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Top R&D investors and international knowledge seeking: the role of emerging technologies and technological proximity

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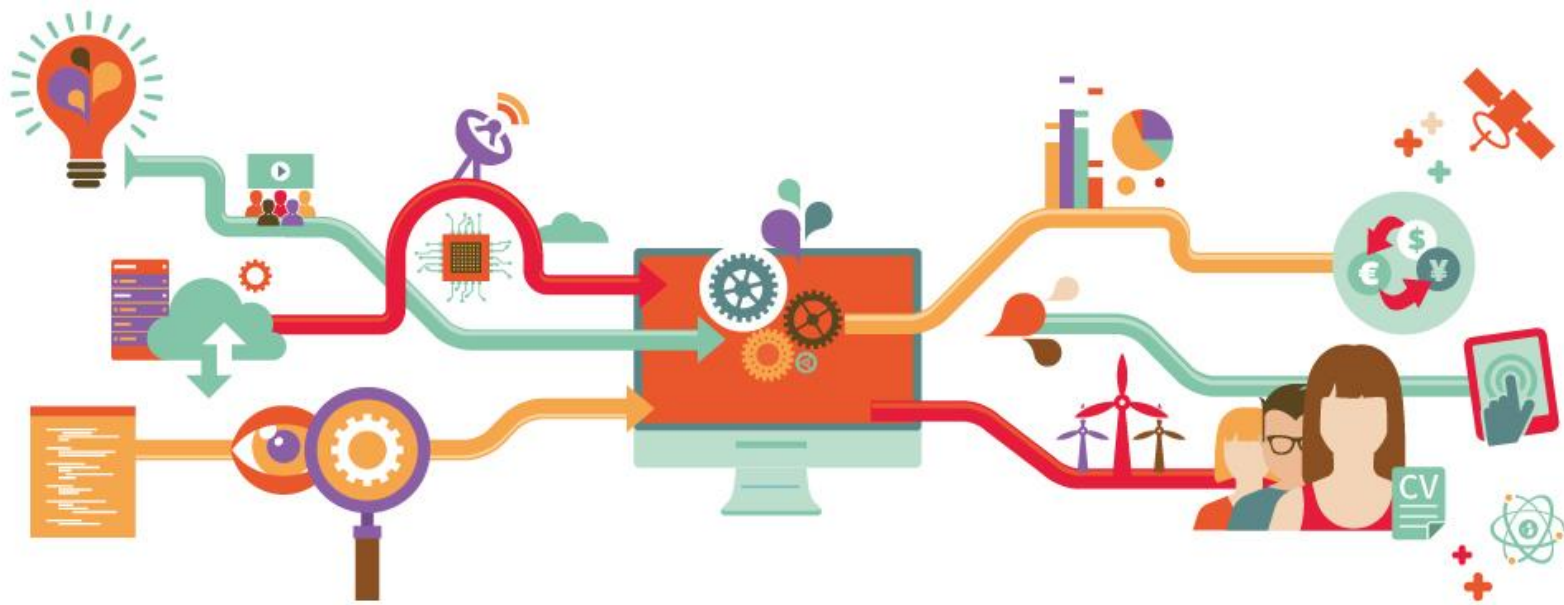
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Top R&D Investors and international knowledge seeking: the role of emerging technologies and technological proximity

Mafini Dosso and Antonio Vezzani
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Joint Research Centre
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Abstract

This paper sheds new lights on the internationalization of technological activities of the top corporate R&D investors worldwide. In particular, we provide evidence on the technological factors determining their international R&D location strategies. The empirical analysis is based on the patenting activities of the top R&D investors, as reported by the EU Industrial R&D Investment Scoreboard, at the USPTO over the period 2010–2012. The technological proximity to the host country in which these companies seek for new knowledge is a key determinant for their R&D location decision. However, technological proximity has a non-linear effect on the companies' location strategies as they search for new technologies not too close to their knowledge base. Furthermore, top R&D investors worldwide target countries with comparative advantages in emerging technologies. Countries willing to attract high-value investments should create an environment conducive to the creation and development of brand new ideas with a high potential impact on the long term growth.

Abstract^{1,2}

This paper sheds new lights on the internationalization of technological activities of the top corporate R&D investors worldwide. In particular, we provide evidence on the technological factors determining their international R&D location strategies. The empirical analysis is based on the patenting activities of the top R&D investors, as reported by the EU Industrial R&D Investment Scoreboard, at the USPTO over the period 2010–2012. The technological proximity to the host country in which these companies seek for new knowledge is a key determinant for their R&D location decision. However, technological proximity has a non-linear effect on the companies' location strategies as they search for new technologies not too close to their knowledge base. Furthermore, top R&D investors worldwide target countries with comparative advantages in emerging technologies. Countries willing to attract high-value investments should create an environment conducive to the creation and development of brand new ideas with a high potential impact on the long term growth.

Keywords: International Knowledge seeking, Multinational Corporations (MNCs), Patents, Emerging technologies, Technological proximity

JEL Classification: O30, F23, L20

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² This Working Paper is issued in the context of the Industrial Research and Innovation Monitoring and Analysis (IRIMA) activities that are jointly carried out by the European Commission's Joint Research Centre (JRC) – Institute for Prospective Technological Studies (IPTS) and the Directorate General Research and Innovation - Directorate A, Policy Development and Coordination.

1. Introduction

The internationalization of research and development (R&D) and innovation-related activities has raised long lasting interests within the economic and innovation literature. This dimension of the globalisation process represents an increasingly important aspect of corporate strategies. In order to gain or maintain a competitive edge, Multinational Corporations (MNCs) increasingly rely on international knowledge networks, notably through cross-borders ownership, mergers and acquisitions, greenfield investments, collaborations and contractual research, and intellectual property transactions. At the same time, countries are competing to strengthen their attractiveness for large scale technology and knowledge intensive activities, as a key source to boost high-quality jobs and competitiveness.

