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Does the global fragmentation of R&D activities pay back? The home region perspective

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Abstract

Multinational corporations (MNCs) increasingly disaggregate their value chain in finer ?slices? across borders and locate each slice according to the competences and resources of the destination countries (Mudambi, 2008). The recent internationalization of R&D confirms a clear dominance of advanced countries as the main source of R&D investments and documents that emerging countries receive a large share of R&D foreign direct investment (FDI), with China and India being the most appealing destinations (UNCTAD, 2005). Despite the growth of R&D FDI in emerging countries, developed countries remain the preferred locations for higher value-added R&D activities (Demirbag and Glaister, 2010; Schmiele, 2009). This pattern suggests that the R&D value chain can also be finely sliced across countries to exploit specific location advantage. This phenomenon is likely to occur in medium technology-intensive industries where emerging countries have strong competitive advantage (Ramamurti, 2009) and can contribute to the specific R&D activity implanted by the MNC.

The efficiency of this fragmentation and geographical dispersion of R&D value chain has been poorly analysed in empirical works (Contractor et al., 2010). We aim to advance extant research by investigating whether developed regions, from which R&D FDI originate, enjoy synergies when geographically dispersing different value-added R&D activities in the foreign locations showing strong comparative advantage. Drawing on a rich database combining patent, R&D FDI and socio-economic information, we estimate a regional knowledge production function (Acs et al., 2002) on a sample of 221 regions of 21 OECD countries from which different types of R&D activities depart toward foreign locations. Following extant research (e.g. Pearce and Papanastassiou, 1999), we classified R&D activities as research,

development and adaptation. Based on the idea that the types of incoming R&D laboratories reveals the type of location specific advantage that the host country can offer (Pearce, 1999), we also identified the most specialized countries in each of these R&D activities. Our analysis confirms that OECD regions geographically dispersing each ?slice? of the R&D value chain in the most specialized destination countries are great knowledge producer at home. Specifically, our results suggest that knowledge production is greater in regions that invest jointly in research in G7 countries, development in non-G7 OECD countries, and adaptation in China and India.?

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Abstract
R&D offshoring has increasingly involved emerging countries as host locations and promoted a greater fragmentation of R&D activities across borders. As a result, a subtle international division of labor in knowledge production has yielded a fine-slicing of R&D activities with the highest value-added activities located in the most advanced countries and the lowest value-added activities in emerging countries. However, no study, to our knowledge, has investigated whether finely sliced foreign R&D activities complement each other in terms of greater knowledge production at home. Drawing on a rich dataset, we estimate a regional knowledge production function and apply a direct complementarity test. Our results suggest that the global fragmentation of R&D activities produces synergic effects on the knowledge production of the home investing OECD regions when R&D activities are optimally rather than randomly located.

Keywords: R&D fine-slicing, R&D optimal location, home region knowledge production, emerging countries

1. Introduction

A large body of research has documented the increasing globalization of R&D and indentified knowledge sourcing as a major driver of this trend (Almeida, 1996; Cantwell, 1995; Florida, 1997; Gerybadze and Reger, 1999; Iwasa and Odagiri, 2004; Patel and Vega, 1999). Multinational corporations (MNCs) offshore R&D to tap into learning opportunities offered by different locations in order to complement knowledge production at home (Cantwell and Santangelo, 2000; Frost, 2001). To this end, MNCs rely on different types of foreign R&D laboratories depending on host location R&D activity-specific advantage (Cantwell and Mudambi, 2005; Kuemmerle, 1999; Pearce and Papanastassiou, 1999; von Zedtwitz and Gassmann, 2002). Traditionally, this literature has investigated the phenomenon of R&D globalization with reference to developed countries. More recently, a number of studies recognizes the increasing involvement of emerging countries as appealing host locations, although advanced countries remain major sources and destinations of R&D offshoring (Ito and Wakasugi, 2007; Manning et al., 2008).

A large supply of science and technology talents, and the upgrading of innovation capacities primarily motivate R&D offshoring in emerging countries (Athreye and Cantwell, 2007; Manning et al., 2008). The involvement of these new players in R&D globalization has promoted a greater geographical fragmentation of R&D by MNCs across technologies and R&D activities. The contribution of R&D offshoring in emerging countries to knowledge production critically varies indeed across technologies and R&D activities (D'Agostino et al., 2010; D'Agostino and Santangelo, 2012). In particular, the underlying rationale of the market for technology argument relates to an international division of labor in knowledge production with more advanced countries focusing on more complex technologies, and emerging countries on more mature technologies (Arora et al., 2001). In addition, a more subtle international division of labor is taking place within the R&D function. MNCs finely slice their R&D function in different geographical locations depending on host competences and resources to enjoy complementarity across different geographically dispersed innovative activities (Contractor et al., 2010). In particular, the most advanced countries remain the favorite locations for the highest value-added R&D activities with lesser value-added R&D activities located in emerging countries (Demirbag and Glaister, 2010; Schmiele, 2011; Thursby and Thursby, 2006).

However, the effects of the greater geographical fragmentation of R&D activity following the boom of R&D offshoring in emerging countries on home knowledge production have been poorly analyzed. The participation of these new players to global innovation networks is still open to debate (Ernst, 2006; Manning et al., 2008). We aim to fill this gap and investigate whether finely sliced R&D activities produces a synergic effect on the knowledge production of the investing OECD home regions from which the bulk of R&D offshoring originates. We argue that synergies rise when finely sliced R&D activities are optimally rather than randomly located across countries. In particular, different R&D "slices" complement each other and contribute to the knowledge production in the investing home region when each "slice" is optimally located in countries enjoying R&D activity-specific comparative advantage. To this end, we rely on a rich dataset and estimate a regional knowledge production function (Acs et al., 2002) on a sample of 221 regions of 21 OECD countries from which different value-added R&D activities depart towards foreign destinations. The reason to adopt a home region perspective is twofold. First, MNCs share the knowledge acquired abroad within their home regional system of innovation (RSI) (Braczyk et al., 1998), which, as a result, may gain from globally dispersed R&D of domestic MNCs (Cantwell and Iammarino, 2001). Second, the innovation literature recognizes the region as a valuable unit of observation to analyze the spatially-bounded factors that influence the innovation of local firms (Cooke, 2005) and the systemic development of knowledge production. In addition, we focus on captive R&D offshoring (Kedia and Mukherjee, 2008; Kotabe and Murray, 2003; Lewin et al., 2009) in medium and low technology-intensive sectors where emerging countries have already matured technological capacities (Ramamurti, 2009).

