Paper to be presented at the DRUID 2012

on

June 19 to June 21

at

CBS, Copenhagen, Denmark,

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

Lorena M. D'Agostino
University of Catania

ldagosti@unict.it

Grazia D Santangelo
University of Catania

graziasantangelo@gmail.com

Abstract

R&D activities are increasingly fragmented across borders and offshored in emerging economies. This trend questions the innovation performance of advanced country regions. However, the effects of the global R&D fragmentation on the knowledge production of the investing home regions are still unexplored. We aim to fill this gap and investigate under what conditions synergic effects between different value-added R&D activities globally offshored on the knowledge production of the OECD investing home region rise. To this end, we estimate a regional knowledge production function and apply a direct complementarity test. Our results suggest that synergies materialize when each R&D activity is offshored optimally rather than randomly.

Jelcodes:O32,R11

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

Lorena M. D'Agostino and *Grazia D. Santangelo*
Facoltà di Scienze Politiche
University of Catania
Via Vittorio Emanuele, 8
95131 Catania
Italy
Email: ldagosti@unict.it; grsanta@unict.it

words count 10,353

R&D activities are increasingly fragmented across borders and offshored in emerging economies. This trend questions the innovation performance of advanced country regions. However, the effects of the global R&D fragmentation on the knowledge production of the investing home regions are still unexplored. We aim to fill this gap and investigate under what conditions synergic effects between different value-added R&D activities globally offshored on the knowledge production of the OECD investing home region rise. To this end, we estimate a regional knowledge production function and apply a direct complementarity test. Our results suggest that synergies materialize when each R&D activity is offshored optimally rather than randomly.

Keywords: R&D activities fragmentation, R&D optimal location, home region knowledge production, emerging countries

JEL-classifications: R12, O32, C2

1. Introduction

R&D offshoring increasingly targets fast-growing emerging economies as appealing host locations, (Ito and Wakasugi, 2007; Manning et al., 2008). Although developed economies still remain the major source of R&D offshoring, fast-growing emerging economies, and especially China and India have become the top destinations of R&D investments (EIU, 2004). The share of R&D sites of US multinational corporations (MNCs) has declined at home, while increasing in China and India (Atkinson, 2007). 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). This rise of fast-growing emerging economies as favorite R&D host locations has promoted a greater geographical fragmentation of R&D, which follows an international division of labor in knowledge production (Lewin et al., 2009). The contribution of R&D offshoring in fast-growing emerging economies to knowledge production critically varies across technologies and R&D activities (D'Agostino et al., 2010; D'Agostino and Santangelo, 2012). More advanced economies focus on the development of more complex technologies, and fast-growing emerging economies of more mature technologies (Arora et al., 2001). In addition, a more subtle international division of labor is taking place within the R&D function whose parts are finely sliced and globally offshored (Lewin et al., 2009). The most advanced economies remain the favorite locations for the higher value-added R&D activities with low value-added R&D activities located in fast-growing emerging economies (Demirbag and Glaister, 2010; Schmiele, 2011; Thursby and Thursby, 2006). This trend results in a fragmentation of the R&D value chain across borders (Contractor et al., 2010) and questions the innovation performance of regions in advanced economies (Manning et al., 2008).

The regional systems of innovation (RSI) approach relies on the idea that spatially bounded knowledge spillovers as well as certain system-specific features make regions unique and innovative (Cooke, 1992). The regional perspective allows to capture the systemic and “open” aspect of knowledge production (Braczyk et al., 1998) and bears critical policy implications. However, scholars have documented an increasing interdependence of RSI in various countries and acknowledged that RSI are not self-sufficient, but need to internationalize over time (Asheim and Coenen, 2005; Cantwell and Iammarino, 2003; Carlsson, 2006; Howells, 1999). The tacit nature of knowledge and the spatial limits on knowledge spillovers increasingly call for offshoring R&D facilities to source new knowledge where it is created (Carlsson, 2006). Surprisingly, there has been little work done with a view toward internationalization of *systems* (Carlsson, 2006). This limit applies to the RSI especially (with the notable exception of Cantwell and Iammarino (2003)). In particular, the effects of the global fragmentation of R&D activities on advanced country regions remain still unexplored despite bearing critical policy implications.

The international knowledge sourcing literature has mostly investigated corporate innovative activity and documented that MNCs increasingly offshore their R&D facilities to enjoy at home critical synergies across foreign laboratories (Almeida, 1996; Cantwell, 1995; Gerybadze and Reger, 1999; Iwasa and Odagiri, 2004; Patel and Vega, 1999; Singh, 2008). In particular, MNCs rank foreign locations, and geographically disperse different types of foreign R&D laboratories depending on host location advantage (Cantwell and Janne, 1999; Kuemmerle, 1999; Pearce and Papanastassiou, 1999; von Zedtwitz and Gassmann, 2002). In addition, this literature has investigated the internationalization of innovative activity in relation to developed host locations, although more recently a number of studies at both corporate and regional level recognize the increasing involvement of fast-growing emerging economies as appealing host locations of R&D offshoring (Chaminade and Vang, 2008; Ito and Wakasugi, 2007; Manning et al., 2008).

We seek to advance RSI and international knowledge sourcing research and investigate under what conditions the global fragmentation of R&D activities improves the knowledge production of the investing home region. To this end, we focus on “captive” R&D offshoring (Kotabe and Murray, 2003; Lewin et al., 2009) and examine R&D activities offshored by MNCs headquartered in OECD regions to subsidiaries in different host locations including China and India, which are the top destinations of R&D investments (UNCTAD, 2005). We use the terms offshoring and internationalization interchangeably. In particular, our research question asks under what conditions synergic effects between different value-added globally offshored R&D activities on the knowledge production of the OECD investing home region materialize.

We argue that the home region’s innovative performance critically depends on the cross-country cross-activity patterns of the R&D offshored from the region. Specifically, synergies between different value-added R&D activities offshored from OECD regions will rise when each activity is offshored optimally rather than randomly. That is, different R&D “slices” complement each other and contribute to the knowledge production in the investing home region when located in host economies enjoying R&D activity-specific comparative advantage.

Our analysis estimate a regional knowledge production function (Acs et al., 2002) on a sample of 221 regions of 21 OECD economies from which different value-added R&D activities depart towards foreign destinations including China and India.

The paper is organized as follows. Section 2 develops the theoretical framework. Section 3 presents the method by discussing the data, the model and the complementarity test which we draw from Milgrom and Roberts (1990) to test synergies between different value-added R&D activities developed offshore. The results of the econometric analysis are presented in section 4. Finally, section 5 draws conclusions and discusses policy implications.

2. Theoretical framework

2.1 Regional systems of innovation and knowledge production

A premise to the innovation system approach is the spatially-bounded systemic and ‘open’ nature of knowledge production (Braczyk et al., 1998; Chesbrough, 2003; Jaffe et al., 1993; von Hippel, 1988). The RSI literature relies on the idea that regional borders (rather than national) better define innovation development through strongly interrelated local actors (Braczyk et al., 1998; Cooke, 2005; Cooke et al., 1997). In this perspective innovation is a collective process, whose actors are not only the firms, but also institutions, which define the pattern, nature and extent of knowledge accumulation within regional borders. Thus, this approach emphasizes the systemic dimension of knowledge production as the regional system provides a soft infrastructure that is conducive to interactive learning (Lundvall et al., 2006). Face-to-face interactions, institutional settings and infrastructures facilitate knowledge flows within regional borders (Asheim, 1996). Geographical proximity eases indeed knowledge codification and transmission, and, as a consequence, knowledge spillovers (Audretsch and Feldman, 1996; Jaffe et al., 1993) and clusters formation (Iammarino and McCann, 2006; Porter, 1990).

