log-transformed fractional number of patent (*PAT_LN*) is estimated as a function of exclusive combinations of R&D activities and on a set of controls. Following Giuri, Torrisi et al. (2005) and Cassiman and Veugelers (2006) to apply the productivity approach to complementarity, we generated two dummy variables, *HOME* and *OFF*.

The first accounts for the level of R&D at home taking value 1 if the R&D expenditures of the region is above the national average. The second accounts for R&D offshoring taking the value 1 if the region has done at least one R&D offshoring investment. Then, four exclusive categories have been created:

- *HOMEOFF* equals 1 if the level of R&D expenditures at home is above the country mean and at least one R&D investment has been offshore from the region (i.e. *HOME*=1; *OFF*=1);
- *ONLYHOME*: equals 1 if the level of R&D expenditures at home is above the country mean, but no R&D offshoring has occurred (i.e. *HOME*=1; *OFF*=0);
- *ONLYOFF* equals 1 if the region has offshore at least one R&D investment, but its level of R&D at home is below the country mean (i.e. *HOME*=0; *OFF*=1);
- *NOHOMEOFF* equals 1 if the level of R&D expenditures at home is below the country mean and no R&D investments has been offshore from the region (i.e. *HOME*=0; *OFF*=0).

Therefore, by mean of an OLS regression we estimate the following model:

$$PAT\_LN_{it} = C_{cit-1}\theta + X_{it-1}\beta + \varepsilon_i \tag{2}$$

where the subscript i refers to region i, the subscript t refers to time, and the subscript c refers to the four combinations of *HOME* and *OFF*.

For the dependent variable, we use the mean values of the period 2005-2006 to smooth the peaks, while all the regressors and controls are two-year lagged (mean values of 2003-2004). C_{cit-1} measures the four possible combinations of complements of region i at time $t-1$. θ is the vector of the coefficients of the combinations C_{cit-1}. X_{it-1} is the vector of exogenous variables chosen as controls and β is the vector of coefficients of the controls.

The test of complementarity is based on the following null hypothesis:

$$\theta_{11} - \theta_{10} \geq \theta_{01} - \theta_{00} \tag{3}$$

where the first subscript refers to activity A and the second to activity B, which in our case correspond to *HOME* and *OFF* respectively. Therefore, the rejection of the equality hypothesis means that the payoff of joint *HOME* and *OFF* is higher than the sum of the two situations occurring separately.

The simple correlation between the two possible complements *HOME* and *OFF* is positive ($\rho = 0.135$) and significant at $p \leq 0.05$. The positive correlation is already a signal of complementarity between the two conditions (Cassiman and Veugelers 2006). Table 2 summarises some information about the four categories we built from the combinations of *HOME* and *OFF*. Column 1 and 2 show the frequency and the percentage of regions for each of the four categories. Column 3 indicates the mean of patents in levels rather in log for each category. Less than half of the regions (44%) have neither a relative high R&D performance nor a R&D offshoring investments. Among the other three combinations, *ONLYHOME* has the higher share (28%). The regions belonging to the joint situation *HOMEOFF* (15%) exhibit an outstanding innovation performance, with an average number of patents far above the other three categories, and almost three times the whole sample mean. This is another signal of complementary, since the combination of high R&D at home and R&D offshoring is associated to very innovative regions. Moreover, the regions that belong to *ONLYOFF* (13%) tend to have double patents on average than *ONLYHOME* regions.

TABLE 2 HERE

Spatial dependency

Since we are using regions, we also want to check whether a spatial dependence exist among them. As highlighted by previous studies (Acs, Anselin et al. 2002; Moreno, Paci et al. 2005), in cross-sectional data of geographically close units of observations it is very likely that innovation output of each unit is affected positively by the innovation performed in the neighbouring regions, which means that the error terms are correlated across observations. The spatial autocorrelation renders the OLS estimator inefficient, although it leaves the coefficients unbiased (Anselin 1988).