Empirical studies examining the patterns, drivers and effects of the international generation of knowledge could be broadly classified along three complementary perspectives. A first approach has investigated the organization and importance of foreign R&D activities in the host countries, notably via the assessment of the contribution of foreign R&D affiliates to research, human resources or employment (Belderbos et al. 2008, OECD 2010). Complementary evidence has been provided through the analysis of inward and outward foreign direct investments in R&D activities (Florida 1997, Kuemmerle 1999, Castelli and Castellani 2013). A third stream of the literature has focused on the international locations of large firms' R&D activities, exploiting the information contained in MNCs' patent documents (Patel and Vega 1999, Cantwell and Piscitello 2005).

These contributions have pointed out the central role of MNCs in the international innovation activities, motivated by the need of adapting or exploiting the technologies developed at home. Further evidence has shown that MNCs increasingly locate research facilities to foreign locations in order to tap into the knowledge and techniques created abroad as a complement to their in-house technological activities, or in order to develop new knowledge and competences (Cantwell et al. 2004, Criscuolo et al. 2005). With respect to the location determinants, besides firm-specific characteristics, important drivers have been identified in relation to the type of activities and the host country's attributes such as: i) the market features, ii) the presence of high quality scientific infrastructure and human resources, iii) the agglomeration forces, iv) tax breaks and government support, legal and intellectual property protection systems. Nevertheless, the relative importance of these drivers also depends on the industries in which such corporations operate and on the different propensities of resorting to the international markets for their knowledge creation activities. Regarding the locations choices, the role of the Triad 'United States-Japan-Europe', as the main destination of the international investment in R&D, has been highlighted.

However, more recent evidence show that internationalization of R&D is taking place at a higher pace and, increasingly towards (and from) the so-called emerging countries (Thursby and Thursby 2006, von Zedtwitz 2006), thus challenging the traditional R&D location theories, whereby MNCs would generally locate knowledge creation activities next to their decisions centres (headquarters). Therefore, the

international distribution of innovation activities is changing over time, notably as more countries build up higher quality or new scientific and technological capabilities. At the same time, the increasing complexity of products leads MNCs to rely on a greater variety of technological competences, which is likely to require the location of R&D facilities in the neighbourhood of excellence research and scientific centres around the world (Moncada-Paternò-Castello et al. 2011). Moreover, in this search of new knowledge firms are bounded by the path-dependent and cumulative nature of the innovation process (Dosi 1988, Cantwell 1989, Dosi et al. 1990).

In the international knowledge seeking strategies this should translate into a certain degree of technological proximity between MNCs and the targeted (host) countries.

In a complementary manner, among the drivers leading a company to invest in foreign locations, is the attempt to tap into specific technological knowledge (Guellec and Pottelsberghe de la Potterie 2001, Cantwell 2009). In particular, firms may be attracted by certain locations with a superior capacity in developing new emerging technologies. Indeed, these technologies are likely to lead to the discovery of path-breaking, brand new products and processes (Schoenmakers and Duyster 2010).

Emerging technologies are receiving an increasing attention both from the policy and the academic communities. Indeed, they are perceived as technologies which can provide solutions to global challenges and a ground for sustainable business opportunities (WEF 2014) with the potential to change the economy and society. However, consensus is still lacking on how to define them and to operationalize their detection (Rotolo et al. 2015). Moreover, although they are expected to yield a positive impact on economic growth, exercises trying to estimate their impact remain scarce. Similarly, empirical evidence on how these emerging technologies actually influence the locations choices of MNCs is still lacking, to the best of our knowledge.

Departing from these latter observations, this paper sheds new lights on the internationalization of technological activities of the top corporate R&D investors worldwide (European Commission 2013). More precisely, we assess: i) the impact of the specialization of the (possible) destination country in emerging technologies in attracting foreign MNCs, and ii) the extent to which MNCs perform a local technological search in their international knowledge seeking strategies.

The remainder of the paper is organized as follows. Section 2 sets down the main theoretical foundations for the analysis of the internationalization of R&D and innovative activity. Section 3 presents the data, and illustrates the empirical strategy and the variables. Section 4 discusses the main findings. Finally, Section 5 concludes.

2. Theoretical background

Inspired by the observations of US MNCs' international activities, the seminal works of Vernon (1966, 1979) constitute an early theoretical discussion on the international location of technological activities. In his attempt to rethink the product cycle (PC)

hypothesis³, Vernon has somehow anticipated some of the current trends observed in the development of international knowledge and innovation networks. He has underlined the prominence of the parent company's home market for the development of innovations. This prominence, although decreasing, is still supported by the current evidence on the higher opportunities for scale economies in R&D, the economies of integration and agglomeration, the importance of demand-led innovation, and the more effective communication between potential customers and suppliers (Vernon 1966, 1979, Cantwell 1995). However, as for the increasing reliance on foreign locations, Vernon did not anticipate that these factors may also extend to other innovative places or world regions characterized by high market potentials, high-skilled workforce and/or specific techno-industrial specializations. This shifting has been favoured by the development of more effective information and communication channels between geographically distant markets and the reduction of income and education disparities among a larger set of countries. Furthermore, in Vernon's theoretical typology, few MNCs would be able to develop global scanning capabilities. These global scanning capabilities, if they ever exist, would refer to the ability of internationally integrated MNCs to collect and interpret information from multiple global locations, with virtually null international communication costs (Vernon 1979). Therefore innovation in these hypothetical MNCs could thus be stimulated from markets located anywhere in the globe. However, to our knowledge the existence of such fully internationally integrated networks still remains scarcely documented in the empirical analyses. Nevertheless, evidence shows that foreign R&D affiliates have gained in autonomy and importance in the knowledge creation activities (Zanfei 2000, Dunning and Lundan 2009), and that MNCs increasingly develop simultaneously intra- and inter-firm networks⁴ for the generation of innovations (Zanfei 2000, Archibugi and Iammarino 2002, Cantwell and Zhang 2011).