However, the self-reinforcing interaction between firms and infrastructures within geographically defined borders may result in structural inertia and system lock-in when the system cannot respond to extra-system innovation-related changes (Grabher, 1993; Narula, 2002). In particular, the spatially bounded nature of knowledge is a double-edge sword as RSI are not self-sufficient in terms of knowledge production and, as a result, need to become more internationalized over time (Asheim and Coenen, 2005; Cantwell and Iammarino, 2003; Carlsson, 2006; Howells, 1999). R&D facilities are indeed offshored where new knowledge is being created (Carlsson, 2006) and this knowledge is then reverse transferred to the home region (Mansfield and Romeo, 1984). Thus, “local and global circuits of interactive learning” (Malmberg, 2003, 157) are equally relevant for knowledge production. Innovation activity takes place increasingly with actors outside the region as global connections are indispensable for knowledge creation (Asheim and Coenen, 2005).

This argument gains great relevance in relation to the relocation of innovation activities in emerging economies. The large availability of science and technology talents, and the parallel upgrading of technological competences (Athreye and Cantwell, 2007; Manning et al., 2008) are promoting the rise of fast-growing emerging economies as knowledge producers. As a result, the need to access local talents and expertise motivate the effort of advanced country regions to participate in international “networks” across the world and become increasingly connected globally (Carlsson, 2006; Manning et al., 2008). Networks external to the region may indeed provide the necessary resources to keep up with the latest global developments (Giuliani and Bell, 2005; Malmberg, 2003; Manning et al., 2008). However, what conditions ensure beneficial effects of the R&D offshoring on advanced country regions remains an open question.

2.2. Global fragmentation of R&D

Recent studies on offshoring document a greater fragmentation of the value-chain functions (Contractor et al., 2010). In particular, the operations within each functions are finely sliced in different activities that are then geographically dispersed in selected locations (Mudambi, 2008). This phenomenon has concerned increasingly the R&D function (Lewin et al., 2009) that was traditionally regarded as a core function to be kept strategically in-house in the headquarter location (Patel and Pavitt, 1991). As a result, a more subtle international division of labor across R&D activities has emerged (Contractor et al., 2010).

In relation to the Western world, a well-established literature has documented that R&D activities are offshored to exploit host location activity-specific advantage in order to source complementary knowledge (Cantwell and Santangelo, 2000; Kuemmerle, 1999; Pearce and Papanastassiou, 1999; von Zedtwitz and Gassmann, 2002). These scholars have proposed an array of classifications of R&D activities primarily relying on the dichotomy augmenting “innovative” 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 processes, and *adaptation* to local customers’ needs (Dunning and Narula, 1995; Hood and Young, 1982; Le Bas and Sierra, 2002a; 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 generation 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 entry 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).

The distinctive feature of the current global fragmentation of R&D activities is the involvement of fast-growing emerging economies as knowledge providers in global value chains (Chaminade and Vang, 2008; Lewin et al., 2009). Increasingly, fast-growing emerging economies host R&D adaptation sites as a result of the growing local scientific and technological base, and technological upgrading. China and India, for example, are the top destinations of R&D offshoring among non-OECD countries and primarily host R&D investments aiming at *adaptation* of products and technologies (Gassmann and Han, 2004; von Zedtwitz and Gassmann, 2002).

2.3. Synergies between globally fragmented R&D activities

The global fragmentation of R&D activities is primarily motivated by the potential synergies between offshored activities, which can be enjoyed at home (Singh, 2008). These synergies materialize due to host location activity-specific advantage and the reverse transfer of different value-added “slices” of knowledge developed offshore to the investing home region.

The discussion developed above points out that the global fragmentation of innovative activities depends on an international division of labor increasingly based on activities’ added value. The modularization of knowledge (Chesbrough and Kusunoki, 2001) and the parallel rise of new players in knowledge production favor the location of higher value-added R&D activities in advanced economies, while the more operational and lesser value-added activities are offshored in fast-growing emerging economies (Demirbag and Glaister, 2010; Filippaios et al., 2009; Ito and Wakasugi, 2007; Schmiele, 2011).

The optimal location of each offshored R&D activity offers activity-specific relative advantage, which each foreign laboratory can reverse transfer to the parent in the investing home region (Mansfield and Romeo 1984). International knowledge sourcing requires indeed a dual embeddedness strategy of the MNC network. Foreign subsidiaries invest to strongly embed in the host country to source new knowledge, and typically the parent firm is embedded in the home region firmly to exploit the local resource endowment (Forsgren et al., 2005; Meyer et al., 2011; Rosenzweig and Singh, 1991). As a result of the “open” nature of knowledge creation (von Hippel, 1988), this dual embeddedness (at home and offshore) enables MNCs to acquire knowledge abroad, and spread and share this knowledge in their home region with local innovative organizations. Indeed, the optimal offshore location of different value-added R&D activities ensures strategic coherence and, as a result, the rise of synergies between internationally (reverse) knowledge inflows into the investing home region which enhance regional knowledge production. Hence the global fragmentation of the value chain parallels a local node, global network geography whereby regions rely on both local systemic relationships and international optimal knowledge inflows (Gertler and Levitte, 2005).

Figure 1 summarizes our argument. The vertical axis reports R&D added value and the horizontal axis R&D activity-specific optimal locations. As the added value of the foreign R&D activity declines, the host R&D activity-specific comparative advantage required to locate the activity optimally also declines. Synergic effects on the investing home region materialize when the highest value-added R&D activities (i.e. research) will be offshored in the most advanced economies such as the G7 countries, intermediate value-added R&D activities (i.e. development) will be offshored in other (non-G7) OECD countries and the lowest value-added R&D activities (i.e. adaptation) in fast-growing emerging economies such as China and India.

[Figure 1 about here]

3. Method

3.1 The data

Our sample refers to 221 regions in 21 OECD countries.[1] For these regions, we built a cross-sectional 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, 2002a). The PCT procedure enables applications for patent rights in multiple countries as alternative to direct applications to national/regional patent offices. In particular, the annual average growth rate of PCT applications that designate EPO is well above that of direct EPO application (Khan and Dernis, 2005). In addition, unlike the USPTO whose overall growth rate of patents is mainly due to US inventors (Khan and Dernis, 2006), EPO is generally considered non-bias toward a particular nation (Le Bas and Sierra, 2002b). EPO designated 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, respectively).[2] We adopt the TL2 level. 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

[1]Due to missing data, 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. Missing data also force us to 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) within these countries.

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

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 revised. This ensures 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. The OECD RDB provides socio-economic indicators for OECD regions.

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.

3.2 R&D activities classification

We focus on 346 R&D offshoring investments in manufacturing sectors originated from the 221 OECD regions between 2003 and 2005.

To operationalize the distinction between *research*, *development* and *adaptation*, we surveyed the studies on R&D globalization (Dunning, 1993; Hood and Young, 1982; Pearce and Singh, 1992; Pearce and Papanastassiou, 1999; Ronstadt, 1977), identified critical keywords and ran a manual keyword search on the description of the investment provided in the fDi Market database. 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. 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). When the description was incomplete, we integrated the information provided with online information and business databases (such as company web sites and Lexis Nexis). These few cases were coded by two researchers independently and the results of the individual coding compared. If there was a mismatch in the coding, further searches were undertaken by each researcher individually and the results compared once again. This process was iterated until agreement between the two researchers was reached. 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. Indeed, in foreign R&D units, the coexistence of different value-added activities is likely to reflect an evolution of the laboratory role within the MNC network (Ronstadt, 1978). 22 R&D laboratories carrying out both *research* and *development* (6.3% of total R&D offshoring investments), and 25 R&D laboratories carrying out both *development* and *adaptation* (7.2% of total R&D offshoring investments). 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.