We contribute to research on R&D offshoring by providing empirical evidence on the complementarity across globally fragmented R&D activities in terms of home knowledge production when R&D activities are optimally rather than randomly located. We also advanced research on international knowledge sourcing which has primarily focused on advanced countries and more recently acknowledged the phenomenon of R&D offshoring in emerging countries. Specifically our study extends the argument of the geographical R&D hierarchy (Cantwell and Janne, 1999) by providing empirical evidence on a more complex hierarchy encompassing both locations and specific R&D activities as well as documenting the participation of emerging countries in global innovation networks.

The paper is organized as follows. Section 2 draws the theoretical framework. Section 3 present the data and section 4 discusses the model. Section 5 elaborates on the complementarity test we adopt. The results of the econometric analysis are presented in section 6. Finally, section 7 draws a few conclusions.

2. Theoretical framework

The value chain is no longer divided into larger grouping such as R&D, Production and Marketing (Contractor et al., 2010). Rather, the operations within each functions are sliced in different activities that are then geographically dispersed in selected locations. This phenomenon has concerned increasingly the R&D function that was traditionally regarded as a core function to be kept strategically in-house in the headquarter country (Patel and Pavitt, 1991). A well established literature indeed documents that firms offshore their R&D activities to exploit host location R&D activity-specific advantage in order to source complementary knowledge (Cantwell and Mudambi, 2005; Cantwell and Santangelo, 2000; Kuemmerle, 1999; Pearce and Papanastassiou, 1999; von Zedtwitz and Gassmann, 2002). The ultimate goal is to build a global network which is strategically coherent and efficient. The distinctive feature of the current global fragmentation of R&D activities is the involvement of emerging countries which are increasingly attracting R&D investments for strategic objectives that go well beyond cost reduction. The global race for talents drives R&D offshoring in emerging countries, where scientists and engineers are abundant at relative low costs (Manning et al., 2008). Emerging countries are regarded indeed as contributors to technology generation in the world economy (Athreye and Cantwell, 2007).

A major result of the involvement of these new players in R&D offshoring is the relocation of R&D activities across countries (Demirbag and Glaister, 2010). In particular, firms still rely on a dispersed R&D structure where the headquartered R&D laboratory at home coordinates the whole MNC's network of geographically dispersed R&D laboratories (Bartlett and Ghoshal, 1990; Filippaios et al., 2009). However, the share of R&D sites of US MNCs has declined in the USA, while increasing in China and India (Atkinson, 2007). Emerging countries such as China and India are becoming also more popular destinations of R&D offshoring than Western Europe which is losing its competitive advantage (Atkinson, 2007; Huggins et al., 2007). In advanced countries, this pattern has risen concerns of a potential hollowing-out of domestic R&D activities, as firms may substitute foreign R&D activities for domestic activities (Narula, 2002b). Notwithstanding, the market for technology argument reinsures that an international division of labor in technology production explains the relocation of R&D activities across countries (Arora et al., 2001). More complex high-tech knowledge is produced in advanced countries, medium- and low-tech knowledge in emerging countries and both are transferred and traded across borders eventually. D'Agostino et al. (2010) document indeed that R&D laboratories of OECD firms in emerging countries contribute to home knowledge production primarily in medium and low technologies.

Recent studies on R&D offshoring acknowledge a more subtle international division of labor which now involves emerging countries and a fine-slicing of their R&D activities. In particular, firms have redefined their core R&D operations not just in terms of technology intensity, but increasingly more in terms of activities' added value. The modularization of technology (Chesbrough and Kusunoki, 2001) and the parallel rise of new players in knowledge production enable firms to focus on activities associated to highest added value, and to source other activities associated with lower added value more efficiently (Ernst and Kim, 2002). As a result, firms focus on a narrower set of high value-added activities in advanced countries, while the more operational and lesser value-added activities are offshored in emerging countries (Demirbag and Glaister, 2010; Filippaios et al., 2009; Ito and Wakasugi, 2007; Schmiele, 2011).

Research on R&D globalization has proposed an array of classifications of R&D activities primarily relying on the dichotomy augmenting "innovative" R&D and exploitative "adaptive" R&D (Kuemmerle, 1999; von Zedtwitz and Gassmann, 2002). A more articulated classification relates to the distinction between *research*, *development* of new products and *adaptation* to local customers needs (Dunning and Narula, 1995; Hood and Young, 1982; Le Bas and Sierra, 2002; Pearce and Singh, 1992; Pearce, 1999; Pearce and Papanastassiou, 1999; Ronstadt, 1977). These studies acknowledge that the host location R&D activity-specific advantage determines the type of incoming R&D activity (Pearce, 1999). In particular, foreign R&D laboratories might undertake basic or applied *research* to acquire new or complementary pre-competitive knowledge and/or to monitor local scientific research. Research is the highest value-added R&D activity, as it assures new generations of innovative products in the long-term (Pearce and Papanastassiou, 1999), and tends to be concentrated in a few countries (Filippaios et al., 2009). The countries hosting the highest value-added R&D activity traditionally are the most advanced with high R&D expenditures, sophisticated markets and large pool of technological idiosyncrasies and scientific knowledge (von Zedtwitz and Gassmann, 2002). The *development* of entirely new commercial products, and/or of specific product and/or process characteristics is still a value-added activity, but of a lower order. Specifically, this R&D activity enables the MNC to enter in all key segments of the global market quickly and efficiently by leveraging location-specific resources in terms of both skills and expertise (e.g. applied scientists, technicians, engineers) and economies of scale in R&D and market demand (Dunning, 1993; Enright, 2009). Development is more geographically dispersed (von Zedtwitz and Gassmann, 2002) but still requires a critical level of local R&D investments and scientific base, which other advanced countries traditionally provide. Finally, *adaptation* is the lowest value-added R&D activity carried out by foreign laboratories as this activity is strongly market-oriented and exploits existing knowledge embodied in established products (Dunning and Narula, 1995; Hood and Young, 1982; Ronstadt, 1977). In particular, the mission of a foreign laboratory carrying out R&D adaptation is to provide technical support to local production for minor product or process adaptation in order to meet local tastes and needs. Traditionally, low income Western countries have hosted this lowest value-added activity (Pearce and Singh, 1992; Pearce, 1999). More recently, MNCs have shifted R&D adaptation sites in emerging countries as a result of the growing scientific and technological base, and parallel upgrading of these new players. China and India, for example, are the top destinations of R&D offshoring among non-OECD and primarily host R&D investments aiming at *adaptation* of products and technologies (Gassmann and Han, 2004; von Zedtwitz and Gassmann, 2002).