During the last three decades, many studies have contributed to further improve our understanding of the patterns and drivers of the internationalization of research and development (R&D) and innovation-related activities. There is clear evidence that companies are increasingly relying on international R&D and innovative activities, through cross-border greenfield investments, mergers and acquisitions, strategic alliances, collaborations and contractual research, standardisation activities and intellectual property transactions. The importance of foreign R&D in the host countries'

³ In the earlier version of the PC model, Vernon (1966) offers an alternative explanation to the patterns of international trade in which the locations of production would not depend exclusively on relative costs, but on the life cycle of the product. In the early stages, the production of the new product is localised at home due to the more effective communication between the supplier and the targeted market. As far as production and demand expand, the producers are more likely to invest in production facilities abroad and re-export the related products from these new locations towards the home market. According to Vernon, this phenomenon is further accentuated, and may extend to less developed economies with cheaper labour costs in the standardized product phase, which entails high output volumes, less uncertainty and higher costs considerations.

⁴ Zanfei refers to this phenomenon as a 'double network' (internal and external to the MNCs) where foreign R&D units have developed increasing capabilities to access and contribute to knowledge available for economic uses (Zanfei 2000). Akin to this notion is the concept of two-way knowledge flows discussed by Cantwell and Zhang (2011), which reflects the growing importance of knowledge spillovers from foreign-owned subsidiaries to indigenous firms.

economies is generally assessed through the contribution of foreign R&D affiliates to the R&D expenditures (funding and performance), the R&D-related employment and to the patenting activities (Patel and Pavitt 1991, Cantwell 1989, 1995, Guellec and van Pottelsberghe de la Potterie 2001, Picci 2010). Another significant way of exploiting innovations in foreign markets is through foreign direct investment (FDI) in R&D activities (UNCTAD 2005, Castelli and Castellani 2013). These studies confirm that MNCs have increasingly moved away from a myopic model of knowledge creation and innovation almost exclusively oriented towards the home country. These international R&D activities have been mainly implemented following the North-North pattern (from and to developed markets), particularly within the Triad countries, i.e. the United States, Europe and Japan. However, studies also point out the increasing importance of emerging countries in the hierarchy of foreign R&D locations (e.g. UNCTAD 2005, von Zedtwitz 2006, OECD 2011).

The interest in the causes of such phenomenon has given birth to a major stream of the literature, which focuses on the motives and determinants of the international knowledge activities of companies. These studies have mainly exploited data relating to FDIs in research (Kuemmerle 1999, Alcácer and Chung 2007) and to the foreign patenting activities of large companies (among others, Cantwell 1989, Patel and Vega 1999, Cantwell and Iammarino 2000, Le Bas and Sierra 2002, Criscuolo et al. 2005, Picci 2010). As suggested by these contributions, it is still more often the case that MNCs implement international R&D activities to adapt the knowledge and technologies developed at home to local market conditions or to adopt a home-base exploiting strategy. Although this locational strategy is still prevailing, evidence also point out the increasing importance of locating R&D activities abroad in fields where both the home and host countries have developed relatively stronger advantages. Such strategy has been referred to as home-based augmenting or asset-augmenting activity (Kuemmerle 1999, Patel and Vega 1999, Cantwell and Iammarino 2000, Le Bas and Sierra 2002, Cantwell et al. 2004). In other words MNCs increasingly tap into the knowledge developed elsewhere in order to complement their own domestic strengths. Le Bas and Sierra (2002), and Criscuolo et al. (2005) at the regional level, suggest that firms actually pursue simultaneously adaptive and innovative international knowledge seeking strategies.

A complementary line of analysis has been dedicated to the main determinants influencing the locational choices of MNCs mainly relying on the inventor(s)'s address (Guellec and van Pottelsberghe de la Potterie, 2001, Picci 2010) and the citations contained in the patents documents (Cantwell and Piscitello 2005). Additional evidence on the main location factors has been also been gathered through surveys⁵ (Florida 1997, UNCTAD 2005, European Commission 2013). These studies show that the internationalization of R&D and innovative activities is mainly driven by a combination of interrelated supply- and demand-side factors, and by the technological and institutional attributes of the home and host economies. Important supply-side factors

⁵ Comprehensive reviews on the determinants of international R&D activities can be found in OECD 2008, 2011.

include the motives and type of R&D activities (UNCTAD 2005, Criscuolo et al. 2005), firm size and corporate performances, the co-location of production activities, as well as the specific managerial and organisational practices of the firms (i.e. R&D management and flexibility, communication and problem-solving, see Moncada-Paternò-Castello et al. 2011). Besides firm-specific characteristics, the decisive factors for MNCs have been identified in relation the host country's attributes such as:

i) the market features (size, growth potential, purchasing power). Following the traditional market and demand-driven orientation, most studies argue that the size and the characteristics of the local markets have a positive influence on the locational choices of firms. That is firms would set up foreign R&D laboratories in order to respond to demand needs/customers preferences.

ii) the presence of high quality scientific infrastructure and human resources. Firms would favour countries well-endowed with for instance universities and, research and technological centers of excellence and with a higher proportion of scientists, engineers or higher education graduates.

iii) the agglomeration forces (clusters, scientific parks, outstanding innovative or creative cities, etc). Firms may favour a particular location in order to beneficiate from the knowledge activities developed by companies from the same industry (intra-industry and specialization spillovers or proximity to other companies) or firms operating in different industries (inter-industry and diversity externalities) (e.g. Cantwell and Piscitello 2005, Alcácer and Chung 2007). Furthermore, agglomeration may exhibit some asymmetries along different dimensions (Boschma et al. 2015) suggesting that the related determinants may affect differently the location decisions of firms across industries (or technologies). Although these forces are expected to play a significant role on the location decision, the application of such a proximity-based approach on country level data would entail several restricting, and even fallacious assumptions. Symmetrically, geographical distance, contrary to proximity, is expected to exert a negative effect on the probability of firms to locate in a country given the increased costs it entails.

iv) tax breaks and government support, legal and intellectual property protection systems. An important structural location determinant is the government direct and indirect support to R&D activities. The traditional rationale for government intervention is that, in its absence private R&D spending may be sub-optimal in certain fields. This sub-optimality may emerge due to the specific time (i.e. beyond the lifetime horizon of companies) and investment requirements for developing certain technologies with expected society-wide impacts. It may also result from the extent to which firm are able to appropriate the returns of their R&D investments. Therefore firms would tend to locate in countries characterized by a strong or reliable protection of intellectual property (ies), thus limiting the risk of leakage or imitation. However, as underlined in the OECD review (2008), evidence on the relationship between IPR and the location decision is rather equivocal. Beyond the expected economic growth and jobs prospects, the commitment of national or regional authorities constitutes a relevant signal and a clear incentive for companies willing to further develop their

research and innovation activities. This may lead to a double gain for the related economies which may attract high-value R&D activities as well as allow local firms to benefit from and build upon them.