71 laboratories were ultimately classified as *research* laboratories, 163 as *development* and 112 as *adaptation* laboratories. We are confident on the robustness of this classification as the final number of laboratories classified in each category does not replicate the distribution of the number of keywords across categories. *Development* is the largest category despite the smallest number of keywords used to identify these laboratories. It seems also reasonable that *development* is the largest category as in manufacturing sectors the transformation of a new product concept in the precise commercial form of the good, or the creation of the engineering details of its production process might entail the participation of several foreign laboratories with specialized research competences, access to distinctive local knowledge, and understanding of differentiated markets (Pearce and Papanastassiou, 1999).

3.3. The model

Following Jaffe (1989) and a large subsequent literature (Acs et al., 2002; Anselin et al., 1997; Bode, 2004; Fritsch and Slavtchev, 2008), we estimate a regional knowledge production function (RKPF). 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 RKPF we estimate analytically is

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

where K is a proxy for the knowledge of region r at time t, $R\&Doffshoring_k$ indicates the number of R&D investments carry out by region r in the k type of R&D activities (with k=*research*, *development* and *adaptation*), and Z includes a measure of innovation-related factors 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. Although patents have several shortcomings (Griliches, 1979), we draw on a large and established literature (Acs et al., 2002; Anselin et al., 1997; Baptista and Swann, 1998; Jaffe, 1989) and use the number of patents as an indicator of regional knowledge production. 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. 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 (1.66 and 6.07, respectively), thus taking care of potential censoring problems.

Knowledge production is the result of firms not innovating in isolation and is affected by several spatially bounded elements (Lundvall, 1992). To account for the systemic regional characteristics of knowledge production, we introduce a set of exogenous variables calculated for the period 2003-2005 and expressed in logarithms. Following prior studies (Sterlacchini, 2008), we include regional population density (*density*) to proxy for general agglomeration economies. A primary city effect is captured by 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 supporting 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, 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 domestic applicant and at least one foreign inventor (*international cooperation*). We also consider the role of education and training (Freeman, 1987) and introduce the labor force's share with tertiary level education (*human capital*) as a proxy for human capital. In line with the literature on RKPF (Acs et al., 2002; Anselin et al., 1997), 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 in non-manufacturing sectors departing from region *r* we include a variable measuring the number of R&D offshoring investments in services (*service 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 (Santangelo, 2000, 2002). In some OECD regions, R&D activities are offshored by the same firm and intra-firm efficiency in managing these offshore R&D activities may bias upward the effect of R&D offshoring on the investing home region's knowledge creation (Singh, 2008). To avoid this potential bias, we include a dummy variable that equals 1 if different R&D activities are offshored from the same firm headquartered in region *r* (*intra-firm*). Industry effects are captured with a binary variable controlling for regions that carry out R&D offshoring in high technology-intensive sectors (*high*) as per the OECD technology-intensive sectoral classification (Hatzichronoglou, 1997). To control for home country effects, we include a binary variable (*Scandinavia*) accounting for Finland, Norway, and Sweden, whose institutional environment notably eases systemic flexibility and learning (Asheim, 1996). Finally, we control for different propensities among regions to patent across technologies (Arundel and Kabla, 1998; Scherer, 1983) with the adjusted revealed technological advantage (*adjRTA*), 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*, weighted by the share of patents in all the regions in technology group *j*, on all the patents in the sample. Values close to +1(-1) represent comparative technological advantage (disadvantage) of region *r* in the technology group *j*.

Table 1 reports the correlation matrix and descriptive statistics for the continuous variables included in the model.

[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), which accounts for the correlation between the innovation output of neighboring regions. In particular, first we test for spatial autocorrelation by a Moran's I test using a binary contiguity matrix, which 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 regions 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 ($p \leq 0.01$). Then, we searched for the most appropriate functional form to model spatial dependence by relying on a set of Lagrange Multiplier tests on the OLS results (i.e. the LM-LAG and the LM-ERR) using the binary contiguity matrix. No remarkable differences are detected between the lag and the error model. We decided to adopt the spatial lag model as it models explicitly the impact of neighboring regions' patents through the coefficient ρ.[4] In particular, our spatial lag model can be expressed as

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

where $WlogK_{rt}$ is the spatially lagged dependent variable for the weight matrix W and ρ is the spatial autoregressive coefficient.

3.4. Testing for synergic effects

The purpose of our analysis is to test synergic effects between different value-added R&D activities globally offshored on the knowledge production of the investing home region when each of these activities is offshored optimally rather than randomly. The continuous variables capturing the number of foreign R&D investment in *research*, *development* and *adaptation* ($R\&Doffshoring_k$) display a skewed distribution with many regions showing zero R&D investments[5]. $R\&Doffshoring_k$ 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

[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.

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

[5]Skewness and kurtosis values for R&D offshoring distribution are respectively 5.63 and 42.74 for $R\&D\ offshoring_{research}$, 4.64 and 29.93 for $R\&D\ offhsoring_{development}$, and 5.91 and 44.6 for $R\&D\ offshoring_{adaptation}$, respectively. These values are well above those of a normal distribution.

parameter. Instead, we derive inequality constraints drawing on the theory of supermodularity and test these constraints on our dataset.

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:

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

$$F(1,1) - F(0,1) \geq F(1,0) - F(0,0) \tag{4}$$

The right-hand side of equation (4) 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 (4) 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). In our analysis F represents K_{rt} in equation (3). Thus, 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 (Milgrom and Roberts, 1990; Mohnen and Röller, 2005).

To operationalize the complementarity test in the case of three activities, we follow the recent work by Caree et al. (2011) and adopt a multiple-inequality restriction framework that corresponds to a definition of strict supermodularity *à la* Milgrom and Roberts. This framework advances alternative test procedures that consider all pair-wise terms (Caroli and Van Reenen, 2001) or estimate only the pair-wise terms of interest (Bresnahan et al., 2002) ignoring the impact of additional terms (e.g. the triple term in the case of three activities). In addition, Carree et al. (2011) testing framework avoids using critical values that yield a sizeable inconclusive area (Kodde and Palm, 1986). Instead, the multiple-inequality restriction framework considers the complete set of activities and relies on a simple Wald test (Carree et al., 2011).

To implement this test, we generate three binary variables, R, D and A. The first takes value 1 if $R\&Doffshoring_{research}$ is greater than 1 and accounts for 33 regions carrying out at least one investment in *research* (55% of investing regions). The second variable equals 1 if $R\&Doffshoring_{development}$ is greater than 1 and accounts for 47 regions carrying out at least one investment in *development* (78% of the investing regions). The third variable takes value 1 if $R\&Doffhsoring_{adaptation}$ is greater than 1 and accounts for 33 regions (55% of the investing regions). We then construct all possible combinations between R&D activities in the binary order as D = ((0,0,1), (0,1,0), (1,0,0), (0,1,1), (1,0,1), (1,1,0), (1,1,1)). We introduce the indicator function $C_{D=(R,\,D,\,A)}$, equal to 1 when the combination is (*R, D, A*), zero otherwise. As a result, the RKPF of equation (3) can then be refined as follows:

$$\log K_{rt} = \alpha + \theta C_{D=(R,\,D,\,A)} + \gamma \log Z_{rt-1} + \rho W \log K_{rt} + \varepsilon_r \qquad (5)$$

θ is the vector of the coefficients of the binary variables generated by the indicator function.

