How global is R&D?: Firm-level determinants of home country bias in R&D

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How Global is R&D?

Firm-Level Determinants of Home Country Bias in R&D*

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Abstract

Despite an increasing internationalization of R&D activities by multinational firms, a major portion of corporate R&D still tends to be concentrated in firms' home countries. We examine to what extent there exists a home country bias in the location of R&D activities of 156 major R&D intensive firms based in Europe, the US and Japan during 1995-2002 and develop hypotheses concerning the firm-level determinants of such home country bias. We define this bias as a share of global R&D activities conducted in the home country that is not proportional to the general attractiveness of the country for multinational firms' R&D activities. We find home bias to be the predominant pattern, but with substantial variation among firms. The extent of the bias increases with the degree of scale and scope economies in R&D, coordination costs of international R&D, and the embeddedness of firms' R&D in home countries' innovation systems. Technology leadership is associated with greater home bias if the home country provides relatively strong intellectual property rights protection and firms face potential knowledge dissipation abroad. Our findings imply that home country bias is to an important extent a response to the economics of R&D and centripetal forces favoring centralization of R&D.

Keywords: *R&D Internationalization; Location strategy; Home country bias; Innovation*

*We acknowledge financial support from EU FP7 grant number SSH7-CT-2008-217436 and KU Leuven grant number DYK-B9640-G.0468.09. We are grateful to the editors Paul Almeida and John Cantwell, Leo Sleuwaegen, Reinhilde Veugelers, Rajneesh Narula, and participants of the 2010 AIB Conference and the 2010 SMS Conference for comments on earlier drafts.

Introduction

There is evidence of an increasing trend in international R&D by multinational firms (UNCTAD, 2005; OECD, 2007). R&D activities are conducted in foreign corporate affiliates not only for traditional aims, such as to adapt home-developed technologies to foreign markets or to support foreign local manufacturing and sales activities, but also to access local technological and scientific expertise abroad and to create new technologies for world markets (Kuemmerle 1997; Ambos, 2005). Despite the growing trend of R&D internationalization, a major portion of corporate R&D is still conducted in the home countries of the multinational firms (Patel and Pavitt, 1991; OECD, 2007; Dunning and Lundan, 2008; Zanfei, 2000; Di Minin and Bianchi, 2011; Blomkvist et al., 2011). The extent to which MNEs concentrate R&D in the home country varies across home countries, industries and firms (UNCTAD, 2005; von Zedtwitz and Gassmann, 2002) and depends on home country characteristics and firms' strategic choices and resources (Pearce, 1989; Narula, 2002; von Zedtwitz and Gassmann, 2002; Berry, 2006; Belderbos et al., 2008). However, despite the attention given to the internationalization of R&D in the literature, no study has attempted to quantify the persistent and disproportional allocation of R&D activities in firms' home countries and to systematically explore its determinants.¹ In pioneering work on the activities of large multinational corporations, Rowthorn and Hymer (1971) and Hymer and Rowthorn (1970) suggested that the international expansion of multinational firms could in principle lead to a convergence of the geographic distribution of multinational activities regardless of the home country of firms, but they concluded that the empirical evidence was not in agreement with this notion. Prior studies have examined the existence of a home country bias in corporate activities such as portfolio investments in (foreign) equity markets (e.g. Lewis, 1999; Ke et al., 2009) and trade (e.g. Chen, 2004; Wolf, 2000), but not specifically in R&D.

¹ Partial exceptions are case studies of, respectively, a small sample of Norwegian firms by Narula (2002), and major telecommunication firms by Di Minin and Bianchi (2011).

In this paper we assess the extent of the home country bias in the location of R&D activities in a large sample of multinational firms and we seek to understand the firm-level determinants of this home bias. We explicitly address the conceptual issue of how to measure home bias, by considering home country bias to exist if the share of global R&D conducted at home exceeds a 'benchmark' share that would be expected if the distribution of R&D would be solely based on the relative attractiveness of countries for R&D investments in the relevant technology domain. In other words, the benchmark share represents the hypothetical distribution of R&D if a firm would not have a home base and would effectively take a 'bird's eye' view of the world, freely locating R&D in accordance with host and home countries' attractiveness. Hence, home bias is not simply a relatively high percentage of R&D concentrated in the home country, but also depends on the favorable or unfavorable conditions for R&D at home and abroad, while these (relative) conditions vary by home country and by industry.

We develop hypotheses on the firm-level determinants of a home country bias in R&D, drawing on the literature streams on R&D internationalization, innovation, and R&D organization. We test our hypotheses on a sample of 156 top R&D spending multinational firms based in 11 different home countries (US, Japan and 9 European countries) and active in the IT hardware, chemicals, pharmaceuticals, electrical machinery and electronics, and engineering and general machinery industries in 1995-1998 and 1999-2002. Using a 'revealed attractiveness' measure of the benchmark value of R&D derived from patent-based indicators on global cross-border R&D flows, we find home bias to be the predominant pattern, in particular for firms based in smaller European countries and Japan, but with substantial variation among firms. Controlling for the home country environment, the home country bias is higher for firms that are active in scale intensive technologies, that have diversified technology portfolios, that face greater costs of coordinating R&D in overseas affiliates, and that are strongly embedded in their home country innovation system. Technology leadership is associated with a greater home bias if the home country provides

relatively strong intellectual property rights protection and firms face potential knowledge dissipation abroad.

Our analysis provides a number of contributions to the literature on R&D internationalization, by explicitly addressing the issue of a home bias and conceptualizing it, by providing first systematic evidence of the drivers of such home bias, and by (re)emphasizing the potential costs of R&D decentralization and internationalization, which have not received much attention in recent empirical work on global R&D. Our results are in line with suggestions in case studies that home country embeddedness as well as superior appropriability conditions in case of R&D centralization play a role (Di Minin and Bianchi, 2011; Narula, 2002), but concludes that the latter effect is conditional on technology leadership and appropriability conditions at home and abroad.

In the next section we provide a brief overview of the relevant theory and derive hypotheses on the firm-level determinants of home bias. The subsequent section describes the data, methods and variables. We then present the empirical results. We discuss the implications of our findings for the literature streams on international R&D and R&D organization in the final section of this paper.

Theory and Hypotheses

The most straightforward framework to examine the home bias and geographic centralization in corporate R&D activities is the centralization vs. decentralization framework of Pearce (1989). In this framework, a distinction is made between centripetal forces that support a tendency to centralize R&D in the firm's home country and centrifugal forces that pull corporate R&D activities to locations outside the home country.

Along with the increasing internationalization of R&D activities by MNEs in the last decades, centrifugal forces have received most attention as location determinants of foreign R&D activities. Centrifugal forces have been categorized as two major motivations of MNEs to

internationalize R&D (e.g. Hakanson and Nobel, 1993; Kuemmerle, 1997; Florida, 1997; Cantwell, 1995). Traditionally, MNEs conducted R&D activities outside their home countries to support manufacturing activities of local subsidiaries or to adapt products and technologies developed in their home countries to local market conditions ('home base exploiting' or 'adaptive' R&D), in line with Vernon's product life cycle theory (Vernon, 1979). A second motivation for international R&D is to develop new technologies overseas by accessing foreign R&D resources and local technological and scientific strengths ('home base augmenting' or 'innovative' R&D). Empirical evidence suggests that this latter motivation is gaining importance in recent years (Florida, 1997; Kuemmerle, 1997; Ambos, 2005; OECD, 2007; Todo and Shimizutani, 2008; von Zedtwitz and Gassmann, 2002; Song et al, 2011; Cantwell and Mudambi, 2005; Song and Shin, 2008; Chung and Yeaple, 2008; Chung and Alcacer, 2002) and can lead to knowledge sourcing with a positive impact on the performance of home country or overall R&D operations (Iwasa and Odagiri, 2004; Penner-Hahn and Shaver, 2005; Griffith et al, 2006; Lahiri, 2010; Nieto and Rodrigues, 2011; Criscuolo, 2009).