Nevertheless, the relative importance of these drivers also depends on the technologies, the industries in which such corporations operate and, on the different propensities of resorting to the international markets for their knowledge creation activities.

Furthermore, the economic literature dealing with technological change has underlined the path-dependent and cumulative nature of this process (Dosi 1988, Cantwell 1989, Dosi et al. 1990). In our framework, this should be reflected in the relationship between companies and host-countries technological profiles. This idea is consistent with Cohen and Levinthal's notion of absorptive capabilities (Cohen and Levinthal 1990), defined as the capacity of scanning, accessing and combining external knowledge. Accordingly, firms are expected to seek for new knowledge in technological areas in which they have developed prior knowledge. More recent studies have also referred to this as the willingness of firms to connect related knowledge assets or to establish corporate technological coherence (Cantwell 2009). Akin to the studies on recombination and innovation (Cecere and Ozman 2014), an important dimension of recombinative capabilities⁶ is the extent to which firms locate their foreign R&D activities where complementary knowledge is available. As pointed out by Cecere and Ozman (2014), *"The indirect effect of proximity on innovation works through the recombination capabilities. High recombinative capabilities are best complemented by local search processes"* (p. 651). However the search for too close knowledge increases the probability of redundancy which may lead to lower expected benefits deriving from international knowledge seeking. As a corollary, the selection of technologically distant locations may open more opportunities for explorative R&D and innovation-oriented search, thus limiting the access to redundant knowledge. This creates a tension between distant and local knowledge seeking for firms willing to maintain a certain level of technological variety. The related trade-offs in firms' strategy may entail a non-linear relationship between the technological proximity and the probability to undertake international R&D activities. Therefore:

H1a: *firms tend to search new technological knowledge in areas close to their current strengths (local search) when they undertake international R&D activities*

H1b: *technological proximity has a non-linear effect on the location decision of firms when they undertake international R&D activities*

Among the reasons leading a company to invest in foreign locations, there is the attempt to enter into specific technologies in which the host country has relatively higher comparative advantages (Guellec and Pottelsberghe de la Potterie 2001, Cantwell 2009). In particular, when taking their location decisions firms may favour host countries with superior capacities in developing new emerging technologies, which could lead to the discovery of path-breaking, brand new products and processes

⁶ Recombinative capabilities refer to the internal capabilities of firms to combine previously unconnected elements or to find new ways of combining previously connected elements.

(Schoenmakers and Duyster 2010). Indeed, emerging technologies are perceived as new technologies with the potential to change the economy and society and to contribute to a further technology-driven economic growth (Hung and Chu 2006, OECD 2012, Rotolo et al. 2015). Such technologies can bring an important contribution to the value-added streams through the transformation of existing industries or the creation of new industry (-ies). By tapping into these technologies, firms may gain considerable advantages in maintaining themselves at the edge of the global technological race.

Hence, the high degree of novelty (or newness) characterizing these technologies (Small et al. 2014), is particularly relevant in our framework. It should be noted that the novelty attached to the emerging technologies may be related both to the method or the function fulfilled by the technology. In other words, emerging technologies may build on different basic principles with respect to those used before (Arthur 2007) or may put an existing technology into a new use (Adner and Levinthal 2002) and thus (re)invigorating already existing knowledge.

In our framework, the search for new technologies implies that companies will prefer locations with a higher specialization in emerging technologies.

However, the two dimensions (radicalness and cumulateness) of emerging technologies imply a tension in the search for new knowledge. From the one hand, the cumulative nature of new technology creation would suggest that companies may obtain additional returns from the adoption of emerging technologies that are close to their technological knowledge; thus somehow relaxing the constraints posed by the companies' absorptive capabilities in their (international) knowledge sourcing strategies. On the other hand, the radical and disruptive character of emerging technologies suggests that companies may look for them in technological domains relatively farther from their knowledge base. Hence companies may either go for location specialized in emerging technologies with a close knowledge base or opt for a 'less close' knowledge base. A priori, we are not able to determine which of the two dimensions prevail in the location decision.

Therefore, on the basis of the above arguments we expect that:

H2a: *firms are more likely to locate their international R&D activities in countries with relatively higher technological advantages in emerging technologies*

H2b: *firms are more likely to locate in countries with relatively higher technological advantages in emerging technologies depending on the level of technological proximity*

These mechanisms have not yet found empirical confirmation. The validation of these hypotheses, especially when jointly hold with H1, would contribute to fill a gap that has been long standing in the empirics of international knowledge seeking.

3. Empirical application

3.1 Data

Our analysis makes use of the 2013 EU Industrial and R&D Investment Scoreboard, which provides annual data on the top 2000 R&D investors worldwide, accounting for about 80% of the world's business investment in R&D (European Commission 2013).⁷ The patents filed by these companies at the US Patent Office (USPTO) have been retrieved from the PATSTAT⁸ database in the framework of a JRC-OECD joint project. The matching has been carried out on a by-country basis using a series of string matching algorithms contained in the Imalinker system (Idener Multi Algorithm Linker) developed for the OECD by IDENER, Seville, 2013.⁹

The matching exercise employs information on the Scoreboard companies' subsidiary structure (about 500,000 subsidiaries) as reported in the ORBIS database. Subsidiaries located in a different country with respect to a company's headquarter have been included when performing the matching of patents to company-level data. Their patent applications have been associated to their ultimate owner. A more extensive description of the approach used to perform the matching between Orbis and PATSTAT can be found in Squicciarini and Dernis (2013), while a thorough illustration of the innovation activities of the world corporate top R&D investors can be found in Dernis et al. (2015).