The conditions of complementarity between *R* and *D* are:

$$\alpha_{12} = \theta_{110} + \theta_{000} - \theta_{100} - \theta_{010} \geq 0$$

$$\alpha_{12} + \alpha_{123} = \theta_{111} + \theta_{001} - \theta_{101} - \theta_{011} \geq 0,$$

between *D* and *A* are:

$$\alpha_{23} = \theta_{011} + \theta_{000} - \theta_{010} - \theta_{001} \geq 0$$

$$\alpha_{23} + \alpha_{123} = \theta_{111} + \theta_{100} - \theta_{110} - \theta_{101} \geq 0,$$

between *R* and *A* are:

$$\alpha_{13} = \theta_{101} + \theta_{000} - \theta_{100} - \theta_{001} \geq 0$$

$$\alpha_{13} + \alpha_{123} = \theta_{111} + \theta_{010} - \theta_{110} - \theta_{011} \geq 0,$$

with one of two inequalities holding strictly for each pair of activities. The test of complementarity is a separate induced one-sided Wald χ^2 test where a combined hypothesis is accepted if all separate hypotheses are accepted (Savin, 1980). In particular, say that the χ^2-value is χ_1^2 for α_{12}, α_{23} and α_{13}, and χ_2^2 for $\alpha_{12} + \alpha_{123}$, $\alpha_{23} + \alpha_{123}$ and $\alpha_{13} + \alpha_{123}$, then for each pair of activities the test indicates complementarity if *either* "$\chi_1^2 > \chi_c^2$ and $\chi_2^2 > -\chi_d^2$" *or* "$\chi_1^2 > -\chi_d^2$ and $\chi_2^2 > \chi_c^2$", where χ_c^2 and χ_d^2 are the critical χ^2 values. That is, the test indicates complementarity if *either* offshoring two R&D activities jointly yields greater knowledge production in the investing home region than offshoring the two activities separately, and offshoring both the two R&D activities while offshoring a third one does not yield a lower home region knowledge production than offshoring the two activities separately; *or* offshoring two R&D activities jointly does not yield a lower home region knowledge production than offshoring the two activities separately, and offshoring the two R&D activities jointly while offshoring a third one yields a greater knowledge production than offshoring the two activities separately.

To test the effect of optimal (*versus* random) offshoring of R&D activities, we first build the binary variables *R*, *D* and *A* to account for host country R&D activity-specific advantage. To this end, we compute the adjusted revealed attractiveness advantage (*adjRAA*) index in each of the three types of R&D activities for the most advanced economies such as the G7, other advanced economies such as the other OECD countries, and China and India, which are the top destinations of R&D offshoring among non-OECD countries.[6] Pearce (1999) indeed documents that the host country advantage determines the type of incoming R&D activities. Specifically, *adjRAA* is calculated as

$$adjRAA = \frac{[(FDI_{ik}/\sum_k FDI_i)/(\sum_i FDI_{ik}/\sum_{ik} FDI_{IK})]-1}{[(FDI_{ik}/\sum_k FDI_i)/(\sum_i FDI_{ik}\,/\sum_{ik} FDI_{ik})]+1} \tag{6}$$

where FDI_{ik} is the number of inward R&D investments in the period 2003-2005 received by group of countries *i* (with *i* = *G*7, *other OECD*, and *China and/or India*) in the R&D activities *k*. Table 2 shows that *G7* economies have an advantage in the highest value-added R&D activities (i.e. research) (*adjRAA* = 0.27), *other OECD* in intermediate value-added R&D activities such as development (*adjRAA*= 0.10), and *China and/or India* are more appealing destinations in adaptation (*adjRAA* = 0.23). Thus, for each OECD region *R*, *D* and *A* are equal to 1 if the region offshores at least one laboratory carrying out *research* in *G7*, *development* in *other OCED*, and *adaption* in *China and/or India*, respectively.

[Table 2 about here]

Then, we repeat the analysis with the three binary variables *R*, *D* and *A* equal 1 if at least an investment in the relevant R&D activity is offshored from region *r* in any country regardless the host country R&D activity-specific advantage.

4. Results

Table 3 shows the estimations of the regional production function in equation (5). Columns 1 presents the results for the three complements where *R*, *D* and *A* are optimally offshored.

[Table 3 about here]

---

[6] The *G7* group refers to all G7 economies, and the *other OECD* group refers to Australia, Austria, Belgium, Czech Republic, Denmark, Finland, Hungary, Ireland, Mexico, the Netherlands, Poland, South Korea, Spain, Sweden, Switzerland, and Turkey.

In model 1, only the variable C_{111} (which in this model corresponds to the joint offshoring of *research* in *G7*, *development* in *other OECD*, *adaptation* in *China and/or India*) is large and statistically significant ($p < 0.05$). In all three models, the magnitudes and signs of these coefficients are in line with our argument of complementarity. The bottom rows in Table 3 shows the direct one-sided Wald χ^2 tests of complementarity and its significance. In accordance with our argument, the synergic effects of geographical fragmented R&D activities on the home region's knowledge production emerge. In model 1, regions carrying out *research* in G7 countries, *development* in other OECD countries and *adaptation* in China and/or India are more innovative than regions carrying out only *research* or only *developmen*t or only *adaptation* in each of these groups of countries. In particular, the strongest complementarity ($p < 0 .01$) is between *development* in other OECD countries and *adaptation* in China and/or India, given that home regions invests also in *research* in G7 countries. Consistent with the innovation system literature (Lundvall, 1992), a number of controls produce statically significant results.

To verify that synergic effects on home knowledge production are the results of host countries advantages in each R&D activity, we re-estimate the RKPF in equation (5) when R&D activities are randomly offshored and report the results in the second column of Table 3 (model 2). In this model, we include host country controls (*G7*, *Other OECD*, and *China & India*) to account for the idiosyncrasies of the host economies considered (e.g. weak intellectual property rights regime) which might affect R&D offshoring location choice (Lall, 2003) and MNCs' technology strategies (Zhao, 2006). The variable C_{110} and C_{100} are positive and significant ($p < 0.05$ and $p < 0.10$), showing a positive effect on home knowledge creation when regions randomly offshore *research* and *development* jointly, and *research* only, respectively. However, the one-sided Wald χ^2 tests of complementarity show no synergic effects on the home knowledge production of the investing home region when different value-added R&D activities are offshored randomly.

In these two models, the G7 group refers to all G7 economies, and, *other OECD* include, among others, Hungary, Mexico, Poland, and Turkey, which the International Monetary Fund does not classified as advanced economies. As a robustness check, we re-run the analysis excluding these four countries from the *other OECD* group. In particular, Table 4 shows that G7 countries are confirmed as favorite host locations for offshoring *research* (*adjRAA* = 0.27), other OECD for offshoring *development* (*adjRAA* = 0.10) and China and/or India for offshoring *adaptation (adjRAA* = 0.22).

[Table 4 about here]

Our econometric results are robust to this specification as Table 5 illustrates. Synergic effects between different value-added R&D activities on the knowledge production of the investing home region rise when each R&D activities is offshored optimally (Model 3) rather than randomly (Model 4).