To deal with this problem, we firstly tested the presence of such misspecification by means of Moran's I test with a binary contiguity matrix.[vi] The null hypothesis of spatial independence is rejected at the 0.01 level of significance, and the index is 0.343 with z-value of 7.720. Therefore, regions tend to cluster in neighbouring groups of high-innovative regions versus low-innovative regions and we have to control for the spatial dependence in the model. Secondly, given the statistically positive result of the test we searched for which model can better describe the spatial dependence by means of a set of Langrage Multiplier tests on the OLS results. Then, on the grounds of these tests, we used the ML estimator because the OLS would be inefficient in case of spatial correlation. Spatial econometrics provides two empirical ways to incorporate spatial autocorrelation in the model, namely either as spatially lagged dependent variable (substantive dependence) or in the error term of the regression (nuisance dependence). In order to choose between the two ways, we run a set of Lagrange Multiplier tests by using the binary contiguity matrix, i.e. the LM-LAG and the LM-ERR. Thus, the specification of the lag model is:

$$PAT\_LN_{it} = C_{cit-1}\theta + X_{it-1}\beta + \rho W PAT\_LN_{it} + \varepsilon_i \tag{4}$$

where $WPAT\_LN_{it}$ is the lagged dependent variable for weight matrix W and ρ is the spatial autoregressive coefficient. A positive and significant effect of this coefficient suggests that the knowledge creation of region i is influenced by knowledge creation in neighbouring regions. For the error model:

$$PAT\_LN_{it} = C_{cit-1}\theta + X_{it-1}\beta + \varepsilon_i \tag{5}$$

with

$$\varepsilon_i = \lambda W \varepsilon_i + u_i \tag{6}$$

where λ is the spatial autoregressive coefficient and u_i is the spherical error term. W is the weight matrix.

Results

Table 3 shows the correlation matrix of variables included in the econometric analysis.

TABLE 3 HERE

Table 4 presents the results the econometric analysis. Column 2 shows the results from the OLS[vii]. The four explanatory variables are all positive and significant at $p \leq 0.01$. As expected, the joint variable *HOMEOFF* has the higher impact on the knowledge creation by comparison to the other three categories. Therefore, jointly conducting R&D at home and offshoring R&D in BRICKST (*HOMEOFF*) generates a higher impact than in the other scenarios. *Ceteris paribus*, an shift from 0 to 1 in the dummy variable *HOMEOFF* produce an increase of about 192% of patents in region *i*[viii]. Doing neither remarkable R&D at home nor any offshoring has the lowest impact on knowledge creation (*NOHOMEOFF*), measured by an impact of 31% *ceteris paribus*. The model explains a notable 95% of total variance as from the R^2. The test of the joint equality of coefficients to zero is rejected.

The LM tests for spatial independence are both rejected at the 0.01 level of significance. Therefore, we estimate both ML models of spatial autocorrelation. Column 3 of Table 4 shows the results of the ML estimates of spatial lag model, while Column 4 reports the results of ML estimates of spatial error model.[ix] The coefficients of explanatory variables are all positive and significant at the $p \leq 0.01$ level. In addition, in this case *HOMEOFF* has the higher impact on knowledge creation than the other two situations. The Akaike's information criterion (AIC) is lower for spatial error model, thus suggesting this model better explains the economic relation of interest.

TABLE 4 HERE

The result of the test of complementarity, shown in the last row of Table 4, suggests to reject the hypothesis of equality at the $p \leq 0.01$ level of significance in all the models, that is the marginal return due to joint presence of outstanding R&D home expenditure and offshoring investments (i.e. *HOMEOFF*) is higher than the marginal return of one of the two conditions separately.

Conclusions

Debate is ongoing on the effects of the R&D offshoring on the home investors' activities. In particular, R&D offshoring by MNEs locate in developed countries towards emerging economies is seen as a threat to innovation capacity of the advanced economies (e.g. Teece 1987; Lieberman 2004). An alternative view sees the cross-border R&D investments as a mean to enhance firms' capability through the coordination of distant activities (Kotabe 1990). This study contributed to this debate by investigating the complementarity between home and offshore R&D activities. By using the productivity approach to complementarity (Giuri, Torrisi et al. 2005; Cassiman and Veugelers 2006), we estimated the knowledge production on 221 OECD TL2 regions as functions of R&D offshoring and R&D at home, and a set of exogenous variables. We found that regions that have done jointly relatively high R&D at home and R&D offshoring generated on average more new knowledge than regions that have done one of the two activities in isolation. Therefore, the complementarity between the two activities is in favour of the thesis that R&D offshoring reinforces innovative capacity at home.

One major shortcoming of this paper is that the complementarity test has been performed by transforming R&D expenditure and R&D offshoring investments in dummy variables, thus losing many information. Alternative approaches to complementarity, such as the adoption approach (Arora and Gambardella 1990; Cassiman and Veugelers 2006), should be also considered in future research. A second major shortcoming is the lack of control of higher order spatial dependency that may bias our result if founded.

Further researches should devoted to investigate possible sectoral differences, and the role of the characteristics of the investments in terms of e.g. destination countries, number of job created, value of the investments.