The geographical fragmentation of R&D activities is primarily motivated by the potential synergies across these activities, which can be enjoyed at home. The fine-slicing of R&D activities may be beneficial to the extent that each "slice" is optimally located. Failing to optimally locate the R&D "slices", firms will suffer from limited strategic coherence and efficiency of their R&D global network, and, as a result, miss synergic effects on knowledge production at home. In particular, the MNC's headquarter orchestrates its geographical dispersed network of R&D laboratories from its home region, where the MNC is strongly embedded (Meyer et al., 2011). Firms typically build their original resource endowments in their home location (Hymer, 1968; Vernon, 1966) to the extent that the home context may either induce or constrain domestic firms' overseas activities (Narula, 2002a). MNCs greatly invest also in embeddedness in selected host locations to source complementary knowledge (Andersson et al., 2002). This dual embeddedness enables MNCs to acquire knowledge abroad, and spread and shared this knowledge in their home region with local innovative organizations ultimately enhancing home region's knowledge production. The RSI approach highlights indeed that firms do not innovate in isolation, and the regional innovation output is the result of spatially bounded interactions between innovators and supporting-innovation institutions that tend to vary considerably between administrative sub-national units (Braczyk et al., 1998; Buesa et al., 2006; Cooke, 2004). Empirical evidence suggests a link between the technological capacity of a region and the innovativeness of the MNCs headquartered in that region (Cantwell and Iammarino, 2003)

Figure 1 summarizes our argument. The vertical axis reports R&D added value and the horizontal axis R&D locations. To enjoy synergies at home, firms need to offshore the highest value-added R&D activities in the most advanced countries. As the added value of the foreign R&D declines, the host location R&D activity-specific comparative advantage required to optimally locate the R&D activity also declines.

[Figure 1 about here]

3. The data

Our sample refers to 221 regions in 21 OECD countries.[1] For these regions, we built a dataset relying on three main sources: the OECD REGPAT database (version January 2010), fDi Markets database, and OECD Regional Database (RDB).

OECD REGPAT collects patent applications filed under the Patent Cooperation Treaty (PCT) where the European Patent Office (EPO) is entitled as the designated office (Khan and Dernis, 2005; Le Bas and Sierra, 2002). The PCT procedure enables applications for patent rights in multiple countries as alternative to direct applications to national/regional patent offices. This insures that the PCT process does not suffer from bias towards any particular country. PCT applications in the OECD REGPAT database are 'regionalized' by allocating inventor and applicant addresses to regional codes (Maraut et al., 2008). The sub-national units are OECD Territorial Grids (OECD, 2008) that classify regions in the OECD member countries at two hierarchical levels: Territorial Levels 2 and 3 (TL2 and TL3).[2] TL2 is more aggregated, consists of 335 regions for the 30 OECD countries and is the division adopted in this study. REGPAT provides also information on the technological content of patents. Drawing on International Patent Classification (IPC, version 8) codes, we assigned each patent's technological field to one of the following technological groups (Schmoch, 2008): Electrical Engineering (1), Instruments (2), Chemistry (3), Mechanical Engineering (4) and Other (5).

The fDi Markets database collects detailed information on ex-novo and expansion investments worldwide since 2003. fDi Markets data are based on cross-border investment announcements by relying on media sources and company data. The database is continuously

[1]The 21 OECD countries included in this study are: Australia, Austria, Belgium, Canada, Czech Republic, Finland, France, Germany, Greece, Hungary, Ireland, Italy, South Korea, Luxemburg, the Netherlands, Norway, Slovak Republic, Spain, Sweden, the United Kingdom, and the United States. Due to missing data, we excluded 9 regions (2 Canadian regions, 2 Spanish autonomous regions and the Canary Islands, 2 Italian autonomous provinces, and Alaska and Hawaii in the US).

[2] For most European countries, TL2 and TL3 correspond to Eurostat NUTS 2 and 3 classifications, respectively.

revised. This insures that only investments announced *and* actually realized are retained in the database. For each investment project, fDi Markets reports the investing company's name and address, the leading industry sector of the investment, the description of the foreign activity, and destination countries, regions and cities.

For the purpose of this study, we focus on R&D investments in manufacturing in medium and low technology-intensive sectors by converting the sectors provided by the fDi Markets database into the OECD classification (Hatzichronoglou, 1997) based on sector R&D intensity (i.e., high, medium-high, medium-low, and low technology sectors). In particular, we focus on medium-high, medium-low, and low technology-intensive sectors, where emerging countries have already matured technological capabilities (Ramamurti, 2009). Due to small numbers, we aggregated these sectors in a single one.

To operationalize the distinction between *research*, *development* and *adaptation* proposed by the studies on R&D globalization (Dunning, 1993; Hood and Young, 1982; Pearce and Singh, 1992; Pearce and Papanastassiou, 1999; Ronstadt, 1977), we surveyed this literature, indentified critical keywords and ran a manual keyword search on the description of the investment provided in the fDi Market database. When the description was incomplete, we integrated the information provided with online information and business databases (such as company web sites and Lexis Nexis). In particular, first we identified R&D laboratories carrying out locally *research* activity where "basic", "scientific", "fundamental", "frontier technology" research and application of such research are explored. In this category, we also included R&D laboratories described as "hub", "centre of excellence", or part of a "global" network of R&D centers, for the strategic importance of their activity within the MNC's R&D network (Hood and Young, 1982; Pearce and Papanastassiou, 1999). Second, we identified R&D laboratories locally carrying out *development* activity in terms of "development" and "solutions" of products or processes already oriented to market (Dunning and Narula, 1995; Hood and Young, 1982; Ronstadt, 1977). Finally, we identified R&D laboratories locally carrying out product and process *adaptation* where current products or technologies are adjusted to the local "customer needs". Also R&D laboratories that "support" local sales and marketing, and provides "technical services" falls into this category (Dunning and Narula, 1995). In the few cases where an R&D laboratory carries out multiple R&D activities, we classified the laboratory in the higher value-added category so that each R&D facility is classified in one of the three mutually exclusive categories. In particular, this criterion applies to 12 R&D laboratories carrying out both *research* and *development* (9.3% of total R&D FDI), and 13 R&D laboratories carrying out both *development* and *adaptation* (10% of total

R&D FDI). No foreign R&D laboratory carries out both *research* and *adaptation*, and none of the R&D laboratories in the sample carries out the three R&D activities jointly. The rational underlying this classification is that in foreign R&D units carrying out multiple R&D activities the core activity is likely to be the one with the highest added value for which the laboratory owns appropriate capabilities.

Finally, we rely on the OECD RDB for socio-economic indicators (e.g., demographic statistics, regional labor market, and innovation indicators). We combined the three data sources by relying on information on the home region of the investing firm provided in fDi Markets. Once identified the home region from which the R&D investment originally departed, we linked the fDi Markets information with the patents and socio-economic information available in REGPAT and OECD RBD, respectively.