[Table 5 about here]

5. Conclusions

This study investigates the effects of the global fragmentation of R&D activities on the knowledge production of the offshoring region. Our findings shows that synergic effects between different value-added R&D activities developed abroad on the knowledge production of the investing home region rise when each R&D activity is optimally offshored. The optimal offshore location of different value-added R&D activities ensures structural coherence and, as a result, the rise of synergies between internationally (reverse) knowledge inflows into the home region.

Our analysis advances research on RSI which has little investigated the internationalization of systems. Indeed, the rise of a local node, global network geography increasingly requires advanced country regions to connect globally with other systems where new knowledge is created (Gertler and Levitte, 2005). However, we suggest that the global connection of the system should not be random. Advanced country regions may gain from R&D offshoring and maintain their leadership to the extent that their R&D internationalization follows a finely grained selection of optimal offshore locations.

In addition, the study contributes to the RSI and the international knowledge sourcing literature which have focused traditionally on advanced economies as host locations and only more recently started looking at emerging economies. Our analysis documents the rise of fast-growing emerging economies as R&D offshoring host locations and the participation of these new players in global innovation networks. In particular, studies in the international knowledge sourcing tradition document a geographical R&D hierarchy (Cantwell and Janne, 1999; Pearce and Papanastassiou, 1999) as firms rank locations when offshoring their R&D depending on host location comparative advantage. However, in these studies such ranking is limited primarily to advanced host locations. Our analysis pushes this argument further by suggesting a truly global ranking of R&D locations. Specifically, we suggest that gains from R&D offshoring depend critically on host location R&D activity-specific comparative advantage, which for low value-added R&D activities can now be detected in emerging economies.

Our analysis bears relevant long- and short-term policy implications. In particular, our study illustrates that the involvement of fast-growing emerging economies in R&D offshoring is not a zero-sum game. Advanced country regions can still maintain their leadership in knowledge production when locating R&D activities offshore optimally. As a result regional governments need to make an effort to effectively select offshore R&D locations in order to enjoy coherent international (reverse) knowledge inflows. To this end, regional policies should aim in the long-run at increasing the numbers of high skilled graduates and supporting flexible R&D capabilities that enable understanding and assimilating diverse (reverse) international knowledge inflows. A major short run policy implication of our analysis is the need to implement workforce restructuring and supporting policies to cope with the rise of fast-growing emerging economies as appealing host locations of low value-added R&D activities, which may divert resources and employment away to these locations.

As any empirical study, our analysis suffers from a number of limitations that may guide the research agenda in the field. In particular, the R&D function may be more finely sliced to have a more accurate understanding of the phenomenon. To this end, the use of secondary data limits our analysis. Future research may address this limitation by collecting detailed information possibly through survey techniques. A further direction along which to develop our study would be to further refine the unit of analysis by conducting a firm-level study. Nonetheless, as a first attempt to assess the effect of the global R&D fragmentation at home, we are confident that our analysis may guide future micro studies.

Figure 1
Optimal location of different value-added R&D activities offshore

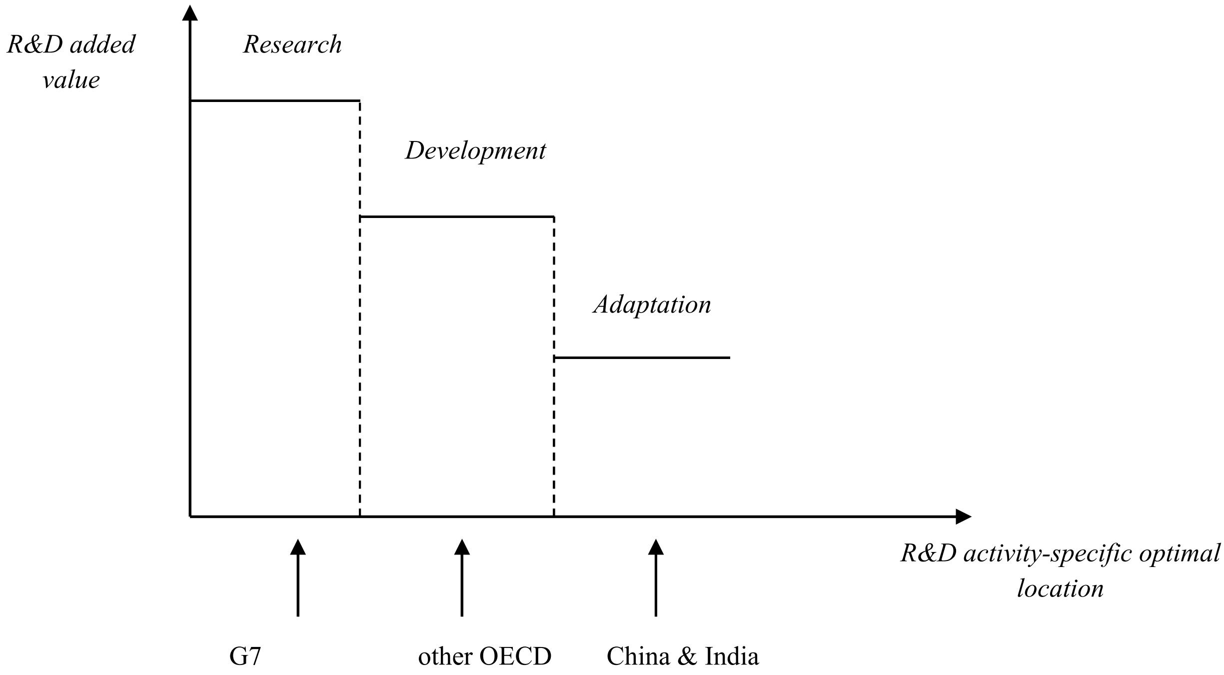

Table 1
Correlation matrix and descriptive statistic

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	K	1													
2	density	0.136**	1												
3	financial intermediation	0.500***	0.384***	1											
4	international cooperation	0.308***	0.211***	0.296***	1										
5	human capital	0.318***	-0.042	0.411***	0.116*	1									
6	R&D business	0.400***	0.061	0.207***	0.308***	0.045	1								
7	R&D university	-0.316***	-0.148**	-0.198***	-0.089	-0.089	-0.433***	1							
8	service R&D offshoring	0.387***	0.132**	0.424***	0.124*	0.202***	0.180***	-0.117*	1						
9	inward R&D FDI	0.363***	0.147**	0.346***	0.179***	0.251***	0.219***	-0.184***	0.429***	1					
10	$adjRTA_{(1)}$	0.421***	0.037	0.372***	0.097	0.268***	0.113*	-0.306***	0.283***	0.267***	1				
11	$adjRTA_{(2)}$	0.166**	0.019	0.274***	0.160**	0.117*	0.037	0.032	0.147**	0.036	0.058	1			
12	$adjRTA_{(3)}$	-0.124*	0.195***	0.207***	0.250***	0.080	-0.075	0.156**	0.012	0.023	-0.311***	0.045	1		
13	$adjRTA_{(4)}$	-0.291***	-0.075	-0.427***	-0.140**	-0.261***	0.034	0.118*	-0.315***	-0.176***	-0.523***	-0.265***	-0.327***	1	
14	$adjRTA_{(5)}$	-0.322***	-0.062	-0.272***	-0.109	-0.195***	-0.059	0.066	-0.151**	-0.156**	-0.352***	-0.219***	-0.037	0.198***	1
Mean		*0.097*	*4.364*	*0.126*	*2.341*	*3.195*	*3.917*	*3.121*	*0.187*	*0.199*	*-0.236*	*-0.099*	*-0.031*	*0.077*	*0.100*
Standard Deviation		*0.086*	*1.548*	*0.041*	*0.856*	*0.338*	*0.582*	*0.791*	*0.541*	*0.528*	*0.268*	*0.233*	*0.211*	*0.227*	*0.308*

Significant at *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$.