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Table 1 - Destination countries ranked by number of investments, 2003-2006

Destination countries	Number of investments	Share of number of investments
China	247	20.69%
India	192	16.08%
USA	69	5.78%
UK	56	4.69%
France	54	4.52%
Singapore	48	4.02%
Spain	42	3.52%
Ireland	36	3.02%
South Korea	35	2.93%
Canada	33	2.76%
Taiwan	28	2.35%
Germany	26	2.18%
Japan	21	1.76%
Malaysia	20	1.68%
Belgium	19	1.59%
Hungary	19	1.59%
Australia	19	1.59%
Israel	17	1.42%
Russia	17	1.42%
Italy	16	1.34%
Sweden	14	1.17%
Thailandia	13	1.09%
Brazil	11	0.92%
Other Countries*	142	11.89%
Total	***1,194***	***100.00%***

*Poland, Austria, Denmark, Mexico, Czech Republic, Romania, Switzerland, Netherlands, Portugal, Hong Kong, Vietnam, UAE, Finland, Turkey, South Africa, Qatar, Colombia, Morocco, Bulgaria, Slovakia, New Zealand, Philippines, Norway, Tunisia, Chile, Saudi Arabia, Ukraine, Nigeria, Armenia, Peru, Malta, Lebanon, Bahrain, Ecuador, Estonia, Costa Rica, Pakistan, Latvia, Croatia, Kenya, Serbia, Slovenia, Jordan, Egypt, Luxembourg, Puerto Rico, Algeria.

Source: fDi Market database.

Table 2 – Frequency of regions and average patents for each of the four categories

	Number of regions	**Percentage of the total number of regions**	**Average of patents**
HOMEOFF	33	15%	1411.416
ONLYHOME	61	28%	317.7508
ONLYOFF	29	13%	849.6957
NOHOMEOFF	98	44%	99.05657
Total	***221***	***100%***	***453.8834****

* It is the average of patents over the whole sample, not the average of the four categories.

Table 3 – Correlation matrix

		Mean	Std. Dev.	1	2	3	4	5	6	7	8	9	10	11
1	PAT_LN	4.82	1.76	1.00										
2	HOMEOFF	*0.15*	0.36	0.44	1.00									
				0.00										
3	ONLYHOME	0.28	0.45	0.04	-0.26	1.00								
				0.56	***0.00***									
4	ONLYOFF	0.13	0.34	0.31	-0.16	-0.24	1.00							
				0.00	***0.02***	***0.00***								
5	NOHOMEOFF	*0.44*	0.50	-0.56	-0.37	-0.55	-0.35	1.00						
				0.00	***0.00***	***0.00***	***0.00***							
6	HK	23.76	8.61	0.24	0.21	0.06	0.05	-0.24	1.00					
				0.00	***0.00***	0.34	0.43	***0.00***						
7	DEN	*268.11*	723.73	0.12	0.12	0.02	0.05	-0.13	0.19	1.00				
				0.07	0.09	0.77	0.47	***0.05***	***0.00***					
8	CAP	0.10	0.29	0.12	0.17	0.11	0.01	-0.23	0.29	0.57	1.00			
				0.08	***0.01***	0.10	0.87	***0.00***	***0.00***	***0.00***				
9	FDI	-116362.80	355203.20	-0.35	-0.24	0.18	-0.17	0.12	-0.07	-0.05	0.04	1.00		
				0.00	***0.00***	***0.01***	***0.01***	0.07	0.28	0.45	0.51			
10	INTERNAT	9.11	9.22	-0.31	-0.09	0.04	-0.08	0.08	0.06	0.11	0.16	0.10	1.00	
				0.00	0.16	0.52	0.22	0.21	0.37	0.10	***0.02***	0.15		
11	EMPL_FIN	67028.95	113252.20	0.64	0.34	-0.16	0.33	-0.32	0.15	0.10	0.09	-0.34	-0.16	1.00
				0.00	***0.00***	***0.02***	***0.00***	***0.00***	***0.03***	0.16	0.16	***0.00***	***0.02***	