In contrast, potential centripetal forces that lead firms to centralize R&D in their home countries have received much less attention in recent studies of international R&D. Early studies by Hewitt (1980) and Hirschey and Caves (1981) emphasized that one reason to centralize firms' R&D activities at home relates to the realization of economies of scale and scope. The (partly) indivisible nature of R&D activities leads to economies of scale and makes it less effective for firms to expand their R&D to new laboratories because assets and personnel of existing R&D sites are not fully utilized (Pearce, 1999; Hirschey and Caves 1981; Hewitt 1980). Firms' R&D activities are also subject to economies of scope due to knowledge spillovers between R&D activities in different technology fields (Henderson and Cockburn, 1996; Leten et al., 2007; Arora et. al. 2011). A second factor keeping R&D at home close to firms' headquarters is the fear of a dissipation of R&D results and technological secrets to (foreign) competitors. Dispersion of R&D across multiple sites renders

corporate control over external knowledge flows more difficult and is likely increase the hazard of knowledge outflows. Geographic proximity to foreign rival firms increases the risk of knowledge spillovers (Alcacer and Chung, 2007; Alcacer and Zhao, 2012; Belderbos et al, 2008; Shaver and Flyer, 2000), while centralizing R&D enables firms to retain tighter control of firms' proprietary assets (Rugman, 1981; Pearce, 1999; Di Minin and Biachi, 2011). The coordination of R&D activities between MNEs' R&D facilities also becomes increasingly difficult and costly if the R&D facilities are globally dispersed. R&D creates knowledge which is partly tacit in nature and therefore requires a high level of communication between the involved parties in order to transfer it (Nobel and Birkinshaw, 1998; Fisch, 2003; Gupta and Govindaranjan, 2000; De Meyer, 1991). Efficient communication necessitates personal contacts and face-to-face interaction, which are both promoted by physical proximity and centralization, although active (but costly) international R&D management practices such as international personnel mobility and co-practice may facilitate effective international communication and knowledge transfer (Frost and Zhou, 2005; Singh, 2008; Lahiri, 2010).

A final factor explaining centralization of R&D at home, which is not part of the original centrifugal-centripetal forces framework, is formed by the possible advantages that R&D conducting firms obtain from maintaining a presence at home. R&D capabilities are developed through persistent interactions with local firms, universities and other knowledge institutions, leading to a co-evolution of technological capabilities (Murmann, 2003; Freeman, 1987; Leydesdorff and Etzkowitz, 1996; Lundvall, 1992; Nelson, 1993). To an important extent, firms develop their technological strength by drawing on technological and organizational capabilities of their home countries (Kogut, 1991) through their strong embeddedness in the local system of innovation. Such embeddedness and 'fit' between firm and home country capabilities is likely to reduce the relative attractiveness and effectiveness of foreign R&D.

Below we draw on the centrifugal vs. centripetal forces framework and the literature streams on international R&D, innovation and R&D organization to derive a set of hypotheses on the firm-level determinants of the home country bias in the location of corporate R&D activities.

Economies of Scale and Scope

Economies of scale and scope can play an important role in firms' decisions to centralize R&D activities in their home country. First, R&D activities are typically characterized by strong scale economies, although substantial differences across technologies and industries are observed (Kuemmerle, 1998; Ambos, 2005). Kuemmerle (1998), for instance, found that the optimal size for R&D facilities is larger for electronics than pharmaceutical firms and attributes this difference to the combinatory character of R&D projects in the electronics sector. As noted above, a main source of scale economies in R&D is the indivisible nature of the resources (laboratories and machinery) that are used in R&D projects. It is more efficient for a firm to fully utilize indivisible assets such as equipment for research at a large central laboratory than to invest in a variety of equipment in dispersed small-scale R&D sites (Pearce, 1999; Hirschey and Caves 1981; Hewitt 1980). When scale economies are large for the type of R&D and technological search conducted by firms, firms need to organize their R&D activities in sufficiently large laboratories to achieve the minimum efficient scale for effective R&D (Perrino and Tipping, 1991; Kuemmerle, 1998; Arora et al., 2011).

Second, centralization decisions are affected by the potential to realize scope economies in R&D activities. Technologically diversified firms are well positioned to benefit from scope economies due to the potential to realize knowledge spillovers between different technology fields (Henderson and Cockburn, 1996; Leten et al., 2007; Nesta and Saviotti, 2005). Sources of scope economies relate to the establishment of technology platforms, joint access to specialized equipment, and synergies in technology development through interdisciplinary interaction, for

example by creating technology fusion innovations that combine knowledge from diverse technology fields (Kodama, 1992). The literature on R&D organization posits that, given the tacit nature of much technological knowledge and the related importance of personal face-to-face contacts, firms can promote the realization of knowledge spillovers, and lower coordination costs, by centralizing R&D (Argyres, 1996; Argyres and Silverman, 2004; Kuemmerle, 1998).

In conclusion, firms conducting R&D activities in scale intensive technologies and firms with a diversified technology portfolio and the potential to realize economies of scope in technology development will benefit from centralization of their R&D activities. Such centralization is likely to imply centralization in the home country, given that this is the location where firms' initial R&D investments have been sunk and where the headquarters is located, and given the advantages of easy communication between the central R&D unit and the headquarters (Di Minin and Bianchi, 2011; Pearce, 1989). This leads to the following two hypotheses:

Hypothesis 1a: The home country bias in R&D is stronger for firms that are active in technology fields in which scale economies in R&D are important.

Hypothesis 1b: The home country bias in R&D is stronger for firms that can benefit from scope economies in R&D, i.e. technologically diversified firms.

Embeddedness in the Home Country Innovation System

Firms do not only rely on internal innovative capabilities but increasingly draw on external knowledge sources such as customers, suppliers, other firms, public research institutes and universities (Chesbrough, 2003; Cassiman and Veugelers, 2006; Laursen and Salter, 2006; Marin and Bell, 2010). To gain access to external knowledge, firms need to participate in local innovation communities and establish close relationships with local firms and institutions to get 'embedded' in

the local innovation system (Frost, 2001; Belderbos, 2003, Andersson et al., 2005; Lane and Lubatkin, 1998; Phene and Almeida, 2008; Santangelo, 2012). A firm is well embedded in a local innovation system when the other actors in the innovation system regard the firm as an insider and this can require substantial commitment in terms of localized involvement in R&D (Cantwell, 2009; Frost, 2001; Song et al, 2011; Cantwell and Mudabmi, 2011).

Both formal and informal mechanisms are used by firms to get embedded in an innovation system (Gertler et al., 2000). Formal mechanisms to link up with local innovation actors typically involve contracts, and encompass activities such as joint R&D projects, licensing, consulting, and training. Informal mechanisms refer to non-contractual interactions, such as informal meetings with scientists and engineers belonging to the local community (Cuervo-Cazurra and Un, 2010). To benefit from local innovation networks, firms need to build relationships with local actors, share information and knowledge, and cultivate mutual trust in the local technical community (Furman, 2003; Li et al., 2010). Relational trust between actors helps to overcome an important obstacle for knowledge exchange, namely the fear of unwanted knowledge spillovers (Dyer and Singh, 1998). Establishing relationships with external organizations and promoting reciprocal knowledge exchange makes knowledge transfer channels function better (Phene and Almeida, 2008). The deeper and more extensive a firm's relationships with local economic actors, the stronger will be its ability to access complex and tacit knowledge from the local environment, which requires frequent personal interactions (Lane and Lubatkin, 1998). Persistent interactions between firms, universities and other knowledge institutions may furthermore lead to a co-evolution in specific technological capabilities among the partners in the national innovation systems (Freeman, 1987; Kogut, 1991; Leydesdorff and Etzkowitz, 1996; Lundvall, 1992; Nelson, 1993; Furman, 2003), strengthening embeddedness and contributing positively to the innovative performance of firms that actively participate in the local innovation system.

Once linkages to a local innovative community are developed in the home country, a firm can maintain this local network at a relatively low cost, whilst constructing linkages with new expert communities in other countries is time-consuming and costly. This may be particularly so if firms set up new R&D activities in different cultural and social environments, which may complicate the process to become recognized as a legitimate actor in local innovation communities (Frost, 2001). Hence, when firms are strongly embedded in their home country innovation system, it is a relatively less attractive option to initiate and extend foreign R&D activities in less familiar innovation systems abroad (Narula, 2002).

While the above arguments relate to the relative efficiency of R&D in the home country and abroad in relationship with home country embeddedness, there are also behavioral, not necessarily efficiency enhancing, explanations for home bias effects of national embeddedness. The extant literature on the geography of innovation, R&D alliances and collaboration has suggested that a strong embeddedness in (local) networks can potentially lead to inertia that holds firms back from entering into other and potentially more successful networks because of group pressure to extend collaborative relationships within the existing community (Gulati et al., 2000; Pouder and John, 1996) and a natural tendency of people and firms to restrict openness to alternative sources of information and alternative ways of technology development and networking when they are 'over-embedded' in existing innovation communities (Nahapiet and Ghoshal, 1998). Such an overembeddedness can result in so-called 'familiarity' or learning traps (Ahuja and Lampert, 2001; Levinthal and March, 1993), reducing the firm's willingness to experiment with new problem solving approaches. Given the pace of technological development in high tech industries, firms focusing disproportionately on technological developments inside their home country's innovation system, risk to miss important technological developments outside their sphere of current search, with potential detrimental effects on their performance and survival in the long run (Levinthal and

March, 1993). This suggests that embeddedness could lead to a self-reinforcing tendency to concentrate R&D at home and a potential suboptimal allocation of R&D resources.