The final dataset includes information on patents filed at the USPTO over the period 2010-2012 for the 1594 MNCs with at least one application at that office. These companies, with headquarters located in 38 different countries, have filed about 470,000 patent applications, representing about 29% of the total patent applications at USPTO over the same period. Table A1 (in appendix) shows the distribution of international patent applications across destinations. The dataset is completed by a series of country-specific information discussed in the next section.

Of course, patents data entail several well-known shortcomings¹⁰. The recourse to patents differs greatly across firms and sectors. Systematic classifications of patents based on their relative value remain very rare so that all inventions are considered of equal importance. Besides some inventions are not patented, although they may lead to successful innovations. Nevertheless patents constitute a relevant and unique proxy to study the inventive activities of companies (Acs and Audretsch 1989, de Rassenfosse et al. 2013) as they are made available on long time periods and increasingly for a larger set of countries¹¹. Moreover patent documents provide a wealth of information

⁷ For more information on the sample of companies included in the EU Industrial and R&D Investment Scoreboard, see <http://iri.jrc.ec.europa.eu/scoreboard.html>.

⁸ PATSTAT is the European Patent Office's Worldwide Patent Statistical Database which contains data about 70 million applications of more than 80 countries. See more details at <http://www.epo.org>.

⁹ For a description of Imalinker, see <http://www.idener.es/?portfolio=imalinker>.

¹⁰ See for instance Griliches (1990), Archibugi (1992).

¹¹ Beyond the overall increase in patent applications, this refers notably to the international efforts and collaboration made to link or to harmonize the patents procedures and data across several national and regional IP Offices, as the IP5 and its Ten foundation projects (see

concerning inventors, the applicants and the technical characteristics of the invention, all relevant for our analysis. The different areas of technology to which patents pertain are classified according to the International Patent Classes (IPC). For comparability and interpretation purposes, these technologies have been reassigned to the 35 technological fields originally developed by Schmoch (WIPO 2013). The R&D locations are determined by using the residence of the inventor(s), which proxy the country (-ies) in which the research leading to the invention has been carried out. Such approach has been used by, among others, Guellec and Pottelsberghe de la Potterie (2001), Archibugi and Iammarino (2002), Le Bas and Sierra (2002), Picci (2010), and Schettino et al. (2013).

3.2 Variables description

To investigate the decision of companies to locate R&D activities abroad, patents are assigned to the country of residence of the inventor(s)¹² at the origin of the technology to be patented. International patenting activities are detected when the location of the inventors differs from that of the Scoreboard company legally owning the intellectual property right. In the multi-inventors and multi-countries cases, fractional counts of the same patent between the different countries are applied.¹³ One fifth of the patent portfolio of our sample has involved inventor(s) from countries different from the headquarter location.

Upon this setting, the determinants of the location decision of top corporate R&D investors are investigated relying on the main factors identified by the previous literature.

The revealed technological advantage (RTA) is a common indicator to assess the degree of technological specialization. It is constructed as the revealed comparative advantage defined by Balassa (1965) which characterizes the relative weight of an economic sector on dimensions such as trade, production, R&D or patents (Patel and Pavitt 1991, Cantwell et al. 2004, Liegsalza and Wagner 2013). In this paper we use the revealed technological advantage (RTA) to compute the host countries' specialization in emerging technologies. As put forward by Rotolo et al. (2015), there are multiple definitions and methodologies in the literature to identify emerging technologies.¹⁴ Among them, the OECD's definition (2013), based on the Kleinberg (2003)

http://www.wipo.int/edocs/mdocs/aspac/en/wipo_inn_tyo_10/wipo_inn_tyo_10_ref_theme03_1.pdf) or Cooperative Patent Classification (CPC) initiative.

¹² The choice of the inventor's country of residence is the most relevant for measuring the technological innovativeness of researchers and laboratories located in a given country. While patent counts by applicant countries reflect more the degree of control on patents by country's residents, wherever the invention is made (OECD.Stat).

¹³ See Dernis et al. (2001) for a more in depth description of the methodology used.

¹⁴ Recently, Rotolo et al. have suggested a reconciling definition of an emerging technology as *"a radically novel and relatively fast growing technology characterised by a certain degree of coherence persisting over time and with the potential to exert a considerable impact on the socio-economic domain(s) [...].Its most prominent impact, however, lies in the future and so in the emergence phase is still somewhat uncertain and ambiguous."* (Rotolo et al. 2015, page 1828). Following this definition, our conception of emerging technologies is *a priori* narrower due to the intrinsic nature of our data.

methodology, constitutes a relevant choice given the nature and the construction of our data.¹⁵ Accordingly emerging technologies are identified at the 4-digit level of the IPC classification on the basis of the sudden and persistent increase in patent applications pertaining to these technological fields. The RTA of a country in emerging technologies is computed as the ratio between its patent share in these technologies and the share of world patents in the same technologies:

$$RTA \text{ in emerging technologies}_{j05_09} = \frac{share_em_{j05_09}}{share_em_{05_09}}$$

where, $share_em_{j05_09}$ denotes the share of country j patents in emerging technologies over the five years preceding the period in which companies patenting activities are observed - that is, 2005-2009 - and $share_em_{05_09}$ is the same share calculated on the overall world patents.

To quantify technological proximity we use the angular separation measure (and its square) originally introduced by Jaffe (1989) in his analysis of knowledge spillovers¹⁶. In our application this is computed between the host country's and the company's vectors of patent shares across technological fields. In particular, technological proximity between company i and country j is computed across vectors in a 35-dimensional technological space (the technological fields identified by Schmoch) and is calculated as:

$$Technological \ proximity_{ij} = \frac{f_i f_j'}{\sqrt{(f_i f_i') * (f_j f_j')}}}$$

where f_i is the distribution of patents filed by a company i across the 35 technological classes defined by Schmoch over the period considered, and f_j represents the distribution of patents of a country j across the same technological classes. As for the RTA measures, the technologies shares within countries are calculated on the five-year period preceding the actual patenting period of companies (2005-2009). On the same period we calculate the (*Log of*) *number of patents* of the hosting country, which proxies its knowledge base.