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

Country	***R&D activity***		
	Research	*Development*	*Adaptation*
G7	0.27	0.00	-0.32
Other OECD	0.11	0.10	-0.33
China and/or India	-0.45	-0.08	0.23

Table 3
Econometric results

	Optimal allocation			*Random allocation*		
		Model 1			**Model 2**	
Dependent variable		K			K	
	Coef.		St. Er.	Coef.		St. Er.
C_{111}	0.061	**	(0.029)	0.071		(0.044)
C_{101}	-0.011		(0.028)	0.036		(0.052)
C_{011}	0.003		(0.023)	0.042		(0.038)
C_{001}	0.007		(0.026)	-0.023		(0.033)
C_{110}	-0.065		(0.054)	0.074	**	(0.036)
C_{100}	0.006		(0.018)	0.053	*	(0.029)
C_{010}	-0.018		(0.024)	0.017		(0.024)
C_{000}	Reference category			Reference category		
Controls						
density	0.008	***	(0.002)	0.008	***	(0.002)
capital	-0.065	***	(0.016)	-0.071	***	(0.016)
financial intermediation	0.743	***	(0.133)	0.690	***	(0.137)
international cooperation	0.014	***	(0.004)	0.013	***	(0.004)
human capital	0.017		(0.011)	0.014		(0.011)
R&D business	0.014	**	(0.007)	0.013	*	(0.007)
R&D university	-0.004		(0.004)	-0.005		(0.004)
service R&D offshoring	-0.011		(0.009)	0.008		(0.009)
inward R&D FDI	0.011		(0.009)	0.015	*	(0.009)
intra-firm	-0.128	***	(0.041)	-0.029		(0.027)
high	0.028	**	(0.014)	0.022		(0.019)
Scandinavia	0.106	***	(0.013)	0.102	***	(0.013)
G7	-			-0.050	**	(0.021)
Other OECD	-			-0.019		(0.020)
China & India	-			0.008		(0.019)
$adjRTA_{(1)}$	-0.012		(0.021)	-0.004		(0.021)
$adjRTA_{(2)}$	-0.010		(0.016)	-0.007		(0.016)
$adjRTA_{(3)}$	-0.092	***	(0.024)	-0.091	***	(0.024)
$adjRTA_{(4)}$	-0.085	***	(0.024)	-0.078	***	(0.024)
$adjRTA_{(5)}$	-0.032	***	(0.012)	-0.034	***	(0.012)
constant	-0.185	***	(0.054)	-0.160	***	(0.054)
Rho constant	0.035	***	(0.012)	0.032	**	(0.012)
Sigma constant	0.048	***	(0.002)	0.047	***	(0.002)
Number of obs.		*221*			*221*	
		Wald χ^2 (one-side)				
Test of complementarity between R and D						
α_{12}		0.76			0.01	
$\alpha_{12} + \alpha_{123}$		3.20**			0.31	
Test of complementarity between D and A						
α_{12}		0.13			1.81	
$\alpha_{12} + \alpha_{123}$		5.53***			0.08	
Test of complementarity between R and A						
α_{12}		0.45			0.02	
$\alpha_{12} + \alpha_{123}$		2.83**			0.68	

Significant at *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$.

Table 4
Revealed attractiveness advantage, by R&D activity and group of country without Hungary, Mexico, Poland and Turkey in *Other OECD*

Country	*R&D activity*		
	Research	*Development*	*Adaptation*
G7	0.27	0.01	-0.34
Other OECD	0.14	0.10	-0.33
China and India	-0.46	-0.07	0.22

Table 5
Econometric results without Hungary, Mexico, Poland and Turkey in *Other OECD*

	Optimal allocation			*Random allocation*		
	Model 3			**Model 4**		
Dependent variable	K			K		
	Coef.		St. Er.	Coef.		St. Er.
C_{111}	0.055	*	(0.029)	0.082	*	(0.042)
C_{101}	-0.020		(0.026)	0.043		(0.052)
C_{011}	-0.011		(0.024)	0.036		(0.037)
C_{001}	0.024		(0.025)	0.005		(0.030)
C_{110}	-0.069		(0.055)	0.078	**	(0.035)
C_{100}	0.005		(0.018)	0.059	*	(0.031)
C_{010}	-0.015		(0.022)	0.019		(0.024)
C_{000}	Reference category			Reference category		
Controls						
density	0.008	***	(0.002)	0.007	***	(0.002)
capital	-0.066	***	(0.016)	-0.066	***	(0.016)
financial intermediation	0.731	***	(0.132)	0.674	***	(0.137)
international cooperation	0.014	***	(0.004)	0.013	***	(0.004)
human capital	0.016		(0.011)	0.011		(0.011)
R&D business	0.013	*	(0.007)	0.014	**	(0.007)
R&D university	-0.004		(0.004)	-0.005		(0.004)
service R&D offshoring	-0.009		(0.009)	0.007		(0.009)
inward R&D FDI	0.011		(0.009)	0.014	*	(0.009)
intra-firm	-0.144	***	(0.055)	-0.027		(0.027)
high	0.029	**	(0.014)	0.032	*	(0.018)
Scandinavia	0.103	***	(0.013)	0.101	***	(0.013)
G7	-			-0.054	**	(0.021)
Other OECD	-			-0.032	*	(0.018)
China & India	-			0.006		(0.019)
$adjRTA_{(1)}$	-0.011		(0.021)	-0.002		(0.021)
$adjRTA_{(2)}$	-0.009		(0.016)	-0.005		(0.016)
$adjRTA_{(3)}$	-0.089	***	(0.024)	-0.087	***	(0.024)
$adjRTA_{(4)}$	-0.082	***	(0.023)	-0.076	***	(0.023)
$adjRTA_{(5)}$	-0.032	***	(0.012)	-0.033	***	(0.012)
constant	-0.182	***	(0.054)	-0.151	***	(0.054)
Rho constant	0.037	***	(0.012)	0.032	***	(0.012)
Sigma constant	0.047	***	(0.002)	0.047	***	(0.002)
Number of obs.	*221*			*221*		
Wald χ^2 (one-side)						
Test of complementarity between R and D						
α_{12}	0.99			0.00		
$\alpha_{12} + \alpha_{123}$	7.13***			0.02		
Test of complementarity between D and A						
α_{12}	0.27			0.11		
$\alpha_{12} + \alpha_{123}$	6.16***			0.16		
Test of complementarity between R and A						
α_{12}	1.98			0.20		
$\alpha_{12} + \alpha_{123}$	3.68**			0.15		

Significant at *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$.

References

Acs, Z.J., Anselin, L., Varga, A., 2002. Patents and innovation counts as measures of regional production of new knowledge. Research Policy 31, 1069-1085.

Almeida, P., 1996. Knowledge sourcing by foreign multinationals: patent citation analysis in the US semiconductor industry. Strategic Management Journal 17, 155-165.

Anselin, L., 1988. Spatial Econometrics: Methods and Models. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Anselin, L., Varga, A., Acs, Z., 1997. Local Geographic Spillovers between University Research and High Technology Innovations. Journal of Urban Economics 42, 422-448.

Arora, A., 1996. Testing for Complementarities in Reduced-Form Regressions: A Note. Economic Letters 50, 51-55.