Together, these arguments suggest that firms with strongly embedded home country R&D operations will have a tendency to locate a disproportionately high share of their R&D activities in their home country. This leads to the following hypothesis.

Hypothesis 2: The home country bias in R&D is stronger, the more embedded the firm is into the innovation system of the home country.

Coordination Costs in International R&D Operations

Keeping coordination costs in check is a key challenge for international R&D operations. International management studies have pointed out that the integration of knowledge among globally dispersed R&D activities of a MNE is key for successful performance (Singh, 2008) and that this requires substantial coordination and communication efforts (Nobel and Birkinshaw, 1998; De Meyer, 1991). However, communication between different R&D sites across borders may be hindered by obstacles such as geographic, cultural and temporal distances (Sosa et al., 2002). Geographic distance between R&D personnel in laboratories can exponentially reduce the probability of communication about a scientific and technical subject matter (Allen, 1977). Cultural differences can cause misunderstandings between communicating partners. Avoiding these by expanding explanations by the sender and increasing tacit knowledge exchange is costly and reduces project efficiency (Fisch, 2003). Although recent developments in information and communication technologies have somewhat reduced this problem (Howells, 1995), effective coordination still requires face-to-face contacts due to the tacit nature of R&D. Hence coordination costs remain an important restriction when conducting globally dispersed R&D activities (von Zedtwitz and Gassmann, 2002). Therefore, when coordination costs in a firm's international R&D

network are likely high due to geographic and cultural distance, decentralized R&D to local affiliates is more costly and less efficient than centralized R&D, such that firms are more likely to concentrate R&D in their home countries.

Hypothesis 3: The home country bias in R&D is stronger, the greater the coordination cost a firm is likely to incur in managing its international R&D network.

Technology Leadership and IPR Protection

Firms' technological strengths are also expected to affect the home country bias in R&D. While technologically lagging firms need to tap into external knowledge (abroad) to improve their competitive position, they may not be able to successfully implement a technology sourcing strategy due to a lack of a sufficient absorptive capacity (Cohen and Levinthal, 1990; Penner Hahn and Shaver, 2005; Song and Shin, 2008). Berry (2006) confirmed in an empirical analysis that technology leaders conduct more foreign R&D than technology laggards, and attributes this to differences in absorptive capacity.

On the other hand, firms conducting foreign R&D activities near rival firms risk leakage of their core technologies due to outward knowledge spillovers (Zhao, 2006; Alcacer and Chung, 2007; Alcacer and Zhao, 2012), hampering effective appropriation of the results of R&D. There is ample evidence that such spillovers to local firms do occur (Driffield et al, 2010; Veugelers and Cassiman, 2004; Haskel et al., 2007), and firms are likely to adjust their local R&D strategies to limit potential outgoing knowledge spillovers (Zhao, 2006; Alcacer and Zhao, 2012). Shaver and Flyer (2000) found that technologically leading firms avoid locating in technological clusters in fear of knowledge dissipation, while technology laggards have strong incentives to collocate with other firms because they can expect more incoming than outgoing knowledge spillovers. Similarly,

Alcacer and Chung (2007) demonstrated that technologically leading firms locate away from industrial competitors to avoid out-going knowledge spillovers.

Di Minin and Bianchi (2011) argue that strong intellectual property management through a dedicated unit can be instrumental in limiting unwanted knowledge dissipation. IP management is very often centralized at headquarters (Arora et al, 2011) and is more effective in ensuring appropriability in case R&D is performed near corporate headquarters, compared with R&D performed in remote locations, as effective IP protection measures require information on context and tacit understanding on the innovation process (Di Minin and Bianchi, 2011). In general, the probability of R&D spillovers will be a function of the number of R&D sites the firm operates, as preventing outflows is easier in one large R&D establishment than in multiple peripheral R&D sites (Feinberg and Gupta, 2004). In particular for technology leaders, concentrating R&D at home is likely to have distinct advantages in terms of the effectiveness of appropriation strategies. Such advantages of centralized IP management and R&D will be most pronounced if the home country has a relatively strong regime of IP rights protection facilitating effective IP management (Griffith et al. 2011). At the same time, relatively weak IPR protection abroad implies greater risks of knowledge dissipation (Branstetter et al, 2006; Zhao, 2006). Since technology dissipation is more serious for technology leaders, they will be most responsive to the relative strength of countries' IPR regimes in their R&D location decisions (Belderbos et al., 2008).

The arguments above suggest that technology leaders may have a smaller home country bias compared with laggards because of their stronger technological capabilities and higher absorptive capacity, but only as long as they have few concerns over knowledge dissipation associated with geographically dispersed R&D. If knowledge dissipation concerns are important because of a high risk of technology leakage due to relatively weak IPR protection regimes abroad while the home country provides advantages of a strong IPR regime facilitating IP management, technology leaders are more likely to centralize R&D activities at home. This leads to the following hypothesis:

Hypothesis 4: The home country bias in R&D is stronger (weaker) if a firm is a technological leader and IPR protection in the home country is strong (weak) compared to IPR protection in potential host countries.

Data, Variables and Empirical Methods

We test hypotheses on patent-derived data on the R&D activities of 156 large, R&D intensive multinational firms during 1995-2002. These firms are the largest R&D spending US, Japanese and European (including firms from France, Germany, United Kingdom, Belgium, the Netherlands, Finland, Sweden, Denmark and Switzerland) firms and are active in five industries: engineering & general machinery; pharmaceuticals; chemicals; IT hardware (computers and communication equipment) and electronics & electrical machinery. The ‘2004 EU industrial R&D investment scoreboard’ was used to identify the sample firms. The scoreboard lists the top 500 corporate investors in R&D headquartered inside the EU, and the top 500 companies based outside the EU. The sample firms are almost equally distributed across the five industries and the three ‘groups’ of countries: the United States, Japan and Europe. Each European country is the home base of multiple firms in the sample, with the number ranging from just 2 for Belgium to 11 for Germany (see Table 1 below).² The smallest yearly R&D budget of the sample firms amounted to 3 million dollars (ARM in United Kingdom) and the largest reached almost 6 billion dollars (Hitachi).

We use patent data drawn from the European Patent Office to derive indicators of the geographic distribution of firms’ R&D activities. Patent data have the advantage of being easy to access, covering long time series and containing detailed information on the technological content,

² We excluded firms that are the product of large international mergers, because of the bias arising from their multiple home countries. An example is AstraZeneca, which was formed in 1999 as a merger of the British firm Zeneca and the Swedish firm Astra.

owners, and inventors of patented inventions. They also have two important shortcomings, being that not all inventions are patented and patent propensities vary across industries and firms (Griliches, 1990; Hall et al, 2005). This concern is mitigated as we chose industries in which the propensity to patent inventions is relatively high (Arundel and Kabla, 1998). Despite the drawbacks, patents are extensively used as indicator of the extent and location of firms' R&D activities (see, for example: Griffith et al, 2006; Criscuolo, 2009; Guellec and Van Pottelsberghe, 2004; Belderbos et al, 2008; Cantwell and Piscitello, 2005; Allred and Park, 2007), given that systematic firm-level data on R&D expenditures by location and technology field are either not collected or not generally available for analysis. We do note that patent-based indicators of R&D are perhaps more likely to represent (foreign) research activities than (foreign) development activities directed at testing, incremental changes and (local) adaptation. So in this sense, our analysis will generally place more emphasis on research activities than on development efforts.

We use data on patent applications rather than grants, because applications are a more encompassing indicator of firms' geographic scope of R&D activities than patent grants, as the latter exclude R&D efforts and inventions that do not result in grants.³ A major reason to use patent data drawn from the European Patent Office (EPO) is that these have the advantage that all patent application data are published, whereas the US patent office (USPTO) only started to publish patent applications from 2001 onwards. The use of patent data from a particular patent office may however also introduce a geographic bias. We discuss the potential implications of the use of EPO patent data further in the empirical results section.