From the Main Science and Technology Indicators database (MSTI-OECD) we take the percentage of Business enterprise expenditure on R&D (BERD) financed by the government of the hosting country (*% Gov BERD expenditure*) and the variables used to calculate the difference in the GDP per capita between the hosting country and the top R&D investors' location, the former minus the latter ($\Delta \log \text{ gdp per capita}$). The two variables are calculated on the period 2005-2009.

¹⁵ Emerging technologies are identified as the 4-digit IPC classes that experienced a patent "burst", a sudden and persistent increase in the number of patents filed in the 2000s (OECD, 2013). Patent bursts reflect the increase of patent applications in comparison to those patterns observed in the previous years and in other technological fields. Only IPC combinations with positive bursts are considered.

¹⁶ Jaffe (1986)'s angular separation is still one of the most widely employed measures in the applied research on technological distance between companies or between companies or other entities (see recent uses among other by Aldieri 2013, Bloom et al. 2013)

From the Barro-Lee dataset (Barro and Lee 2010) the difference between the share of tertiary education in the host and origin countries is calculated (*Δ of % of tertiary education*). Unfortunately, these figures derive from census data and are available only with intervals of five years. Our application employs those relative to 2005.¹⁷

Finally, as a common practice in the R&D internationalization literature we control for a series of geographical measures drawn from the *GeoDist* database. This database provides a series of gravity variables developed and described by Mayer and Zignago (2005, 2011). In particular, we use the (*log of*) the *kilometric distance* between the capital of the hosting and original country location of the Scoreboard company and two binary variables as follows: *Common borders* that takes value 1 if the two countries share a border, and *Common language* is they share the same language. Table A2 (in appendix) shows that the correlations between the explanatory variables are generally quite low.

3.3 Econometric strategy

In the empirical application, we model a company's decision to locate its international technological activities upon firms' location and location-specific technological conditions, traditional R&D location factors, and other controls commonly used in the economic geography literature. The drivers of the location decision are estimated with a multilevel mixed-effects logistic regression which allows controlling for both fixed and random effects. The probability of a firm *i* operating in sector *j* to locate in a given country *c* could be written as:

$$P(y_{cij} = 1 | x_{cij}, \mu_i, \gamma_j) = F(\beta x_{cij} + \mu_i + \gamma_j)$$

where x_{ij} identifies the drivers of the company decision to locate in a given foreign country presented in the previous section, μ_i and γ_j are company- and industry- specific random intercepts, and $F(\cdot)$ is the cumulative logistic distribution mapping the linear predictor to the probability of success ($y_{cij} = 1$) with $F(\vartheta) = \exp(\vartheta) / \{1 + \exp(\vartheta)\}$. The random parameters define the stochastic portion (unobserved) of the choice function which can be correlated over alternatives. This property relaxes the assumption of lack of correlation among alternatives characterizing conditional logit models that gives rise to the independence of irrelevant alternatives (IIA) property and its restrictive substitution patterns (Train 2003).

This setting allows a more appropriate modelling of a firm decision to locate in a given country by directly dealing with the clustered structure of the data, where each cluster has its own choice behaviour. Indeed, in the present setting instead of considering all observations at once, these are organized as a series of N independent clusters (our companies) nested into I different clusters (industries).

The mixed logit model has a great flexibility, however the computational burden of the simulation techniques involved has limited its application until the computational capacity of computers has reached levels to ensure results in an admissible time. A

¹⁷ We also tried to use figures relative to 2000 and 2010. The use of different time periods does not affect the results.

similar setting has been used by, among others, Basile et al. (2008) to analyse the subsidiary location of multinational firms in 50 European regions, and Griffith et al. (2014) to ascertain the importance of corporate income taxes in determining where firms choose to legally own their intellectual property rights.

4. Results

The estimation results, summarized in Table 1, provide support for the research hypotheses put forward in the theoretical background. The first two columns (Spec. 1 and Spec. 2) report the estimation results including the differences in language, the geographical distances, the (possible) host country's knowledge base and our main focal variables (the RTA of the host country in developing emerging technologies, the measure of its technological proximity with a given company and its square). The remaining variables discussed above are included in Spec. 3 and 4. Finally, in Spec. 5 we introduce the interaction between a country relative specialization in emerging technologies and its technological proximity with a company.

The distance from the headquarters' location affects negatively the probability of locating innovation activities in a given foreign country, the relative estimated coefficients are negative and strongly significant for all the specifications. However, sharing a common border turns out to not have a significant effect. This finding suggests that despite the strong decrease in communication costs and the increase of communication facilities experienced with the advent of ICT technologies, the organizational and managerial costs of international R&D teams still represent an important barrier to locate R&D activities abroad. On the other hand, when locating abroad companies do not simply "pass the border", but carefully choose their location on complementary criteria as sharing a common language. The dummy indicating the commonality of spoken language positively affects the firms' location decisions. Indeed sharing a common language increases the efficiency in transferring and aggregating knowledge (Grant 1996).

Our proxy for a country knowledge base, or innovation capacity, is positive and significant in all the specifications. Companies tend to locate where knowledge opportunities are higher. This finding is in line with many studies stressing the importance of scientific resources as a motive for R&D investments.

The results support our hypotheses H1a and H1b on the preference of companies to search in the neighbourhood of their current knowledge when they undertake international knowledge seeking activities. The technological proximity between a company and a given country increases the probability of locating R&D investments in this country.

The coefficient capturing this effect is positive in all the specifications and does not vary when additional controls are included. These results support the local search hypothesis. The square of the technological proximity enters with a negative sign in the estimation, where the coefficient of the linear term increases in magnitude; this

suggests a curvilinear relationship between technological proximity and the company's location decision. Firms are more likely to locate in countries whose technological profiles are neither too similar nor too different. This result generalizes previous findings on the alliance strategies in the Information Communication Technologies sector (Cecere and Ozman 2014).