4. The Model

Following Griliches's (1979) and Jaffe's (1989), we estimate a knowledge production function (KPF) in the form of a two-factor Cobb–Douglas production function which relates an output measure for 'knowledge' to input measures. Traditionally, studies using the KPF focus on R&D expenditure and university research as input measures, and firms and geographical locations of firms (countries or sub-national territorial entities) (Jaffe, 1989) as the unit of analysis. For the purpose of this study, we follow Jaffe (1989) and a large subsequent literature (Acs et al., 2002; Anselin et al., 1997; Bode, 2004; Fritsch and Slavtchev, 2008), and adopt TL2 regions as the unit of analysis. We consider R&D investments in *research*, *development* and *adaptation* to foreign countries as main inputs, controlling for other local sources of knowledge. Thus, the regional knowledge production function (RKPF) we estimate analytically is

$$\log K_{rt} = \alpha + \beta \log R\&D\ offshoring_{krt-1} + \gamma \log Z_{rt-1} + \varepsilon_r \quad (1)$$

where K is a proxy for the knowledge of region r at time t, $R\&D\ offshoring_k$ indicates the number of R&D investments carry out by region r in the k type of R&D activities (with k equals to *research*, *development* and *adaptation*), and Z typically includes a measure of the innovation-related characteristics within region r. The last three terms refer to $t-1$. The parameters β and γ are output elasticities. Positive and significant coefficients of β and γ indicate positive effects of different inputs on regional knowledge production. The traditional measures of regional knowledge are innovation counts or patents (Acs et al., 2002; Anselin et al., 1997; Baptista and Swann, 1998; Bode, 2004; Fritsch and Slavtchev, 2008; Jaffe, 1989). Although patents have several shortcomings (Griliches, 1979), we use the number of patents as an indicator of regional innovation. In particular we take the fractional count of PCT applications aggregated by the region *r* of residence of the inventor in year 2006-2007 (2-year average) normalized by thousand inhabitants, and transform it in logarithm and. Therefore, for each region we count the share of patents owned by the inventors resident in that region by thousand inhabitants. No regions have zero patents. The fractional counts render the dependent variable more similar to a continuous than a discrete variable. Also, the transformation in logarithm of the dependent variable shows skewness and kurtosis values close to a normal distribution (skewness is 1.66 and kurtosis 6.07), thus taking care of the censoring problems that can arise when dealing with patents.

As knowledge production emerges as a result of firms not innovating in isolation and is affected by several spatially bounded elements (Lundvall, 1992), we introduce a set of exogenous variables calculated for the period 2003-2005 and expressed in logarithms to account for the systemic regional characteristics of knowledge production. Following prior studies (Sterlacchini, 2008), we included regional population density (*density*) to proxy for agglomeration economies. To capture a primary city effect, we introduced a binary variable (*capital*) that takes value 1 if the region hosts the country capital city, where R&D laboratories and firms' headquarters are usually located to be closer to government research centers with major in-house R&D activities (Feldman, 2003). To control for the role of local financial institutions to support the needs of innovative firms (Cooke et al., 1997), we use the share of employment in financial intermediation (*financial intermediation).* Lundvall (1992) highlights also the significance of R&D organization in innovation systems. While in the past knowledge production was mainly the result of internal R&D laboratories' efforts, now knowledge production increasingly relies on a more open innovation process (Chesbrough, 2003) where firms collaborate with external actors. The rise in international technological partnerships shows that these collaborations tend to be cross-borders (e.g. Narula and Hagedoorn, 1999). Therefore, we control for international inter-regional collaboration by including the share of patents with multiple inventors, at least one of whom is located in a different country (*international cooperation*). In addition to Lundvall's (1992) elements, we considered the role of education and training as suggested by Freeman (1987) and introduced the labor force's share with tertiary level education (*human capital*) as a proxy for human capital. Although the focus of our research is on external sources, the contribution of the region's industry and universities to regional knowledge production is taken into consideration in line with the literature on KPF (Acs et al., 2002; Anselin et al., 1997). Thus, we include two additional variables for the regional shares of industry (*R&D business*) and university R&D expenditure (*R&D university*). To take account of the effect of R&D offshoring departing from region r in other (non medium and low technology-intensive) manufacturing sectors on regional knowledge production we include the number of R&D investments offshored in high technology-intensive sectors (*high-tech R&D offshoring*). We also control for the number of inward R&D investments in each region (*inward R&D FDI*) to account for agglomeration of innovative activities that may contribute to regional knowledge production (Santangelo, 2000, 2002). To consider the different propensities among regions to patent across technologies (Arundel and Kabla, 1998; Scherer, 1983), we introduced the adjusted revealed technological advantage (RTA), which accounts for regional relative specialization in each of the five groups of technologies based on the patent IPC codes ($adjRTA_j$ where j=(1), (2), (3), (4), and (5)):

$$adjRTA_{rj}=(RTA_{rj}-1)/(RTA_{rj}+1) \quad (2)$$

where $RTA_{rj}=(P_{rj}/\sum_j P_r)/(\sum_r P_{rj}/\sum_{rj} P_{rj})$ and P_{rj} is the number of patents in region r in the technology group j. Thus, this index gives the share of patents in region r in the technology group j (numerator), weighted by the share of patents in all the regions in technology group j, on all the patents in the sample (denominator). Values close to +1(-1) represent comparative technological advantage (disadvantage) of region r in the technology group j. We also include a binary variable for home regions in G7 economies (*G7 home*).

Table 1 reports the correlation matrix and descriptive statistics for the variables included in the econometric analysis.

[Table 1 about here]

To reinforce the efficiency of our estimations, we apply a spatial econometric technique (Acs et al., 2002; Moreno et al., 2005). With cross-sectional data for geographically close units of observations, it is very likely that the innovation output of each region will be correlated to innovation performed in neighboring regions (i.e. the error terms are correlated across observations). Spatial autocorrelation causes the inefficiency of OLS estimator, although it leaves the coefficients unbiased (Anselin, 1988). Accordingly, we test for the presence of misspecification by a Moran's I test using a binary contiguity matrix. The contiguity matrix captures spatial dependency for regions sharing a border. We built the binary contiguity matrix manually to include islands[3] and to take account of non-contiguous

[3]These regions include: Prince Edward Island in Canada; Sicily, Sardinia, Corsica, the Greek Archipelago and the Balearic Islands in the Mediterranean Sea; and Åland in Finland.