We constructed patent datasets of firms at the consolidated level, i.e. all patents of the parent firm and its consolidated (majority-owned) subsidiaries are taken into account. The consolidation was conducted on a yearly basis to take into account changes in the group structure of sample firms

³ The patent grant rate at the European Patent Office is, on average, 59% (Van Pottelsberghe, 2007). We discuss potential bias due to the use of EPO data in the final paragraph of the empirical results section.

due to acquisitions, mergers, green-field investments and spin-offs. For this purpose, yearly subsidiary lists of firms included in corporate annual reports, yearly 10-K reports filed with the SEC in the US and, for Japanese firms, information on foreign subsidiaries published by Toyo Keizai in the yearly 'Directories of Japanese Overseas Investments' were used. Address information of patent inventors is used to determine the country of origin of patents, assuming that inventors live in the vicinity of their workplace. Inventor addresses give a much more accurate indication of patents' geographic origin than company addresses as firms frequently assign patent ownership to another subsidiary than where the research is conducted, such as the corporate headquarters (Deyle and Grupp, 2005) or subsidiaries that are located in countries with a (relatively) low patent income tax rate (Griffith et al, 2011). For these reasons, the OECD manual of patent statistics (2009) recommends to base geographic patent variables on inventor addresses. If a patent lists inventors based in more than one country, the patent is counted in full in each country.

Dependent Variable: Home Country Bias in R&D

Based on the firms' patent applications we derive the actual share of the firms' technology development activities in their home countries. We do this for two 4 year periods within the period of investigation (1995-1998 and 1999-2002). We take this conservative approach aggregating over 4 years because yearly patent data, as 'intermediate output' indicators of R&D activities, can fluctuate based on accidental R&D performance differences rather than reflecting underlying R&D allocation decisions. In particular for firms with smaller R&D budgets and smaller numbers of yearly patent applications, the share of home country invented patents can be volatile over years. A 4 year aggregation will provide a more reliable picture of actual R&D locations and home country shares in global technology development activities. The two-period approach then still allows for the examination of changes over time in the home bias and the use of panel data techniques to exploit the information in this variation. The approach gives us a total of 298 observations across

the two periods for the 156 firms. Most firms are observed twice; a small number of firms (15) is observed only in one of the two periods because they emerged as independent major players in their sector after spinoffs (e.g. ASML in semiconductors), or were not included in the analysis before a merger.

Based on the consolidated patent data in the 4-year periods, we first calculate the share of patents invented in the home country. We then compare this share with a hypothetical 'benchmark' share. The ratio between the two shares is the home bias. The benchmark share represents the hypothetical distribution of R&D if a firm would not have a home base and would effectively take a 'bird's eye' view of the world, freely locating R&D in accordance with countries' attractiveness. Such attractiveness will be related to the industry and technology domains of the firm, as specializations and capabilities of countries differ across industries. The derivation of a benchmark that reflects the attractiveness of various (host) countries is not trivial. We chose a 'revealed attractiveness' measure to calculate the benchmark value: the actual distribution of foreign R&D activities in the world over host countries. The logic of this measure is that one expects that, conditional on the fact that firms decide to locate R&D activities abroad, the distribution of foreign R&D activities should reflect the relative attractiveness of the various (potential) host countries. Equation (1) defines the home bias of firm i in industry k :

$$\text{home bias}_{i,t} = \frac{\text{actual home R \& D share}_{i,t}}{\text{benchmark home R \& D share}_{k,t}} \quad (1)$$

where suffix t refers to the two 4-year periods. A ratio greater than 1 indicates a home country bias in the location of R&D.

In order to operationalize the benchmark home R&D share, we take all patent applications at the European Patent Office (in each 4-year period) of which the inventors reside in different countries than the patent owning corporation, and calculate the share of each host country in this global distribution of 'foreign invented' patents. We do this per main technology domain with

relevance for the industry in which the sample firms are active: For the pharmaceutical and chemical industries we use the main technology class "Chemistry and Pharmaceuticals", for the electronics and IT hardware industries we use the domain "Electrical Engineering" and for the engineering and machinery industry we use the domain "mechanical engineering". The main technology domains are taken from a technology classification that assigns all IPC (International Patent Classification) technology codes on EPO patents to one of five main technology classes based on similarities of technologies. This classification has been jointly created by three institutions: Fraunhofer-Gesellschaft-ISI, Institut National de la Propriété Industrielle (INPI), and Observatoire des Sciences and des Techniques (OST) (OECD, 1994).

Insert Table 1 about here

Columns (3) and (4) of Table 1 illustrate the key ingredients of the home bias measure in terms of average values for the sample firms per home country over the two periods. The table shows that on the basis of the distribution of patent-derived foreign R&D activities in the world⁴, the United States is the most attractive location for foreign R&D, with a share of 'global foreign R&D' of 19 per cent. The US firms in the sample conduct on average 74 per cent of their R&D at home. This indicates a relatively 'mild' average home bias, which is confirmed by the fifth column

⁴ These numbers are comparable to the numbers on foreign owned patents published by the OECD (e.g. OECD, 2009) and are derived with the same methodology. There is a non-trivial variation in the benchmark value (the foreign patent shares of countries) across main technology domains. For instance, 23% of foreign patents in chemical and pharmaceutical fields are invented in the US during 1999-2002, while this share is only 14% in mechanical engineering and machinery.

of Table 1, where the average home bias across US firms is 3.8.⁵ Overall, a home bias is present, on average, in the R&D activities of firms in all home countries under consideration, with the home bias largest for firms based in Finland (98.6) and smallest for UK firms (3.1). The comparison of the benchmark share with the actual share of home R&D shows that there is a home country bias (a ratio greater than 1) for almost all observations (289 out of 298; not in Table 1).

Table 1 shows that the average home bias is substantially larger for firms in some but not all smaller countries, as well as for Japan. Although firms in small open economies such as Denmark and Sweden are conducting a sizeable share of their R&D abroad, which is greater than the share of foreign R&D of firms based in most large home countries, their domestic R&D share is still not commensurate to the minor role that their home countries play in global R&D attractiveness. For the sample firms based in Belgium and Switzerland this is different, as they pair a strong R&D internationalization to a relatively strong attractiveness of their economies for (foreign) R&D. Note, however, that the average home country bias for the smaller countries is based on a small number of observations and should not be taken as a clear indicator of the overall home bias of MNEs in these countries. The final four columns of Table 1 show that the averages hide a wide variation across firms. For instance, in Denmark chemical firm Borealis exhibits a 'foreign R&D bias' rather than a home bias, while pharmaceutical firm Lundbeck conducts more than 100 times as much R&D abroad as would be predicted by the benchmark share. It is this type of cross-firm variation that is the focal point of attention in our analysis of the firm-specific determinants of the home country bias in R&D.

Explanatory Variables

⁵ This is the average across the two periods. We note that the numbers in column (5) are very close, but not exactly equal, to the ratio between the numbers in columns (3) and (4) because the numbers in column 5 are derived as an average over individual firms' home bias ratios. The average of a series of ratios is not exactly equal to the ratio of the averages of the nominator and denominator.

The importance of *scale economies* (hypothesis 1a) in a firm's R&D activities is measured as the weighted average level of scale economies characterizing the technologies that are present in the firm's patenting activities. For the latter we take all patents that are assigned to the parent firm at the start of the period of analysis and are applied for in the 5 years preceding this period. We distinguish between the five main ISI-INPI-OST technology classes because data on scale economies of technologies are not available at a more fine-grained level. The degree of scale economies in a main technology field is related to the predominance of large R&D laboratories in the field, based on the notion that the presence of scale economies in R&D will lead firms to conduct R&D in large laboratories.⁶ We draw on external survey data on the size of R&D laboratories (Ambos, 2005; Kuemmerle, 1998; Perrino and Tipping, 1991), and take the share of large laboratories in an industry as our measure of the scale intensive nature of technologies. We set the threshold for large laboratories at 200 employees. Prior studies have found that in general a laboratory size of 50-100 employees is a minimum for effective R&D, but that there are differences across disciplines in optimal laboratory size (Perrino and Tipping, 1991). The share of large laboratories ranges from 6% in Chemicals to 43% in Pharmaceuticals. At the firm level, the degree of scale economies is the weighted average of the scale economy indicators, with the share of the firm's patents in the five technology fields as weights. Hypothesis 1a predicts a positive influence on the home bias.