Table 1: The firms' decision to locate R&D in a foreign country

	Spec. 1	Spec. 2	Spec. 3	Spec. 4	Spec. 5	Spec. 6
Log number of patents (<i>destination</i>)	0.675*** (0.015)	0.676*** (0.015)	0.677*** (0.015)	0.777*** (0.017)	0.779*** (0.017)	0.779*** (0.017)
RTA in emerging technologies (<i>destination</i>)	0.509*** (0.049)	0.583*** (0.050)	0.759*** (0.100)	0.501*** (0.062)	0.592*** (0.063)	0.836*** (0.109)
Technological proximity	1.809*** (0.084)	4.214*** (0.328)	4.773*** (0.430)	1.750*** (0.090)	4.720*** (0.360)	5.514*** (0.464)
Technological proximity (square)		-2.651*** (0.349)	-2.689*** (0.349)		-3.273*** (0.383)	-3.342*** (0.384)
Tech. proximity * RTA in emerging technologies			-0.431** (0.213)			-0.603*** (0.219)
Kilometric distance (log)	-0.189*** (0.020)	-0.202*** (0.020)	-0.201*** (0.020)	-0.237*** (0.021)	-0.252*** (0.021)	-0.251*** (0.021)
Common borders (0/1)	0.018 (0.079)	-0.029 (0.079)	-0.030 (0.079)	0.002 (0.081)	-0.050 (0.081)	-0.051 (0.081)
Common language (0/1)	1.022*** (0.046)	1.060*** (0.046)	1.062*** (0.046)	1.040*** (0.051)	1.068*** (0.051)	1.071*** (0.051)
% BERD expenditure (<i>destination</i>)				0.013*** (0.002)	0.013*** (0.002)	0.013*** (0.002)
Δ of log gdp per capita (<i>origin/destination</i>)				-0.187*** (0.036)	-0.177*** (0.036)	-0.178*** (0.036)
Δ in % of tertiary education (<i>origin/destination</i>)				-0.001 (0.003)	0.001 (0.003)	0.001 (0.003)
Constant	-7.919*** (0.239)	-8.336*** (0.246)	-8.564*** (0.271)	-8.684*** (0.265)	-9.188*** (0.272)	-9.507*** (0.297)
<i>Random effects</i>						
Industrial	1.380*** (0.458)	1.260*** (0.424)	1.258*** (0.423)	1.422*** (0.477)	1.276*** (0.434)	1.273*** (0.433)
Company	2.122*** (0.183)	2.050*** (0.178)	2.052*** (0.179)	2.198*** (0.196)	2.107*** (0.189)	2.109*** (0.189)
Observations	39,282	39,282	39,282	35,068	35,068	35,068
Number of industries	31	31	31	31	31	31
Chi-square	3209	3230	3232	3103	3134	3138
Log-likelihood	-22949	-22919	-22917	-21444	-21407	-21403
LR test vs logistic (p-values)	0.000	0.000	0.000	0.000	0.000	0.000

Standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Random effects are the estimated variances of the random intercepts at the industry and company level. The LR test strongly supports the model used with respect to the logistic regression.

Also our hypothesis H2a translating the effect of superior host-country capabilities in emerging technologies on the location decision is confirmed. The related coefficient is positive and stable across the different specifications used. *Ceteris paribus*, and

especially considering that technological proximity is controlled for, companies show a higher probability to locate R&D activities in countries with higher revealed technological advantages in emerging technologies.

This first set of results is particularly interesting from an innovation (and education) policy perspective. Countries willing to attract higher values investments, as those related to R&D activities, should create an environment conducive to the creation and development of brand new ideas with a high potential impact on the long term growth. Indeed, Schoenmakers and Duyster (2010) showed that, contrarily to the conventional wisdom, radical innovations are based on existing knowledge, to a greater extent than non-radical ones do, and mainly derive from the (re)combination of mature and emerging technologies pertaining to different technological areas. This suggests that supporting a multidisciplinary environment, which facilitates the exchange and integration of different knowledge, could be a valuable option to attract further private investments.

Figure 1 presents the predicted location probabilities for different values of technological proximity (right axis) and countries revealed technological advantages in emerging technologies (left axis). The figure shows the inverted-U relationship between technological proximity and a company’s location decision discussed above. Most of the company-country observations have technological proximity values lying in the increasing part of the curve, however for about 10% of the company-country observations (involving almost 500 different companies) the value of the Jaffe measure implies a negative marginal effect of proximity on location probabilities. For these observations, technological profiles are "too close".

Figure 1: Predicted location probabilities for different values of technological proximity and country RTAs in emerging technologies

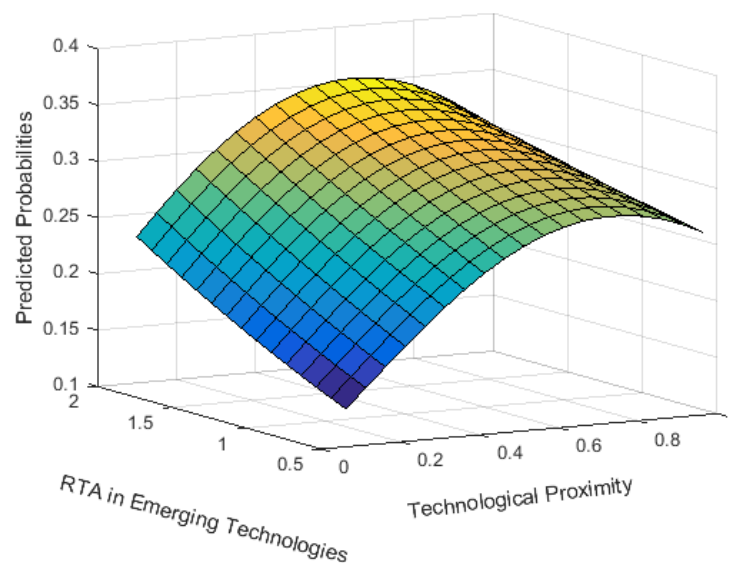


Figure 1 somehow illustrates the tension underlying our hypothesis H2b. For each level of technological proximity, the location probability increases with a country

specialization in emerging technologies (lighter colours going from the right to the left of the figure). However, the negative sign of the coefficient for the interaction between technological proximity and RTA in emerging technologies suggests the existence of a trade-off effect. A higher technological proximity increases the location probabilities especially in those countries with a relatively low specialization in emerging technologies, whereas a low technological proximity seems to be more important for location decisions in countries with a higher specialization in emerging technologies.