regions which are separated by few kilometers width of sea- or lake-water (e.g., the French region of Calais and the British region of Dover, and the US and Canadian states along the Great Lakes). This approach was motivated by the argument that the weights should be chosen on the basis of the structure of dependence, rather than on a simple pre-packaged description of the spatial relation (Anselin, 1988). Therefore, although we use the simplest weights to account for spatial effects, we want also to account for the obvious geographical proximity among regions without a common border. Moran's index of spatial correlation rejects the null hypothesis that patents from contiguous regions are independent ($p \leq 0.01$ level of significance). Therefore, we searched for the most appropriate functional form to model spatial dependence using a set of Lagrange Multiplier tests on the OLS results (i.e. the LM-LAG and the LM-ERR) using the binary contiguity matrix in order to indentify the most appropriate functional form. One form used in applied empirical work is the spatial lag model, expressed as

$$\log K_{rt} = \alpha + \beta \log R\&D\ offshoring_{krt-1} + \gamma \log Z_{rt-1} + \rho\ W \log K_{rt} + \varepsilon_r \qquad (3)$$

where $WlogK_{rt}$ is the spatially lagged dependent variable for the weight matrix W and ρ is the spatial autoregressive coefficient. A positive and significant effect of this coefficient suggests that the knowledge production of region r is influenced by the knowledge production in neighboring regions. Another form of spatial dependence is often expressed as a spatial autoregressive process for the error term in a regression model. Analytically, this can be reported as:

$$\log K_{rt} = \alpha + \beta \log R\&D\ offshoring_{krt-1} + \gamma \log Z_{rt-1} + \varepsilon_{\mathrm{r}} \qquad (4)$$

with

$$\varepsilon_r = \lambda\ W \varepsilon_r + u_r \qquad (5)$$

where λ is the spatial autoregressive coefficient and u_r is the spherical error term. W is the weight matrix. The LM tests do not show remarkable difference between the lag and the error model. We decided to adopt the lag model (equation 3) because it gives additional information about the impact of neighboring regions' patents through the coefficient ρ.[4]

5. Complementarity test

The purpose of our analysis is to test whether the different value-added R&D activities are complementary in terms of knowledge production of the investing home region

[4] For reasons of space, the OLS estimates and LM tests are not shown, but are available upon request.

when each of these activities is optimally located across borders. The continuous variables capturing the number of foreign R&D investment in *research*, *development* and *adaptation* (*R&D offshoring*$_k$) display a skewed distribution with many regions showing zero R&D investments.[5] *R&D offshoring*$_k$ can be regarded as a rare event, where the presence of one investment is a sign of R&D offshoring activity. This feature of the variables induced us to work with discrete variables to test complementarity, which implies that we cannot introduce an interaction term in the regression framework to test for the sign of the interaction parameter. Instead, we derive an inequality constraint drawing on the theory of supermodularity and test this constraint on our dataset.

As discussed above, the concept of complementarity refers to the simultaneous presence of specific elements (e.g. different R&D activities) which are mutually reinforcing. More formally, following Milgrom and Roberts (1990), in the case of two elements complementarity can be defined as follows:

Definition: *Let A and B be two activities. Each activity can be performed (A=1) or not performed (A=0). The function F(A, B) is supermodular and A and B are said to be complements only if:*

$$F(1,1) - F(0,1) \geq F(1,0) - F(0,0) \qquad (6)$$

The right-hand side of equation (6) defines the marginal increase from performing only activity A ($F(1,0)$) rather than neither activity ($F(0,0)$). The left-hand side describes the marginal increase from performing both activities ($F(1,1)$) rather than only B ($F(0,1)$). Hence, equation (6) states that the marginal increase of adding one activity (i.e. A), when already performing the other (left-hand side), is higher than the marginal increase from performing only one activity (right-hand side). This productivity (direct) approach is alternative to the adoption (indirect) approach based on the correlation of the residuals in the reduced-form (Arora and Gambardella, 1990), which suffers from the omission of exogenous variables (Arora, 1996; Athey and Stern, 1998). When testing the complementarity between different R&D activities departing from the region in question, the productivity approach is a direct test whether the RKPF of equation (3) is supermodular (Belderbos and Sleuwaegen, 2007; Milgrom and Roberts, 1990; Mohnen and Röller, 2005).

To implement this test, we generated three binary variables, R, D and A. The first takes value 1 if *R&D offshoring*$_{research}$ is greater than 1 and accounts for 21 regions carrying

[5] Skewness and kurtosis values for R&D offshoring distribution are respectively 4.85 and 30.96 for *R&D offshoring*$_{research}$, 5.34 and 37.46 for *R&D offhsoring*$_{development}$, and 3.40 and 35.91 for *R&D offshoring*$_{adaptation}$, respectively. These values are well above those of a normal distribution.

out at least one investment in *research* (50% of investing regions). The second variable equals 1 if *R&D offshoring*$_{development}$ is greater than 1 and accounts for 30 regions carrying out at least one investment in *development* (71% of the investing regions). The third variable takes value 1 if *R&D offhsoring*$_{adaptation}$ is greater than 1 and accounts for 17 regions (40% of the investing regions).

Carree et al. (2011) show that the indirect approach can be applied to more than two complements. However, due to missing observations we are not able to work with the triple category *RDA* as suggested by Carree et al. (2011). Therefore, we proceeded by testing the complementarity between each pair of R&D activities in three different specifications of equation (3). In each specification, we account for the excluded category by introducing a binary variable. In particular, using the dummies *R*, *D*, and *A* we construct all possible combinations between pairs of R&D activities (i.e. *RD*, *DA*, and *RA*), and end up with three groups of four categories each. In addition, we qualified these three groups by accounting for host country R&D activity-specific advantage in order to identify the optimal location for each R&D activity. To this end, we computed the adjusted revealed attractiveness advantage (*RAA*) index in each of the three types of R&D activities for the most advanced countries such as the G7, other advanced countries such as the other OECD countries, and China and India, which are the top destinations of R&D offshoring among non-OECD countries. Pearce (1999) indeed documents that host country advantage determines the type of incoming R&D activities. Specifically, we calculated the *RAA* index as follows:

$$RAA_{ik} = \frac{(FDI_{ik}/\sum_k FDI_i)/(\sum_i FDI_{ik}/\sum_{ik} FDI_{ik})-1}{(FDI_{ik}/\sum_k FDI_i)/(\sum_i FDI_{ik}/\sum_{ik} FDI_{ik})+1} \quad (7)$$

where FDI_{ik} is the number of inward R&D investments in the period 2003-2005 received by group of countries i (with i equal to G7, other OECD countries, and China and/or India) and in R&D activities k. Table 2 shows the adjusted *RAA*. As expected, G7 countries are specialized in the highest value-added R&D activities (i.e. *research*) (*RAA* = 0.22). Other OECD countries are relative more appealing destinations in intermediate value-added R&D activities such as *development* (*RAA*= 0.05). Finally, China and India are specialized in *adaptation* (*RAA* = 0.20).