Arora, A., Gambardella, A., 1990. Complementarity and External Linkages: The Strategies of the Large Firms in Biotechnology. The Journal of Industrial Economics 38, 361-379.

Arundel, A., Kabla, I., 1998. What percentage of innovations are patented? empirical estimates for European firms. Research Policy 27, 127-141.

Asheim, B., 1996. Industrial districts as 'learning regions': a condition for prosperity. European Planning Studies 4, 379-400.

Asheim, B.T., Coenen, L., 2005. Knowledge bases and regional innovation systems: Comparing Nordic clusters. Research Policy 34, 1173-1190.

Athey, S., Stern, S., 1998. An Empirical Framework for Testing Theories About Complementarities in Organizational Design, NBER Working Paper 6600.

Athreye, S., Cantwell, J., 2007. Creating competition?: Globalisation and the emergence of new technology producers. Research Policy 36, 209-226.

Atkinson, R.D., 2007. The Globalization of R&D and Innovation: How do Companies Choose where to Build R&D Facilities? Evidence provided before the U.S. House of Representatives Committee on Science and Technology, Subcommittee on Technology and Innovation, Washington, DC.

Audretsch, D.B., Feldman, M.P., 1996. R&D Spillovers and the Geography of Innovation and Production. The American Economic Review 86, 630-640.

Baptista, R., Swann, P., 1998. Do firms in clusters innovate more? Research Policy 27.

Bode, E., 2004. The spatial pattern of localized R&D spillovers: an empirical investigation for Germany. Journal of Economic Geography 4, 43-64.

Braczyk, H.-J., Cooke, P., Heidenreich, M., 1998. Regional Innovation Systems: The Role of Governance in a globalised World. Routledge.

Bresnahan, T., Brynjolfsson, E., Hit, L.M., 2002. Information technology, workplace organization, and the demand for skilled labor: firm level evidence. Quarterly Journal of Economics 117, 339–375.

Cantwell, J., 1995. The globalisation of technology: what remains of the product cycle model? Cambridge Journal of Economics 19, 155-174.

Cantwell, J., Iammarino, S., 2003. Multinational corporations and European regional systems of innovation. Routledge.

Cantwell, J., Janne, O., 1999. Technological globalisation and innovative centres: the role of corporate technological leadership and locational hierarchy. Research Policy 28, 119-144.

Cantwell, J., Santangelo, G.D., 2000. Capitalism, profits and innovation in the new techno-economic paradigm. Journal of Evolutionary Economics 10, 131-157.

Carlsson, B., 2006. Internationalization of innovation systems: A survey of the literature. Research Policy 35, 56-67.

Caroli, E., Van Reenen, J., 2001. Skill-biased organizational change? Evidence from a panel of British and French establishments. Quarterly Journal of Economics 116, 1449–1492.

Carree, M., Lokshin, B., Belderbos, R., 2011. A note on testing for complementarity and substitutability in the case of multiple practices. Journal of Productivity Analysis 35, 263-269.

Chaminade, C., Vang, J., 2008. Globalisation of knowledge production and regional innovation policy: Supporting specialized hubs in the Bangalore software industry. Research Policy 37, 1684-1696.

Chesbrough, H., 2003. Open Innovation: The New Imperative for Creating and Profiting from Technology. Harvard Business School Press, Boston.

Chesbrough, H., Kusunoki, K., 2001. The Modularity Trap: Innovation, Technology Phase Shifts and the Resulting Limits of Virtual Organizations, in: Nonaka, I., Teece, D.J. (Eds.), Managing industrial knowledge: creation, transfer and utilization. SAGE, London.
Contractor, F.J., Kumar, V., Kundu, S.K., Pedersen, T., 2010. Reconceptualizing the Firm in a World of Outsourcing and Offshoring: The Organizational and Geographical Relocation of High-Value Company Functions. Journal of Management Studies 47, 1417-1433.
Cooke, P., 1992. Regional innovation systems: Competitive regulation in the new Europe. Geoforum 23, 365-382.
Cooke, P., 2005. Regionally asymmetric knowledge capabilities and open innovation: Exploring 'Globalisation 2'-A new model of industry organisation. Research Policy 34, 1128-1149.
Cooke, P., Uranga, G.M., Etxebarria, G., 1997. Regional innovation systems: Institutional and organisational dimensions. Research Policy 26, 475-491.
Demirbag, M., Glaister, K.W., 2010. Factors Determining Offshore Location Choice for R&D Projects: A Comparative Study of Developed and Emerging Regions. Journal of Management Studies 47, 1534-1560.
Dunning, J.H., 1993. Multinational Enterprises and the Global Economy. Addison-Wesley, Reading, MA.
Dunning, J.H., Narula, R., 1995. The R&D activities of foreign firms in the United States. International Studies of Management and Organisation 25, 39-73.
EIU, 2004. Scattering the seeds of invention: The globalisation of research and development. Economist Intelligence Unit, London.
Enright, M.J., 2009. The location of activities of manufacturing multinationals in the Asia-Pacific. Journal of International Business Studies 40, 818-839.
Feldman, M.P., 2003. The Locational Dynamics of the US Biotech Industry: Knowledge Externalities and the Anchor Hypothesis. Industry & Innovation 10, 3111-3329.
Filippaios, F., Papanastassiou, M., Pearce, R., Rama, R., 2009. New forms of organisation and R&D internationalisation among the world's 100 largest food and beverages multinationals. Research Policy 38, 1032-1043.
Forsgren, M., Holm, U., Johanson, J., 2005. Managing the embedded multinational – A business network view. Edward Elgar, Cheltenham.
Freeman, C., 1987. Technology Policy and Economic Performance: Lessons from Japan. Pinter, London.
Fritsch, M., Slavtchev, V., 2008. Determinants of the Efficiency of Regional Innovation Systems. Regional Studies, 1-14.
Gassmann, O., Han, Z., 2004. Motivations and barriers of foreign R&D activities in China. R&D Management 34, 423-437.
Gertler, M.S., Levitte, Y.M., 2005. Local Nodes in Global Networks: The Geography of Knowledge Flows in Biotechnology Innovation. Industry and Innovation 12, 487-507.
Gerybadze, A., Reger, G., 1999. Globalization of R&D: recent changes in the management of innovation in transnational corporations. Research Policy 28, 251-274.
Giuliani, E., Bell, M., 2005. The micro-determinants of meso-level learning and innovation: evidence from a Chilean wine cluster. Research Policy 34, 47-68.
Grabher, G., 1993. The weakness of strong ties: the lock-in of regional development in the Ruhr area, in: Grabher, G. (Ed.), The Embedded Firm. Routledge, London.
Griliches, Z., 1979. Issues in Assessing the Contribution of Research and Development to Productivity. The Bell Journal of Economics 10, 92-116.
Hatzichronoglou, T., 1997. Revision of the High-Technology Sector and Product Classification. OECD Science, Technology and Industry Working Papers, 1997/2 doi:10.1787/134337307632. .
Hood, N., Young, S., 1982. US Multinational R&D: Corporate Strategies and Policy Implications for the UK. Multinational Business 2, 10-23.
Howells, J., 1999., 1999. Regional systems of innovation?, in: Archibugi, D., Howells, J., Michie, J. (Eds.), Innovation Policy in a Global Economy. Cambridge University Press, Cambridge, pp. 67–93.
Huggins, R., Demirbag, M., Ratcheva, V.I., 2007. Global knowledge and R&D foreign direct investment flows: recent patterns in Asia Pacific, Europe and North America. International Review of Applied Economics 21, 437-451.