The level of *technology diversification* of a firm's technology portfolio as an indicator of potential *economies of scope* (Hypothesis 1b) is measured as the spread of patents in the firm's five year prior patent portfolio over technology fields. Here we can distinguish 30 more detailed technology fields of the ISI-INPI-OST technology classification, which are subfields of the five

⁶ A similar approach -examining size distribution patterns to arrive at estimates of scale economies- has been commonly taken in industrial organization research, where firm/plant size distribution patterns within/across industries are used to assess the minimum efficient scale of operations (e.g. Acs and Audretsch, 1993; Rogers, 1993).

main technology classes (OECD, 1994). The technology diversification variable is calculated as the inverse of the Herfindahl index; this variable takes larger values when the technology portfolio of a firm is more diversified. Hypothesis 1b predicts a positive effect.

We take a revealed measure of embeddedness derived from the firms' patenting activities. *Embeddedness* of a firm's R&D activities within the home country's innovation system (Hypothesis 2) is measured by the intensity with which a firm's home country invented patents cite patents by other firms and institutions located in the home country. Frequent citations to patents by local inventors reveal that the firm draws more heavily on the local innovation base in its technology development activities. Patent citations restrict the scope of patent claims to novelty and represent a link to the pre-existing knowledge base upon which patents have been built (Criscuolo and Verspagen, 2008; Jaffe et al., 2004). This feature has been used by prior studies (e.g. Fleming and Sorenson, 2004; Singh, 2008) to justify the use of patent citations as information on the knowledge base that firms are drawing upon in their technology activities.⁷ The embeddedness measure is the number of cites to patents invented in the home country (excluding self cites) divided by the firm's home country invented patents in the firm's five-year prior patent portfolio. A patent is taken to originate in a firm's home country if at least one patent inventor has its residence there.

We similarly take a partially revealed measure of international R&D coordination costs specific to the firms' international operations. Rather than attempting to include proxies for a range of influences on coordination costs, such as language, distance, and cultural aspects, our revealed measure takes actual patterns of the intensity of cross-border patent citations as indicator of the ease of communication and collaboration. The *coordination costs* that a firm is expected to face in international R&D is measured as the inverse of the average cross-border 'technology transfer intensity' between the home country and all the other countries in which a firm has manufacturing

⁷ Using data on EPO patents and responses to the Community Innovation Survey (CIS) for a sample of French firms, Duguet and MacGarvie (2005) find a positive correlation between the number of citations in firms' patents and the intensity at which firms have sourced external knowledge, confirming the appropriateness of patent citations as indicator of external knowledge flows.

or sales affiliates. Hence, we treat the countries in which a firm has existing establishments as the most relevant potential locations to establish R&D facilities. The technology transfer intensity between two countries is calculated as the relative frequency by which the patents invented in the two countries cite each other, and can vary by technology field (Belderbos et al., 2008). A greater intensity of patent citations suggests a greater ease and intensity of communication and collaboration in R&D between two countries in a technology field, which may be due to differences in the importance of tacit knowledge, language, and geographic and cultural proximity. Formally, the technology transfer intensity between countries h and j , for ISI-INPI-OST main technology field k , is calculated as follows:

$$\text{technology transfer intensity}_{hj,k} = \frac{\text{Citations}_{hj,k} + \text{Citations}_{jh,k}}{\text{Patents}_{h,k} + \text{Patents}_{j,k}}$$

where $\text{Citations}_{hj,k}$ is the number of citations in patents applied by residents of country h (the home country of the firm) to patents applied by residents of host country j at the level of the main technology field k , and $\text{Patents}_{h,k}$ and $\text{Patents}_{j,k}$ are the number of patent applicants in respectively countries h and j at the level of main technology field k . Using the technology transfer intensity for the main technology field which is most closely related to a firm's industry, the technology transfer efficiency faced by the firm is then calculated as the average of the bilateral technology transfer intensities for each pair of the firm's home country and (potential) host countries for R&D. Information on the firms' affiliate network is taken one-year before the 4-year period of analysis. The inverse of the firm-level technology transfer efficiency is a measure of the difficulties the firm is expected to face in terms of international transfer of knowledge, should it decide to locate R&D facilities in the countries of its affiliate network. Hypothesis 3 predicts a positive sign for *coordination costs*.

Technology leadership of a firm is calculated at the level of the firm's main industry and technology domain. It is measured as the worldwide share of the firm's patent applications in the

main ISI-INPI-OST technology class that is most relevant to the industry. This variable is calculated on the five-year prior patent portfolio of the firm. To examine the interplay between technology leadership and *IPR protection*, the interaction effect of technology leadership and the level of IPR protection in the home country relative to potential host countries is included in the model. The relative IPR protection level is calculated as a ratio of the intellectual property rights index in the home country to the average of the indices for the host countries that are likely to be taken into account as potential R&D locations. We take the IPR index from the Global Competitiveness Report published by the World Economic Forum. This index is constructed based on the opinions of multinational firms and experts on the strength of patents, trademarks and copyright protection; it takes values between 0-10, with high scores for intellectual property right systems that are highly aligned with international standards.⁸ Countries in which a firm has prior manufacturing or sales operations are considered as potential R&D locations. Hypothesis 4 suggests a negative main effect of technology leadership, and a positive interaction effect of leadership and the IPR index.

Control Variables

We control for a range of time-variant and time invariant firm-specific attributes that may influence the home bias in R&D. First of all, we include a set of *home country dummies* (with the US as reference group). As we are interested in the sources of firm heterogeneity in the home country R&D bias, we control for general home country influences on the home bias related to country size, geography, culture and so forth. The model also includes a dummy for the *second period*, to control for industry-wide and global macroeconomic influences on the home bias.⁹ We also include a set of time variant firm-specific controls. The *international sales ratio* is the ratio of

⁸ Use of the patent protection index due to Park and Wagh (2002) gives qualitatively similar results.

⁹ We also estimated specifications with sector dummies included, but the sector dummies were never jointly significant.

overseas sales over total sales, and controls for the degree of sales and manufacturing internationalization of the firm. It is expected to carry a negative sign as internationalization increases the need to adapt products and processes to foreign markets and to engage in local knowledge sourcing (e.g. Kuemmerle, 1997; von Zedtwitz and Gassmann, 2002). The home bias in R&D may also be lower for firms that have more *experience in international R&D*, since experiential learning in R&D internationalization can improve firms' capabilities to conduct and benefit from foreign R&D (Belderbos, 2003; Cantwell and Mudambi, 2005; Di Minin and Bianchi, 2011; Ambos and Ambos, 2011). The international experience of a firm in R&D is measured by the number of years since a firm applied for its first foreign-invented patent. The size of firms' *R&D expenditures* may affect the home bias if larger budgets allow spreading R&D investments across locations without sacrificing critical mass in R&D resources in these locations. We include the value of the firms' *R&D expenditures*, deflated and converted into dollar values (expressed in thousand dollars). Finally, we include the firm's *age* and the square term of this variable. On the one hand, younger firms may have a more international and less home-oriented approach to R&D and knowledge sourcing than firms that have long operated in their home countries (Narula, 2002). On the other hand, firms may be more likely to focus on R&D internationalization only after they have built up a solid business at home, in line with Vernon's product cycle theory (Vernon, 1969). We allow for a more complex relationship between the home bias in R&D and firm age by testing for a nonlinear relationship. Information on R&D expenditures, firm age and sales are obtained from Worldscope, Compustat and corporate annual reports. All the control variables are one year lagged to the four-year analysis periods.

Methods

Given that we utilize longitudinal data, with most firms observed twice, we use panel data techniques to relate the home bias in R&D to the set of hypothesis testing and control variables. We

estimate a random effects panel data regression model, which allows controlling for unobserved heterogeneity at the firm level. The Breusch-Pagan test statistic suggested that a random effects model is preferred over a pooled cross-sectional analysis. Estimation of a fixed effects model, on the other hand, is not feasible with a maximum of only 2 observations per firm. The variable of interest, the home bias in R&D, does not change rapidly over time such that a fixed effects estimator relying solely on the within dimension sharply reduces degrees of freedom and the variation in home bias to be analyzed (Hall et al., 2005). Fixed effects analysis would also reduce the number of firms that can be included in the analysis as several firms (15) are only observed once, and does not allow analyzing the effect of time-invariant firm-specific factors such as the home country, which provide essential information in our analysis.

We applied a logarithmic transformation to the home bias measure (dependent variable) and the continuous right hand side variables. This has the advantage that the dependent variable no longer has bounded variance but can in principle vary between minus and plus infinity, allowing the use of linear regression models. The logarithmic specification also implies that we can interpret the estimated coefficients as elasticities.¹⁰ The logarithm was taken after adding the value 1 in case the variable contained values of zero.