[Table 2 about here]

The RKPF of equation (3) can then be refined as follows:

$$\log K_{rt} = \alpha + \theta C_{rt-1} + \gamma \log Z_{rt-1} + \rho\, W \log K_{rt} + \varepsilon_r \quad (8)$$

where C_{rt-1} denotes all possible combinations of each pair of complements *RD*, *DA*, and *RA* in the host countries showing R&D activity-specific advantage of region r at time t-1. θ is the vector of the coefficients of the combinations C_{rt-1}. The test of complementarity is based on the following null hypothesis:

$$\theta_{11} - \theta_{10} \geq \theta_{01} - \theta_{00} \quad (9)$$

where for each pair the first subscript refers to the higher value-added R&D activity and the second subscript refers to the lower value-added R&D activity. As mentioned above, to account for the excluded category in each specification of equation (8) *Z* also includes a binary variable measuring the investments in the excluded category in the specialized group of host countries. That is, *R in G7*, *D in other OECD* and *A in China/India*.

The complementarity test is a Wald χ^2 one-sided test run in two steps. The first step tests the null hypothesis of equality. If the null is rejected, then the second step tests the null of submodularity *versus* supermodularity (i.e. complementarity). Thus, a significant Wald χ^2 one-sided test in the second step reveals the existence of complementarity since the test rules out that performing only one R&D activity has a lower effect on the investing home region's knowledge production than performing jointly two R&D activities.[6]

6. Results

Table 3 shows the estimations of the regional production function in equation (8). Columns 1 to 3 present the results for the pair *RD*, *DA*, and *RA* models, respectively.

[Table 3 about here]

In line with the innovation system literature (Lundvall, 1992) a number of controls produce statically significant results. In model 1, the variable C_{11} (which in this model corresponds to the joint offshoring of *research* and *development* in G7 and other OECD countries, respectively) is large and statistically significant. In model 2, the variables C_{10} and C_{01} (which in this model correspond to offshoring of *development* in other OECD but not of *adaptation* in China and India, and offshoring of *adaptation* in China and India but not of *development* in other OECD, respectively) are negative and statistically significant. In all three models, the magnitudes and signs of these coefficients are in line with the hypothesis of complementarity.[7] The last row in Table 3 shows the direct Wald χ^2 one-sided test of

[6]We test the inequality constrains in STATA following the procedure described at http://www.stata.com/support/faqs/stat/oneside.html

[7]In all specifications, the combination C_{00} is dropped due to collinearity. An alternative solution to the collinearity problem would be to drop the constant in the models estimated. However, the spatreg STATA command used here does not allow this option. Consequently, our complementarity test is performed on three (C_{11}, C_{10}, and C_{01}) of the four categories, according to the following rule:

complementarity for each of the three models and its significance. In line with our argument, in these models the synergic effects of geographical fragmented R&D slices emerge. In model 1, regions carrying out *research* in G7 countries and *development* in other OECD countries are more innovative than regions carrying out only *research* or only *developmen*t in each of these groups of countries ($p \leq 0.01$). In model 2, regions carrying out *development* in other OECD and *adaptation* in China and/or in India are more innovative than regions carrying out only one the two R&D activities ($p \leq 0.01$). In model 3, we also found a complementarity effect between *research* offshored in G7 countries and *adaptation* in China and/or India ($p \leq 0.05$).

To check the robustness of our argument, we re-build the categories *RD*, *DA*, and *RA* when R&D activities are randomly offshored. Table 4 shows the estimations of the RKPF in equation (8) without accounting for host location R&D activity-specific comparative advantage. In these models, a set of controls for groups of destination countries of R&D investments is used to account for the idiosyncrasies of the host economies considered (e.g., country R&D intensity or weak Intellectual Property Rights regime) which might affect the R&D offshoring location choice (Lall, 2003) and MNCs' technology strategies (Zhao, 2006) In particular, each of the variables measures the number of R&D investments offshored from OECD regions and hosted by G7, other OECD countries, and China and/or India in the *C* pair of R&D activities (i.e. $G7_C$, $Other\ OECD_C$, and $China/India_C$, where *C* equals *RD*, *DA*, and *RA*). Like in previous estimations, in each model we control for the excluded category by with the variables *R*, *D* and *A*, which in these estimations account for investments in *research*, *development* and *adaptation* R&D activities randomly offshored. Unlike in previous estimations, in the estimations reported in Table 4 in some OECD regions pairs of R&D activities are randomly offshored by the same firm. To account for greater intra-firm efficiency in managing these pairs of offshoring R&D activities, in each of these models we include three variables which equals the number of firms headquartered in region *r* that offshore R&D in the relevant pair of activities ($intra\text{-}firm_{RD}$, $intra\text{-}firm_{DA}$ and $intra\text{-}firm_{RA}$).

[Table 4 about here]

Columns 1 to 3 present the results for the pair *RD*, *DA*, and *RA* models, respectively. Among the combinations of R&D activity pairs, only the variable C_{11} (joint offshoring of *development*

$$\theta_{11} - \theta_{10} \geq \theta_{01} \qquad (9^*),$$

However, if we take C_{00} as the benchmark for the other three dummies, tests involving 4 (Equation 9) and 3 (Equation 9*) dummies are equivalent.

and *adaptation*) in Model 5 is statistically significant. The last row in the table shows the direct Wald χ^2 one-sided test of complementarity for each of the three models and its significance. In line with our argument no synergic effects emerges when the R&D activities are randomly located across borders. Thus, regions carrying out pairs of R&D activities do not gain additional innovative capacity by comparison with regions carrying out only one R&D activity of the pair.

7. Conclusions

The recent R&D offshoring in emerging countries has promoted a greater geographical fragmentation of R&D activity. Extant research on R&D offshoring suggests a fine-slicing of R&D activities based on a subtle international division of labor in knowledge generation with the highest value–added R&D activities located in the most advanced countries and the lowest value-added R&D activities in emerging countries (Contractor et al., 2010; Demirbag and Glaister, 2010). This strategy is primarily motivated by synergies across R&D activities and locations which allegedly enhance knowledge production at home. We contribute to this stream of research and test whether the fine slicing of R&D produces a synergic effect on the knowledge production of investing OECD home regions when each slice is optimally located across countries. In particular, we distinguish between *research*, *development* and *adaptation,* and identify G7, other OECD, and China and India as optimal locations for each of these activities, respectively. Drawing on the theory of supermodularity, we test the complementarity between these activities in terms of knowledge production of the investing home region. Our analysis shows that synergic effects between different R&D activities on the investing home region knowledge production materialize when finely sliced R&D activities are optimally located across countries. Our regional level analysis is motivated by the RSI literature that recognizes the region as a valuable unit of observation to investigate the spatially-bounded and systemic nature of knowledge production.