Iammarino, S., McCann, P., 2006. The structure and evolution of industrial clusters: Transactions, technology and knowledge spillovers. Research Policy 35, 1018-1036.
Ito, B., Wakasugi, R., 2007. What factors determine the mode of overseas R&D by multinationals? Empirical evidence. Research Policy 36, 1275-1287.
Iwasa, T., Odagiri, H., 2004. Overseas R&D, knowledge sourcing, and patenting: an empirical study of Japanese R&D investment in the US. Research Policy 33, 807-828.
Jaffe, A., 1989. Real Effects of Academic Research. The American Economic Review 79, 957-970.
Jaffe, A., Trajtenberg, M., Henderson, R., 1993. Geographic localization of knowledge spillover as evidenced by patent citations. The Quarterly Journal of Economics 108, 577-598.
Khan, M., Dernis, H., 2005. Impact of Patent Co-Operation Treaty Data on Epo Patent Statistics and Improving the Timeliness of EPO Indicators, OECD Science, Technology and Industry Working Papers 2005/2. OECD Publishing, Paris.
Khan, M., Dernis, H., 2006. Global overvie of innovative activties from the patent indictors perspective, OECD Science, Technology and Industry Working Papers 2006/3. OECD Publishing, Paris.
Kodde, D., Palm, F., 1986. Wald criteria for jointly testing equality and inequality restrictions. Econometrica 54, 1243–1248.
Kotabe, M., Murray, J.Y., 2003. Global Sourcing Strategy and Sustainable Competitive Advantage. Industrial Marketing Management 33, 7-14.
Kuemmerle, W., 1999. Foreign direct investment in industrial research in the pharmaceutical and electronics industries—results from a survey of multinational firms. Research Policy 28, 179-193.
Lall, S., 2003. Indicators of the relative importance of IPRs in developing countries. Research Policy 32, 1657-1680.
Le Bas, C., Sierra, C., 2002a. ‘Location versus home country advantages’ in R&D activities: some further results on multinationals’ locational strategies. Research Policy 31, 589-609
Le Bas, C., Sierra, C., 2002b. Location versus home country advantages’ in R&D activities: some further results on multinationals’ locational strategies. Research Policy 31, 589-609
Lewin, A.Y., Massini, S., Peeters, C., 2009. Why Are Companies Offshoring Innovation? The Emerging Global Race for Talent. Journal of International Business Studies 2009/05/07/online.
Lundvall, B.-Å., 1992. National systems of innovation: towards a theory of innovation and interactive learning. Pinter, London.
Lundvall, B.-Å., Intakumnerd, P., Vang, J., 2006. Asian Innovation Systems in Transition. Edward Elgar, Cheltenham.
Malmberg, A., 2003. Beyond the cluster—local milieus and global economic connections, in: Peck, J., Yeung, H.W.C. (Eds.), Remaking the Global Economy. Sage, London, pp. 145–159.
Manning, S., Massini, S., Lewin, A.Y., 2008. A Dynamic Perspective on Next-Generation Offshoring: The Global Sourcing of Science and Engineering Talent. Academy of Management Perspectives 22, 35-54.
Mansfield, E., Romeo, A., 1984. Reverse transfers of technology from overseas subsidiaries to American firms. IEEE Transactions on Engineering Management 31, 122-127.
Maraut, S., Dernis, H., Webb, C., Spiezia, V., Guellec, D., 2008. The OECD REGPAT Database: A Presentation, OECD Science, Technology and Industry Working Papers. OECD Publishing.
Meyer, K.E., Mudambi, R., Narula, R., 2011. Multinational Enterprises and Local Contexts: The Opportunities and Challenges of Multiple Embeddedness. Journal of Management Studies 48, 235-252.
Milgrom, P., Roberts, J., 1990. Rationalizability, Learning, and Equilibrium in Games with Strategic Complementarities. Econometrica 58, 1255-1277.
Mohnen, P., Röller, L.-H., 2005. Complementarities in innovation policy. European Economic Review 49, 1431-1450.
Moreno, R., Paci, R., Usai, S., 2005. Spatial spillovers and innovation activity in European regions. Environment and Planning 37, 1793-1812.
Mudambi, R., 2008. Location, control and innovation in knowledge-intensive industries. Journal of Economic Geography 8, 699-725.
Narula, R., 2002. Innovation systems and ‘inertia’ in R&D location: Norwegian firms and the role of systemic lock-in. Research Policy 31, 795-816.

Narula, R., Hagedoorn, J., 1999. Innovating through strategic alliances: moving towards international partnerships and contractual agreements. Technovation 19.
OECD, 2008. Territorial Grid of OECD Member Countries. OECD Public Governance and Territorial Development Directorate.
Patel, P., Pavitt, K.L.R., 1991. Large Firms in the Production of the World's Technology: An Important Case of Non-Globalisation. Journal of International Business Studies 22, 1-21.
Patel, P., Vega, M., 1999. Patterns of internationalisation of corporate technology: location vs. home country advantages. Research Policy 28, 145-155.
Pearce, R., Singh, S., 1992. Globalizing research and development. The MacMillan Press.
Pearce, R.D., 1999. Decentralised R&D and strategic competitiveness: globalised approaches to generation and use of technology in multinational enterprises (MNEs). Research Policy 28, 157–178.
Pearce, R.D., Papanastassiou, M., 1999. Overseas R&D and the strategic evolution of MNEs: evidence from laboratories in the UK. Research Policy 28, 23-41.
Porter, M.E., 1990. The Competitive advantage of nations. Free Press, New York.
Ronstadt, R., 1977. Research and Development Abroad by U.S. Multinationals. Praeger, New York.
Ronstadt, R.C., 1978. International R&D: The Establishment and Evolution of Research and Development Abroad by Seven U.S. Multinationals. Journal of International Business Studies 9, 7-24.
Rosenzweig, P.M., Singh, J.V., 1991. Organizational Environments and the Multinational Enterprise. Academy of Management Review 16, 340-361.
Santangelo, G.D., 2000. Inter-European Regional dispersion of Corporate ICT Research Activity: the case of German, Italian and UK regions. International Journal of Economics of Business 7, 275-295.
Santangelo, G.D., 2002. The regional geography of corporate patenting in information and communications technology (ICT): domestic and foreign dimension. Regional Studies 36, 495-514.
Savin, N.E., 1980. The Bonferroni and the Scheffe´ multiple comparison procedures. Review of Economic Studies 47, 255–273.
Scherer, F.M., 1983. The propensity to patent. International Journal of Industrial Organization 1, 107-128.
Schmiele, A., 2011. Drivers for international innovation activities in developed and emerging countries. The Journal of Technology Transfer, 1-26.
Schmoch, U., 2008. Conception of a Technology Classification for Country Comparisons. WIPO.
Singh, J., 2008. Distributed R&D, cross-regional knowledge integration and quality of innovative output. Research Policy 37, 77-96.
Sterlacchini, A., 2008. R&D, higher education and regional growth: Uneven linkages among European regions. Research Policy 37, 1096-1107.
UNCTAD, 2005. World Investment Report. TNCs and the Internationalization of R&D. United Nations, Geneva.
von Hippel, E., 1988. The Sources of Innovation. Oxford University Press, New York.
von Zedtwitz, M., Gassmann, O., 2002. Market versus technology drive in R&D internationalization: four different patterns of managing research and development. Research Policy 31, 569-588.
Zhao, M., 2006. Conducting R&D in Countries with Weak Intellectual Property Rights Protection. Management Science 52, 1185-1199.