This finding echoes the exploiting-exploring organizational strategies discussed by March (1991) and revisited, among others, by Kummerle (1997), and Patel and Vega (1999), in the context of corporate R&D internationalization. Where, in the latter case companies, seeking for new technological opportunities, are willing to explore technological domains relatively farer from their knowledge base; in the first case companies' location decision may be driven by the objective of reinforcing their actual knowledge base.

The positive impact of the percentage of BERD financed by the government confirms the importance of the R&D and innovation support policies, at least in attracting foreign R&D investments.

Controlling for the other factors, companies tend to favour countries with lower levels of GDP per capita. This may reflect the search for skilled labour at a lower cost and is in line with the evidence showing an increasing participation of “less” developed countries in the global knowledge market.

Our proxy for the differences in the countries education levels is positive but the significance does not hold across specifications. In other words, we do not find clear evidence that higher education levels confer advantages in attracting foreign R&D investments of Top R&D investors worldwide. However, it should be considered that the majority of developed and developing countries that constitute our sample have attained high levels of schooling. Therefore, opting for measures related to the quality and organization of the education systems could be preferable and provide clearer results.

5. Conclusion

This paper has shed new lights on the determinants of the international knowledge seeking strategies of the top R&D investors worldwide. Using patent applications at the USPTO we have been able to map their international R&D activities on the basis of the inventor(s)'s location contained in the patent documents. Two main mechanisms were scrutinized, the extent to which companies resort to the international knowledge markets to reinforce their technological knowledge base and to tap into technologies with higher long-term potentials.

Our findings show that top R&D investors worldwide actually perform R&D internationally to search technological knowledge in areas close to their current strengths, i.e. they favour a *local technological search*. However, technological proximity

has a non-linear effect on the international location decision of firms. That is to say that, firms will favour countries which perform relatively well in the technological areas where they have established prior advantages, but only up to a certain threshold. This finding echoes with the Cohen and Levinthal's notion of absorptive capacity.

In a complementary manner, firms also look for the potential advantages deriving from emerging technologies in order to maintain themselves at the edge of the global technological race. However, companies somehow face a trade-off between locating in a country specialized in emerging technologies and a country with a closer technological knowledge. In other words, the attraction effect of emerging technologies fades away with higher levels of technological proximity.

Emerging technologies are receiving an increasing attention both from the policy and the academic communities. Indeed, they are perceived as technologies which can provide solutions to global challenges and ground for sustainable business opportunities (WEF 2014) with the potential to change the economy and society (Rotolo et al. 2015). Most of the attention has been posed on the definition of different approaches to detect which technologies have the greatest potential impact in the medium and long-term. However, very little knowledge concerning the impact that the realization and widespread use of these emerging technologies has been so far produced. More research is needed to understand the conditions for the emergence of certain technologies and their effects on country and regional development paths.

Our contribution suggests that creating an environment conducive to the development of emerging technologies not only could lead to a sustained growth, but is also a leverage for countries to attract high value foreign investments. Particularly interesting from a policy perspective is the fact that emerging technologies largely derive from the use of existing technologies for new purposes (Adner and Levinthal 2002) and that radical innovations steam from existing knowledge as a (re)combination of mature and emerging technologies from different domains (Schoenmakers and Duyster 2010). Indeed, creating multidisciplinary environments that facilitate the exchange and integration of different knowledge areas (or supporting multi-technology projects) can trigger new technological opportunities. Moreover, public policies encouraging entrepreneurial initiatives in areas related to new technologies may lead to technological advancements typically not yet foreseen by policy-makers and/or potential customers. Finally, supporting the commercialization of products incorporating these emerging technologies can foster their diffusion and the development of (new) industries. Analysing which kind of policies are likely to have the highest impact is beyond the objective of this contribution. We are confident that the renewed interest on innovation and industrial policies will provide new evidence to guide the policy action.

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Appendix

Table A1: Distribution of patent applications across foreign destinations

Country	% of patents	Country	% of patents
United States	31.6	Belgium	1.6
Germany	12.8	Austria	1.4
China	12.3	Australia	1.0
United Kingdom	7.0	Korea, Republic Of	1.0
France	5.7	Taiwan	0.9
Japan	4.6	Finland	0.8
Canada	4.1	Spain	0.7
India	3.2	Ireland	0.4
Italy	2.6	Denmark	0.4
Israel	1.8	Norway	0.4
Switzerland	1.8	Brazil	0.3
Netherlands	1.7	Russian Federation	0.3
Sweden	1.7		

Table A2: Correlations between explanatory variables

	Avg.	1	2	3	4	5	6	7	8
1 Log number of patents (destination)	9.250	1							
3 Technological proximity	0.354	0.061	1						
2 RTA in emerging technologies (destination)	1.117	-0.271	-0.057	1					
4 Log of Kilometric distance (origin/dest.)	8.430	-0.093	-0.097	0.066	1				
5 Common borders (0/1)	0.056	0.024	0.034	-0.027	-0.487	1			
6 Common language (0/1)	0.143	-0.105	0.064	0.110	-0.119	0.408	1		
7 % BERD expenditure (destination)	7.914	-0.327	0.035	-0.047	0.022	-0.038	-0.115	1	
8 Δ log gdp per capita (origin/destination)	-0.326	0.228	-0.025	-0.255	-0.123	0.042	-0.003	-0.387	1
9 Δ in % of tertiary education (origin/dest)	-5.000	0.036	0.002	0.110	-0.281	0.167	0.0621	0.145	0.412

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