Table 4 - Econometric results

Variable	OLS model (2)	ML model (4)	ML model (5)
Dependent variable			
PAT_LN			
Explanatory variables			
HOMEOFF	5.326*** (0.323)	1.446*** (0.239)	1.359*** (0.238)
ONLYHOME	4.676*** (0.303)	0.973*** (0.170)	0.934*** (0.168)
ONLYOFF	4.946*** (0.331)	1.091*** (0.241)	0.993*** (0.242)
NOHOMEOFF	3.556*** (0.254)		
Controls			
HK	0.014 (0.010)	0.012 (0.008)	0.029*** (0.011)
DEN	0.000 (0.000)	0.000* (0.000)	0.000 (0.000)
CAP	-0.12* (0.257)	0.218 (0.300)	0.108 (0.294)
FDI	0.000** (0.000)	0.000* (0.000)	0.000*** (0.000)
INTERNAT	-0.036*** (0.007)	-0.038*** (0.008)	-0.040*** (0.008)
EMPL_FIN	0.000*** (0.000)	0.000*** (0.000)	0.000*** (0.000)
_cons		2.852*** (0.247)	2.556*** (0.313)
rho			
_cons		0.041*** (0.007)	
sigma			
_cons		1.000*** (0.048)	0.986*** (0.047)
lambda			
_cons			0.064*** (0.011)
Number of observations	221	221	221
F-statistics	F(10,221) = 606.22*** p-value = 0		
R^2	0.95	0.62	0.62
AIC	679.7488	680.874	680.775
LM-ERR	52.013 p-value = 0		
LM-LAG	39.637 p-value = 0		
Likelihood ration test		32.25 p-value = 0	38.423 p-value = 0
Complementary test HOMEOFF=HOME+OFF	F(1, 211) = 118.79*** p-value = 0	F(1, 211) = 138.79*** p-value = 0	F(1, 211) = 138.79*** p-value = 0

legend: * p≤.10;** p≤.05; *** p≤.01;

Table A1 – Variable Definitions

Variable	Description	Source	Period*	Proxy for:
Dependent variable				
PAT_LN	PCT applications which have designed EPO at the international phase by inventor's residence and fractional count. Log-transformed.	REGPAT	2005-2006	Knowledge creation
Explanatory variables				
RDhome	Regional R&D expenditure (PPP)	RDB	2003-2004	Local R&D input to knowledge creation
RDoff	Number of R&D offshoring investments	fDi Market	2003-2004	R&D offshoring input to knowledge creation
Controls				
DEN	Population density	RDB	2003-2004	Inter-firm relationships
CAP	Dummy variable taking the value 1 if the region hosts the country capital city	RDB	2003-2004	Role of public sector
INTERNAT	Share of patents with multiple inventors in which at least one inventor is not resident in the same country of region *i*	REGPAT	2003-2004	R&D organisation
HK	Share of population with tertiary education (ISCED 5 - 6)	RDB	2003-2004	Educational system
EMPL_FIN	Share of employment in financial intermediation	RDB	2003-2004	Role of public sector
FDI	Net FDI inward stock (country level), calculated as FDI inward stock minus FDI outward stock.	UNCTAD	2003-2004	International attractiveness of the country to foreign investors

*All variables are taken as two-year average.

[i] Due to lack of some of the regional data we excluded Japan, Turkey, Mexico, Iceland, Denmark, Switzerland, New Zealand, Poland and Portugal, and 9 regions (2 Canadian regions, 2 Spanish autonomous regions and the Canary Islands, 2 Italian autonomous provinces, and Alaska and Hawaii in US).

[ii] The OECD members are: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, South Korea, Luxemburg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom, and United States.

[iii] Level 0 refers to the country as whole, while Level 1 indicates groups of macro regions.

[iv] The Nomenclature of Territorial Units for Statistics (NUTS, from the French "nomenclature d'unités territoriales statistiques") has been developed by the European Union to have a uniform geographical breakdown for statistics purpose and for policy-making. NUTS comprises three levels. NUTS divisions do not always correspond to administrative divisions within the country. REGPAT relies on the NUTS version available in July 2007. However, differences exist between TL and NUTS regions for some EU countries. Belgium, Greece and the Netherlands, being small countries, their NUTS 2 level corresponds to TL3. For United Kingdom, the NUTS 1 corresponds to TL2. For Denmark, which has not a NUTS 2 division, the TL2 gather the TL3/NUTS3 regions.

[v] When more than one inventor participates to the patent, the patent is equally shared among them. Therefore, for each region we counted the shares of the inventors who are resident in that region.

[vi] The binary contiguity matrix takes the value of 1 if the pair of regions share a border, 0 otherwise.

[vii] The model is run without the constant term. The exclusion of the constant is required in order to include all the 4 exclusive dummies.

[viii] The impact of a dummy variable on the log-transformed dependent variable is calculated as follows: $g = \exp\left(\theta - \frac{1}{2}V(\theta)\right) - 1$, where g is the percentage impact, θ is the coefficient of the dummy, $V(\theta)$ is the estimated variance of the coefficient.

[ix] In ML models we need to include the constant term, thus one of the dummy variables has to be excluded due to perfect collinearity.