We offer two contributions. First we advance research on R&D offshoring which has so far documented the location of R&D activities in emerging countries. However, these studies have poorly analyzed empirically the effects of the greater geographical fragmentation of R&D on home knowledge production. Our study provides empirical evidence of the synergic effects across finely sliced R&D activities when these activities are optimally located. We also contribute to the international knowledge sourcing literature by extending the argument of the geographical R&D hierarchy (Cantwell and Janne, 1999). In particular, our study suggests a more complex hierarchy involving both locations and specific R&D activities. The argument of the geographical R&D hierarchy contends that firms rank locations when geographically allocating their R&D. Our analysis pushes this argument further by suggesting a more finely grained ranking of R&D locations by MNCs. Specifically, we suggest that firms finely slice their R&D depending on location R&D activity-specific comparative advantage in order to enjoy synergic effects along the hierarchy. In addition, we show that MNCs now rank also emerging countries when selecting R&D destinations. This implies that these new players participate to global innovation networks as successfully hosts of selected R&D activities that synergically contribute to knowledge production at home.

As any empirical study, our analysis suffers from a number of limitations that may guide the research agenda in the field. In particular, the unit of analysis can be further refined by conducting a firm-level study. Nonetheless, as a first attempt and considering the RSI literature, our analysis offers preliminary evidence on the issue at hand and may provide some guidance for future micro studies. Similarly, the R&D function may be more finely sliced in order to have a more accurate understanding of the phenomenon. This would clearly require more detailed information that can be possibly collected through survey techniques. Finally, host locations are far to offer homogeneous R&D activity-specific advantages within their borders. Thus, a further direction along which to develop our analysis is to consider sub-national units within destination countries to investigate in greater details optimal localization strategies of specific R&D activities.

Figure 1
The fine-slicing and optimal global allocation of R&D activities

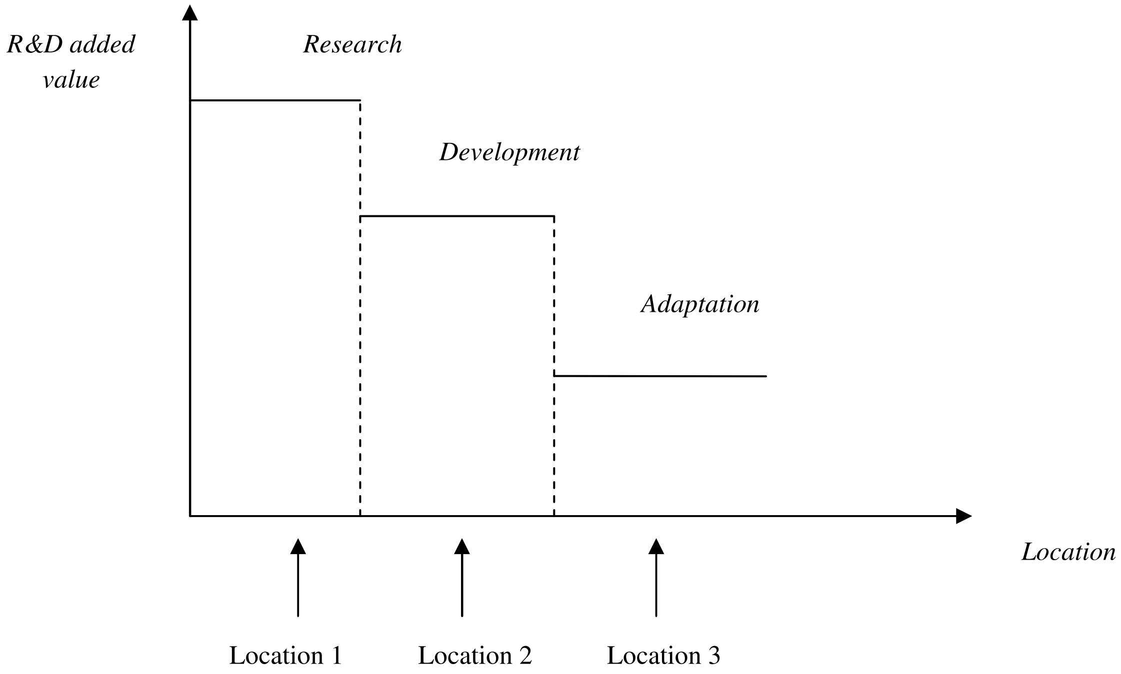

Table 1
Correlation matrix and descriptive statistics

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 K	1																	
2 density	0.136**	1																
3 capital §	0.128*	0.426***	1															
4 financial intermediation	0.500***	0.384***	0.496***	1														
5 international cooperation	-0.158**	0.152**	0.172**	-0.075	1													
6 human capital	0.318***	-0.042	0.339***	0.411***	-0.041	1												
7 R&D business	0.400***	0.061	-0.070	0.207***	0.046	0.045	1											
8 R&D university	-0.316***	-0.148**	-0.050	-0.198***	0.133**	-0.089	-0.433***	1										
9 high-tech R&D offshoring	0.509***	0.225***	0.219***	0.495***	-0.126*	0.254***	0.207***	-0.241***	1									
10 inward R&D FDI	0.279***	0.270***	0.204***	0.345***	0.164**	0.294***	0.270***	-0.117*	0.387***	1								
11 adjRTA$_{(1)}$	0.421***	0.037	0.237***	0.372***	-0.147**	0.268***	0.113*	-0.306***	0.371***	0.247***	1							
12 adjRTA$_{(2)}$	0.166**	0.019	-0.005	0.274***	-0.027	0.117*	0.037	0.032	0.107	0.087	0.058	1						
13 adjRTA$_{(3)}$	-0.124*	0.195***	0.078	0.207***	0.061	0.080	-0.075	0.156**	0.028	0.118*	-0.311***	0.045	1					
14 adjRTA$_{(4)}$	-0.291***	-0.075	-0.208***	-0.427***	0.201***	-0.261***	0.034	0.118*	-0.367***	-0.174***	-0.523***	-0.265***	-0.327***	1				
15 G7 home §	0.062	0.003	-0.192***	0.366***	-0.194***	-0.010	-0.036	0.138**	0.174***	0.073	0.078	0.31***	0.170**	-0.152**	1			
16 R in G7 §	0.191***	0.186***	0.152**	0.189***	0.076	0.113*	0.088	-0.026	0.312***	0.268***	0.141**	0.099	-0.031	-0.035	0.053	1		
17 D in other OECD §	0.198***	0.041	0.089	0.221***	-0.033	0.116*	0.151**	-0.116*	0.360***	0.183***	0.162**	0.033	-0.015	-0.079	0.175***	0.175***	1	
18 A in China/India §	0.199***	0.156**	0.209***	0.282***	-0.033	0.129*	0.138**	-0.137**	0.363***	0.260***	0.091	0.003	0.101	-0.073	0.110	0.250***	0.479***	1
Mean	*0.097*	*4.364*	*0.095*	*0.126*	*1.890*	*3.195*	*3.917*	*3.121*	*0.309*	*0.681*	*-0.236*	*-0.099*	*-0.031*	*0.077*	*0.579*	*0.045*	*0.041*	*0.050*
Standard Deviation	*0.086*	*1.548*	*0.294*	*0.041*	*0.624*	*0.338*	*0.582*	*0.791*	*0.709*	*0.812*	*0.268*	*0.233*	*0.211*	*0.227*	*0.495*	*0.208*	*0.198*	*0.218*