Summary statistics and correlations for the (transformed) variables in the analysis are provided in Table 2. Apart from a relatively high, but not unexpected, correlation between technology leadership and R&D expenditures,¹¹ all correlations between the independent variables are well below 0.5 and do not indicate multicollinearity concerns.

Insert Table 2 about here

¹⁰ In case of firm age, the analysis includes the logarithm of age and the square of this logarithm.

¹¹ Omitting R&D expenditures or substituting it by an R&D intensity measure does not materially change the empirical results.

Empirical Results

The results of the random effects panel data regression analyses are reported in Table 3. Model 1 only includes the control variables, and serves as reference case for the hypotheses-testing model 2. The Wald test statistic shows that the model fit (model 2 vs. model 1) improves significantly when the hypotheses testing variables are added. The estimates show positive and significant coefficients for the variables *economies of scale* and *economies of scope (technology diversification)* -the latter at the 10 per cent level (two sided tests)- in support of Hypotheses 1a and 1b. A positive and significant (at the 10 per cent level) coefficient for the home country *embeddedness* variable confirms Hypothesis 2, while the positive and significant (at the 10 per cent level) coefficient of *coordination costs* provides support for Hypothesis 3. The magnitude of the effects of these hypotheses testing variables can be easily seen as the coefficients represent elasticities. A doubling of the degree of scale economies increases the home bias by more than 19 per cent; while a doubling of scope economies (diversification) increases the bias by 14 per cent. For the coordination costs and embeddedness variables these effects are respectively 15 and 7 per cent.

Insert Table 3 about here

Hypothesis 4 also finds support in the empirical analysis. The main effect of *technology leadership* is negative and significant, while the interaction effect between leadership and the

relative *IPR protection* index is positive and significant.¹² The moderating effect of relative IPR strengths of home and (potential) host countries on the relationship between technological leadership and the home bias in R&D is illustrated in Figure 1. The figure shows the predicted home bias level for varying values of technological leadership and relative IPR strength calculated at the mean of the other explanatory variables. The categories “bottom”, “laggards”, “average”, “leaders”, and “top” of the technology leadership axis correspond to minimum, mean minus one standard deviation, mean, mean plus one standard deviation, and maximum values of technology leadership, respectively. The figure shows that, for firms based in home countries with relatively strong IPR protection, the home country bias increases with technological leadership. The magnitude of the effect is substantial: the predicted home country bias almost doubles between the lowest and highest technology leadership values. A much less pronounced relationship is observed for firms based in countries with average relative IPR protection levels. For firms based in home countries with relatively weak levels of IPR protection, the home country bias decreases with technological leadership.

Insert Figure 1 about here

Among the control variables, the country dummy coefficients indicate significant differences on average in the home country bias depending on the home country of the firm. The estimates indicate that UK firms on average exhibit the smallest home country bias, followed by US firms (the reference group). The highest home bias is found for firms based in Finland, followed by

¹² We note that a specification that includes the main effect of IPR protection is less evident as the variation in IPR values is largely captured by the home country dummies. Inclusion of the main effect of IPR protection in the regressions nevertheless produced comparable results.

firms based in Sweden, Japan, and the Netherlands -although we note again that the country effects on the home bias are based on small numbers of firm observations for the smaller European countries. The dummy for the second period has a positive and significant coefficient. This indicates that, after controlling for firm, sector and country effects, there are other factors that increased the home bias in R&D for the sample firms over the period 1995-1998 to 1999-2002.

The time variant firm-level control variables international R&D experience and international sales ratio are not significant. Firm R&D expenditures has a significantly negative coefficient, which is consistent with the notion that firms with larger R&D budgets are more able to reach scale economies in multiple R&D sites. The log linear term of firm age is significantly negative, while its squared term is significantly positive. This indicates a curvilinear relationship with home bias. The estimated coefficients suggest that the home bias declines with firm age relatively strongly up to an age of 40, after which the home bias modestly increases again. This suggests that, once controlled for different level of embeddedness, firms are more likely to reduce their reliance on home country R&D once they get older. Traditional multinationals with a very long history tend to have greater levels of home bias than firms that are 30 years of age, but not much more so than younger firms.

Alternative Specifications and Robustness Tests

We chose a benchmark based on the attractiveness of countries for international R&D as revealed by global patent data. An alternative way to calculate a benchmark is to model attractiveness in a more pro-active manner: select a series of factors known to be important for R&D location decisions from the extant literature and surveys (e.g. Thursby and Thursby, 2006; Athukorala and Kohpaiboon, 2010) and put some weighting scheme on these factors to arrive at an attractiveness index that determines the benchmark value for R&D in the country. We also pursued this alternative method. Specifically, we estimated a regression model relating the sample firms' foreign invented patents in the two 4-year periods in 32 host countries to a set of key host country

characteristics (e.g. technological strength, IPR protection, market size, wage level of engineers). The coefficients of these variables had the correct sign and were significant. The benchmark value was then calculated as the predicted number of patents in the home country based on these estimated coefficients and the values for the country characteristics applicable for the home country, and taking into account the total size of firms' patent activities. Substituting the regression-based home bias measure gave qualitatively comparable results, with somewhat higher standard errors for some of the variables. We attribute this to a potential lower degree of accuracy in the regression-based measure, due to the narrower scope (weights are derived from behavior by a specific sample of firms) and the relatively limited explanatory power of this type of regression analysis (the R squared of the regression model was 30 per cent).

One concern with the use of European Patent Office data is a potential bias occurring due to a greater propensity to patent inventions generated in Europe, in particular inventions by European firms for which the European Patent Office is the preferred patent authority. In the analysis, potential differences in the propensity to patent (at the European patent office) will be largely incorporated in the country dummies. Although there may be other sources of heterogeneity in patent propensities, there appears no a priori strong argument to suggest that different patent propensities systematically affect the *relationship* between the home bias and the hypothesis-testing variables. We conducted further tests to assess the potential presence of a propensity to patent bias. We recalculated the benchmark share of the home countries in the sample once more based on 'triadic' patents: i.e. patents filed simultaneously in Europe, the US, and Japan, using information on patent families provided by the OECD (Webb et al, 2005). On average only 45 per cent of the patents filed with EPO - used to calculate the benchmark value- are filed in the other two legal jurisdictions as well. This reduces the empirical base to examine locations of R&D activities substantially, but this is not a strong concern for the calculation of the benchmark given the large numbers of patents per country. Using such 'triadic' patents to calculate the benchmark shares

produced very similar benchmarks for the home countries (the correlation with the original benchmark value was 99 per cent), indicating that a locational bias from using EPO data is likely to be limited. We did not pursue a similar exercise for the patent variables of the sample firms, as the substantial reduction in the patent base of firms to determine R&D locations and citations would undermine the reliability of the variables of interest.

We argued that the embeddedness of firms into their home country innovation system, often stemming from co-evolution of R&D capabilities of firms and the innovation system and long-term involvement in R&D networks and scientific and expert communities, may provide firms with a range of benefits of maintaining more centralized R&D operations in the home country. One aspect of such co-evolution that is not necessarily fully captured by our embeddedness variable is the specific co-specialization of technological capabilities of the firms and other R&D actors in their home countries, providing benefits in terms of shared expertise and critical mass (e.g. Kogut, 1991). We examined whether this is a possible additional driver of home bias by adding a co-specialization measure to the empirical model. We calculated a co-specialization index, the Jaffe index (Jaffe, 1986, 1989) of uncentered correlation between the firms' distribution of patents over technologies (IPC 3 digit classes) and the distribution of home country patents over the technologies. The index was calculated on 3-year patent stocks preceding the analysis period. The co-specialization measure was positively and significantly correlated with the embeddedness measure as one would expect, but the correlation coefficient was relatively modest (0.23). When including the co-specialization index in model 2, the empirical results showed a positive coefficient for the index but the coefficient was not significantly different from zero (a p-value of 0.17). We interpret this as indicating that the embeddedness variable may pick up most of the relevant features of co-specialization already. There was little change in the other coefficient estimates and the empirical model appeared robust to the inclusion of the measure.

The empirical results indicated relatively strong effects of scale economies in R&D on the home bias. We examined this relationship in some more detail. If the inefficiency consequences of not centralizing scale intensive R&D activities are mainly found up to a level of minimum efficient scale, then it may well be that firms with a large R&D budget are relatively less bounded by efficiency restrictions as they are able to operate multiple laboratories at this minimum scale. We tested potential firm heterogeneity in the effect of scale economies by adding an interaction effect between the R&D expenditures of the firm and the scale economy variable. This interaction effect was negative as expected, and significant. The estimates indicated that for firms with the highest R&D budgets the elasticity of the home bias with respect to economies of scale drops down to zero. We take these additional results as further evidence that the presence of scale economies is an important driver of R&D (non-)dispersion.

Conclusions and Discussion

The literature on R&D internationalization by multinational firms has both documented the increasing importance of foreign R&D, in particular for technology sourcing, and the fact that a major portion of R&D still tends to be located in the home country. In this paper we examined whether there is a home country bias in the location of R&D activities and which firm-level characteristics influence the extent of such a home country bias. Empirically we drew on a dataset on the patenting activities of 156 high R&D spending European, American and Japanese multinational firms active in five high-tech industries for the periods 1995-1998 and 1999-2002.

Conceptually, we conceive a home bias as the deviation between the actual amount of R&D that is conducted at home and a benchmark value for home R&D, equal to the amount of R&D that one would expect a firm to conduct at home if the global distribution of R&D would be exclusively determined by the relative attractiveness of countries for R&D. Using a 'revealed' R&D attractiveness indicator by sector, based on the global distribution of foreign owned patents, our

analysis showed that almost all sample firms conduct more R&D at home than one would expect from the relative attractiveness of their home countries. Hence, a first observation is that R&D is less global than one may perhaps expect based on the perceptions in the literature on the growing importance of international R&D.

At the same time, we suggest that the answer to the question on the global character of R&D is much more nuanced. Our analysis revealed substantial heterogeneity in home bias between firms based in the same country and we demonstrate that there are a number of firm-specific drivers of the home bias. These drivers are related to the nature of firms' technologies, their relationships with home country R&D actors, the location of their foreign affiliates and associated coordination costs, and the need to protect proprietary technologies. The home country bias is larger when scale economies are important in technology development and when firms have diversified technology portfolios and are able to benefit from scope economies, suggesting that centripetal forces related to the nature of R&D activities are an important driver of the home bias in R&D. The home bias is also larger when firms' R&D activities are strongly embedded in the innovation system of their home countries and when the costs of coordination and communication with overseas affiliates in global R&D activities are likely to be greater. Technology leaders have a larger home country bias when their home country has a relatively strong level of IPR protection allowing for effective centralized IP management and firms face risks of knowledge dissipation and appropriability problems when dispersing R&D activities abroad. In contrast, if concerns about foreign IPR protection are less important and when the home country itself has relatively weak IPR protection, technological strength is associated with a smaller home bias.

Our research contributes to the international R&D literature by providing a first conceptual treatment of the home bias in R&D and by systematically analyzing what factors influence firms' decisions *not* to disperse R&D internationally. Taken together, our findings suggest that the home country bias in R&D should to an important extent be considered a response to the economics of

R&D and centripetal forces favoring centralization -forces which have received only scant attention in the recent (empirical) literature on the internationalization of R&D. The concentration of a large share of R&D activities at home can be explained as a rational response to economic and environmental factors such as scale and scope economies, international coordination costs, and relative degrees of IPR protection provided in different countries. Given the presence of strong scale and scope economies, starting R&D in a given country is likely to create a path dependency in R&D investments and a home bias in R&D (e.g. Kogut, 1991; Di Minin and Biachi, 2011). This in itself does not necessarily imply inertia or 'lock-in' to the detriment of R&D performance, but can be explained from a rationale related to efficient R&D organization, enhanced by a 'fit' between home country and firms' R&D capabilities and firms' embeddedness in the home country innovation system. In that sense, we would like to emphasize that the term home 'bias' should not be seen as having a negative connotation. On the other hand, there is a distinct possibility that path dependency does lead to over-embeddedness and inertia in R&D, which could be overcome by R&D internationalization and exposure to different sources of (tacit) knowledge, as emphasized by the R&D internationalization literature. Our findings suggest that the growing literature on international R&D and firm performance (e.g. Lahiri, 2010; Nieto and Rodrigues, 2011; Singh, 2008; Griffith et al, 2006; Penner Hahn and Shaver, 2005) should examine the role of the factors we identified in our study as drivers of heterogeneity in home bias as potential moderators of the relationship between R&D internationalization and firm performance. Some factors, such as the role of international coordination and inter-organizational linkages and co-practice in effectively organizing for international R&D, have received attention (e.g. Singh, 2008; Lahiri 2011; Frost and Zhou, 2005), but others, such as the role of scale and scope economies, did not. Future research could examine the exact nature of the relationship between home bias in R&D and firms (innovation) performance.

Several managerial implications can be drawn from the above observations - although we note the caveat that our analysis did not investigate the performance consequences of global R&D as such. While there are obvious advantages to internationalizing R&D in terms of an increased breadth of search and access to local technological expertise, our findings suggest that R&D globalization is not a panacea for all firms. Managers should pay appropriate attention to the costs and risks of dispersed R&D. For instance, R&D internationalization in the context of major scale and scope economies is less likely to improve performance, as knowledge sourcing advantages may be offset by scale and scope disadvantages. Depending on the configuration of locations and characteristics of the technologies, the difficulties and costs of coordinating geographically dispersed R&D may also reduce or outweigh potential benefits. Likewise, dispersed R&D can be a liability, in particular for leading firms that face relatively unfavorable appropriation conditions abroad. We also argue that simple figures on international R&D are not the right benchmark for managers to judge how global their R&D actually is in comparison with competitors. An appropriate globalization benchmark takes the relative attractiveness of the home and key (potential) host economies into account, and will differ across industries, home countries and firms. Internationalization strategies followed by other firms do not necessarily constitute an appropriate model or benchmark for firms that 'lag behind', while simple R&D globalization rankings are most likely to provide a misguided picture in terms of 'best practice'..

Our findings contribute to the literature on the advantages and disadvantages of R&D centralization (Leiponen and Helfat, 2011; Argyres and Silverman, 2004; Argyres, 1996; Chacar and Lieberman, 2003; Henderson and Cockburn, 1996; Arora et al., 2011). Leiponen and Helfat (2011) argue that while there are advantages of centralization in R&D, there is substantial heterogeneity in these advantages depending on firms' innovation strategies. Our analysis suggests a range of sources of this heterogeneity, such as scale and scope economies related to the composition of firms' technology portfolios, and differential coordination costs when linking up distant R&D

centers. Our work further suggests that centralization of firms' R&D activities at the location of headquarters enables close linkages with IP management improving effective knowledge appropriation, which is particularly important for leading firms in their technology domains.

We find that home bias in R&D differs markedly across countries. German and Japanese firms, for instance, generally have a stronger home bias than US firms. This observation is consistent with prior findings in the literature (e.g. Ambos, 2005). On the other hand, and more surprisingly, strong home biases are also observed in small European economies such as Finland, the Netherlands, and Sweden. Although firms based in these countries are characterized by high levels of R&D internationalization to compensate for the smaller innovation base in their home countries (Pavitt and Patel, 1999), multinational firms based in these countries still locate a substantial portion of their R&D at home, which is not commensurate with the attractiveness of their home countries for global R&D investments. One possible reason is the co-evolution of the national innovation system and the technological capabilities of large multinational enterprises originating in some smaller countries (e.g. Nokia in Finland, Philips in The Netherlands). The leading local multinational firms tend to be responsible for a majority share of private R&D spending. The strong position and reputation of these firms in their home market may allow them to occupy preferential positions on the labour market for graduates and PhDs, to influence the direction of research specialization of collaborating local universities, and to influence local public R&D and innovation policies to favour their R&D activities (Furman, 2003; Murmann, 2003). Such specific firm-specific benefits could explain a relatively strong centralization of R&D at home, while at the same time these characteristics may render a country less attractive for foreign R&D investors. The latter stems from a difficulty to attract talented personal given the dominance of the local leading firms on the labor market for scientists and engineers, and by the firms' dominant role in the local system of innovation and close-knit R&D networks, making it more difficult for foreign 'outsiders' to integrate in these networks and access tacit knowledge (Cantwell and Mudambi,

2011; Belderbos and Somers, 2012). We note that a caveat of our analysis is that our measures of embeddedness and co-specialization may not reflect such benefits in full, while revealed measures of benchmark attractiveness based on international R&D flows may be affected in this context.