Significant at *** $p \leq .01$; ** $p \leq .05$; * $p \leq .10$.
§ Dummy

Table 2
Revealed attractiveness advantage, by R&D activity and group of country

Country	***R&D activity***		
	Research	*Development*	*Adaptation*
G7	0.22	-0.02	-0.32
Other OECD	0.06	0.05	-0.22
China and India	-0.3	-0.02	0.2

Table 3
Econometric results

	Model 1			Model 2			Model 3		
Complements	*RD*			*DA*			*RA*		
Dependent variable	K			K			K		
	Coef.		St. Er.	Coef.		St. Er.	Coef.		St. Er.
C_{11}	0.095	**	(0.044)	0.020		(0.027)	0.040		(0.036)
C_{10}	-0.029		(0.021)	-0.074	**	(0.029)	-0.030		(0.022)
C_{01}	-0.036		(0.023)	-0.059	**	(0.024)	-0.036		(0.022)
Controls									
density	0.006	**	(0.003)	0.007	**	(0.003)	0.006	**	(0.003)
capital	-0.036	*	(0.019)	-0.037	**	(0.019)	-0.033	*	(0.019)
financial intermediation	0.618	***	(0.163)	0.639	***	(0.163)	0.616	***	(0.165)
international cooperation	-0.011	*	(0.006)	-0.014	**	(0.006)	-0.012	*	(0.006)
human capital	0.023	*	(0.013)	0.020		(0.013)	0.024	*	(0.013)
R&D business	0.022	***	(0.007)	0.022	***	(0.007)	0.023	***	(0.008)
R&D university	0.004		(0.005)	0.006		(0.005)	0.004		(0.005)
high-tech R&D offshoring	0.025	***	(0.007)	0.025	***	(0.007)	0.025	***	(0.007)
inward R&D FDI	0.001		(0.005)	0.000		(0.005)	0.001		(0.005)
$adjRTA_{(1)}$	0.027		(0.022)	0.030		(0.022)	0.026		(0.023)
$adjRTA_{(2)}$	0.015		(0.018)	0.017		(0.018)	0.016		(0.018)
$adjRTA_{(3)}$	-0.071	***	(0.025)	-0.071	***	(0.025)	-0.071	***	(0.025)
$adjRTA_{(4)}$	-0.046	*	(0.027)	-0.042		(0.027)	-0.044		(0.027)
G7 home	-0.031	***	(0.010)	-0.034	***	(0.010)	-0.031	***	(0.010)
R in G7				-0.013		(0.019)			
D in other OECD							-0.019		(0.022)
A in China/India	-0.029		(0.021)						
constant	-0.183	***	(0.063)	-0.178	***	(0.063)	-0.184	***	(0.064)
Rho constant	0.093	***	(0.014)	0.097	***	(0.014)	0.089	***	(0.014)
Sigma constant	0.054	***	(0.002)	0.054	***	(0.002)	0.055	***	(0.002)
Number of obs.	*221*			*221*			*221*		
Complementarity test: $C_{11} \geq C_{10} + C_{10}$									
***Wald* (one-side)**	10.44 ***			11.62***			5.84***		

Significant at *** $p \leq .01$; ** $p \leq .05$; * $p \leq .10$.

Table 4
Robustness check

	Model 4			**Model 5**			**Model 6**		
Complements	*RD*			*DA*			*RA*		
Dependent variable	K			K			K		
	Coef.		St. Er.	Coef.		St. Er.	Coef.		St. Er.
C_{11}	0.003		(0.032)	0.065	**	(0.032)	-0.020		(0.042)
C_{10}	0.005		(0.023)	0.035		(0.022)	-0.025		(0.022)
C_{01}	0.001		(0.023)	0.004		(0.029)	-0.037		(0.026)
Controls									
density	0.006	**	(0.003)	0.007	**	(0.003)	0.007	**	(0.002)
capital	-0.033	*	(0.019)	-0.042	**	(0.018)	-0.034	*	(0.018)
financial intermediation	0.555	***	(0.169)	0.669	***	(0.167)	0.584	***	(0.160)
international cooperation	-0.012	*	(0.006)	-0.011	*	(0.006)	-0.012	**	(0.006)
human capital	0.025	*	(0.013)	0.026	**	(0.013)	0.025	*	(0.013)
R&D business	0.022	***	(0.008)	0.023	***	(0.007)	0.022	***	(0.007)
R&D university	0.004		(0.005)	0.006		(0.005)	0.007		(0.005)
high-tech R&D offshoring	0.000		(0.005)	-0.002		(0.005)	0.000		(0.005)
inward R&D FDI	0.027	***	(0.007)	0.020	***	(0.006)	0.022	***	(0.007)
$adjRTA_{(1)}$	0.034		(0.023)	0.029		(0.022)	0.038	*	(0.021)
$adjRTA_{(2)}$	0.018		(0.018)	0.020		(0.017)	0.024		(0.017)
$adjRTA_{(3)}$	-0.076	***	(0.025)	-0.066	***	(0.025)	-0.073	***	(0.024)
$adjRTA_{(4)}$	-0.036		(0.027)	-0.041		(0.026)	-0.042		(0.025)
G7 home	-0.030	***	(0.010)	-0.033	***	(0.010)	-0.034	***	(0.009)
R				0.000		(0.015)			
D							-0.019		(0.014)
A	0.014		(0.019)						
$G7_C$	-0.039	*	(0.020)	-0.057	***	(0.020)	-0.014		(0.024)
Other $OECD_C$	-0.045	**	(0.021)	-0.000		(0.023)	0.007		(0.025)
China/$India_C$	0.001		(0.022)	-0.060	***	(0.022)	0.031		(0.027)
intra-$firm_{RD}$	0.106	**	(0.049)						
intra-$firm_{DA}$				0.101	***	(0.033)			
intra-$firm_{RA}$							0.319	***	(0.067)
constant	-0.175	***	(0.064)	-0.201	***	(0.063)	-0.182	***	(0.061)
Rho constant	0.088	***	(0.014)	0.082	***	(0.014)	0.085	***	(0.014)
Sigma constant	0.054	***	(0.002)	0.053	***	(0.002)	0.052	***	(0.002)
Number of obs.	*221*			*221*			*221*		
Complementarity test: $C_{11} \geq C_{10} + C_{10}$									
***Wald* (one-side)**	0.01			0.44			1.64		

Significant at *** $p \leq .01$; ** $p \leq .05$; * $p \leq .10$.

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