A limitation of our study is that our analysis of home bias in R&D does not distinguish between the two major motivations for foreign R&D investments, i.e. local knowledge sourcing versus adaptation of technologies to local markets. Trends in ‘aggregate’ foreign R&D and R&D home bias may hide substantial changes in the composition of foreign R&D activities, away from adaptation to new knowledge creation drawing on local capabilities (e.g. Chung and Yeaple, 2008; Alcacer and Chung, 2007; Chung and Alcacer, 2002). This will be associated with a greater specialization of different R&D sites depending on local capabilities, with different levels of internationalization and home bias depending on the specific technological domain. Analysis at the more fine-grained technology level may uncover these heterogeneous patterns across types and domains of R&D. A related heterogeneity is between research activities on the one hand, and development activities on the other. By their nature, development expenditures are often more effective if localized in firms’ major foreign markets, and differences in overall R&D home bias may be partially explained by the differential importance of development activities. Our patent based indicators of R&D internationalization and home bias do not allow making this distinction, and only a few studies have been able to investigate the limited data on the composition of foreign R&D activities (e.g. Shimizutani and Todo, 2008; Belderbos et al., 2009).

A major question for future research is which country characteristics influence home bias. Analyzing home country factors in detail requires detailed information on variations in innovation systems, the evolution of R&D, and government policies. Such a focused analysis would need to examine firms based in a much larger set of countries. Our study only covered firms based in a limited number of developed countries (Western Europe, US and Japan) and the home countries of the sample firms can be considered relatively similar in terms of their research environments. It

would therefore be interesting to expand the sample with firms from emerging economies, such as China and India, which play an increasingly important role in the world economy (UNCTAD, 2005). The R&D infrastructure of these countries is quite different from those of developed countries and one may expect that the home country bias in R&D varies with the development stage of countries. There are several other fruitful avenues for future research on the home country bias in the location of R&D activities, some of which may address limitations of our analysis. First, any calculation of home bias will be affected by the definition of the 'benchmark' that would constitute an 'unbiased' distribution of R&D. We addressed this conceptually by employing a 'revealed attractiveness to R&D' measure, and conducted a sensitivity test employing an alternative regression-based benchmark calculation, but any benchmark will harbor a degree of discretion and measurement error. Insights into business internationalization phenomena could increase if research in the broader domain of international business (e.g. Ke et al, 2009) endeavors to develop similar concepts of home country bias using explicit benchmarks. We hope that future research further explores how a bias in economic activity should be defined and measured. Second, while relative degrees of IPR protection at home and abroad appear to be an important consideration in decisions on R&D centralization, relative risks of knowledge dissipation will also be related to the presence of 'lagging' rival firms at home and abroad and the utilization of specific knowledge protection mechanisms by leading firms such as secrecy, internal collaboration across laboratories (e.g. Alcacer and Zhao, 2012), or strategies of leading firms to form close knit networks with local innovation partners (e.g. Cantwell and Mudambi, 2011). These more detailed questions on dissipation risks and appropriation strategies at home and abroad provide promising avenues for future research. Finally, future work could examine changes in the home country R&D bias over time, employing datasets with longer time frames than ours. Our study was limited to the examination of the home bias in two periods, 1995-1998 and 1999-2002, and our results suggested a secular increase of the home country R&D bias that could not be explained by the variables in our

model. It would in particular be of interest to see if this trend continued, or whether the home country bias in R&D has been reduced in recent years as a result of the increasing trend towards international R&D.

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Figure 1: Predicted values of the home country bias in R&D as function of technology leadership and the relative strength of home country IPR protection

Table 1: Home Country Bias in R&D by Home Country, 1995-2002

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Home Country	Number of Firms	Average R&D Share at Home	Average Benchmark R&D Share at Home	Average Home Country Bias	Smallest Home Country Bias	Firm Name	Largest Home Country Bias	Firm Name
Finland	4	0,73	0,01	98,63	66,02	Nokia	124,28	Kemira
Denmark	3	0,37	0,01	36,17	0,36	Borealis	102,50	Lundbeck
Sweden	6	0,58	0,02	24,94	6,59	SKF	45,11	Micronic Laser Systems
Japan	56	0,92	0,05	21,56	8,31	Advantest	46,16	SMC
Netherlands	4	0,58	0,04	15,02	5,47	ASM	27,64	Stork
Switzerland	3	0,33	0,05	7,48	0,46	Saurer	15,61	Schindler
France	5	0,57	0,09	6,41	3,80	Thomson	9,00	Bull
Germany	11	0,74	0,14	5,76	2,99	Süd Chemie	7,45	Schwarz Pharma
Belgium	2	0,33	0,06	5,74	5,04	Solvay	6,20	UCB
United States	54	0,74	0,19	3,80	0,44	AGCO	6,52	Danaher
United Kingdom	8	0,43	0,14	3,12	0,42	Filtronic	7,08	ARM

Table 2: Descriptive Statistics and Correlations

Variable	Mean	Std. Dev.	Min	Max	1	2	3	4	5	6	7	8	9	10
1 Home Country Bias (Dependent Variable)	2.14	1.06	-1.03	4.82										
2 Scale Economies	3.12	0.51	1.83	3.76	0.09									
3 Technology Diversification	1.38	0.59	0	2.66	0.13	-0.28								
4 Embeddedness	3.46	1.27	0	5.46	-0.14	0.23	0.22							
5 Coordination Costs	3.06	0.60	1.54	5.73	0.28	-0.28	0.01	-0.55						
6 Technology Leadership	-2.05	1.70	-6.81	1.51	-0.02	0.20	0.30	0.25	0.00					
7 International R&D Experience	2.40	0.66	0	3.04	-0.08	-0.08	0.28	0.11	0.03	0.37				
8 R&D expenditures	12.30	1.41	8.05	15.51	0.04	0.32	0.34	0.35	-0.04	0.82	0.41			
9 International Sales Ratio	3.61	0.72	0.69	4.62	-0.23	-0.17	-0.12	-0.34	0.39	0.02	0.09	-0.07		
10 Firm Age	4.18	0.70	1.61	5.48	0.16	-0.27	0.39	-0.09	0.28	0.21	0.43	0.27	0.03	
11 Period 2 (1999-2002) Dummy	0.52	0.50	0	1	0.02	0.00	-0.05	0.06	-0.14	-0.03	0.27	0.01	0.08	0.04

Note: see the main text for the definition of the variables. Significant ($p < 0,05$) correlations in bold.

Table 3: Random effects panel data analysis of the firm-level determinants of home country bias in R&D

Variables	Model 1	Model 2
Scale Economies (H1a)		0.1964** (0.0996)
Scope Economies (Technology Diversification) (H1b)		0.1442* (0.0768)
Home Country Embeddedness (H2)		0.0713* (0.0368)
R&D Coordination Costs (H3)		0.1521* (0.0814)
Technology Leadership (H4)		-0.6199*** (0.1598)
Technology Leadership * Relative Home IPR Protection (H4)		0.5269*** (0.1283)
International R&D Experience	0.0441 (0.0699)	0.0284 (0.0675)
R&D expenditures	-0.0684** (0.0327)	-0.1109** (0.0464)
International Sales Ratio	0.0154 (0.0590)	-0.0364 (0.0581)
Firm Age	-1.9354*** (0.4687)	-1.5600*** (0.4525)
Firm Age * Firm Age	0.2656*** (0.0615)	0.2115*** (0.0598)
Period 2 (1999-2002) Dummy	0.0739** (0.0358)	0.1692*** (0.0419)
<i>Country Dummies</i>		
Belgium	0.4204 (0.4088)	0.0805 (0.3982)
Denmark	0.9976*** (0.3421)	1.0305*** (0.3632)
Finland	3.3253*** (0.2967)	3.4426*** (0.3289)
France	0.4952* (0.2667)	0.4438* (0.2600)
Germany	0.1992 (0.2043)	0.2738 (0.1910)
Japan	1.8424*** (0.1186)	1.5251*** (0.1266)
Netherlands	1.2509*** (0.2938)	1.3884*** (0.2816)
Sweden	1.7349*** (0.2535)	1.7461*** (0.2717)
Switzerland	-0.1881 (0.3562)	0.4127 (0.3591)
United Kingdom	-0.6542*** (0.2239)	-0.5950*** (0.2263)
Constant	5.2198*** (0.8890)	3.9536*** (1.0267)
Number of Observations	298	298
Number of Firms	156	156
R-Squared	0.738	0.774
Wald Chi Square	454.99***	559.77***
Wald test		31.88***

Notes: Standard errors in parentheses. ***, **, * indicate significance at 1, 5 and 10 per cent. The US is the reference group for the home country dummies.

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