***How Global is R&D?***

***Determinants of the Home Country Bias in R&D Investments***


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## Abstract

Despite an increasing importance of international R&D activities by multinational firms in recent years, a major portion of corporate R&D still tends to be concentrated in firms' home countries. This paper assesses and analyzes the degree of the home country bias in global R&D investments by 162 European, US and Japanese multinational firms during 1995-2002. We assess the extent of home country bias by examining the difference between actual home country R&D and the R&D level to be 'expected' given the country's attractiveness for R&D activities. Second, we formulate hypotheses concerning the firm-level determinants of the home country bias. Empirical results confirm the existence of a home bias in R&D activities and show that the home bias increases with the degree of scale economies in firms' technologies, firms' technological diversification due to economies of scope, and the embeddedness of firms' R&D in the home country innovation system. Experience in operating R&D facilities abroad reduces home bias. Technology leaders show a smaller home bias except when their home countries provide a particularly favorable regime of intellectual property rights protection.

## 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 affiliates not only for traditional aims such as to adapt home-developed technologies to foreign markets, but also to access local technological expertise abroad and to create new technologies (Kuemmerle 1997; Belderbos, 2003; Belderbos et al., 2006; Von Zedtwitz and Gassmann, 2002; Ambos, 2005). Despite the growing trend of R&D internationalisation, a major portion of corporate R&D is still conducted in MNEs home country (Patel and Pavitt, 1991; OECD, 2007; UNCTAD, 2005; von Zedtwitz and Gassmann, 2002; Dunning and Lundan, 2008; Zanfei, 2000). The extent to which R&D activities by MNEs concentrate in the home country varies largely across firms (UNCTAD, 2005; von Zedtwitz and Gassmann, 2002). In general, firms from small open European economies conduct more R&D abroad, whereas Japanese firms show a high concentration of R&D in the home country (Niosi and Godin, 1999; Belderbos, 2001). The propensity to stay at home varies across industries (UNCTAD, 2005; Narula, 2002; Serapio and Dalton, 1999). However, it also varies across firms within industries depending on firms' strategic choices and resources (von Zedtwitz and Gassmann, 2002; Berry, 2006).

While an expanding literature has explored the determinants of foreign R&D location decisions, surprisingly little attention has been given to factors keeping multinational firms' R&D in home countries. While the existence of a home country bias is broadly observed in various economic activities, such as production (Delgado, 2006), portfolio investment in equity markets (French and Poterba, 1991; Lewis, 1995; Portes and Rey, 2005) and trade (McCallum, 1995; Nitsch, 2000; Chen, 2004; Wolf, 2000), research has not yet addressed the home country bias in firm R&D activities in a systematic manner.[1]

In this paper we seek to understand the extent and determinants of the home country bias in R&D activities. We first estimate the extent of the home country bias in R&D of multinational firms by determining a benchmark value for home R&D and comparing this to the actual value of R&D conducted at home (both firm level). The benchmark value of home R&D is the amount of R&D that one would expect to be conducted at home if the distribution of R&D would be fully determined by country characteristics that have been found to affect the attractiveness of R&D locations (such as market size, technological and scientific strengths, cost of R&D personnel, strength of IPR regime). The logic of this approach is that in an unbiased geographic distribution of R&D activities, the share of global R&D conducted in a home country is fully determined by the relative attractiveness of the home country for R&D activities. The deviation of the actual value of R&D in the home country from the estimated benchmark forms our (firm-level) measure of home country bias. In a second step, we develop hypotheses on firm-level determinants of home country bias, drawing on the R&D organization and internationalization literature. We argue that variations in the home country bias stem from firm-level differences in economies of scale, technological diversification, embeddedness in the home country innovation system, coordination costs of international R&D, internationalization experience, and technological leadership in relationship with the strength of IPR regimes.

We test our hypotheses in an empirical analysis of the patent activities of 162 top R&D spending firms that are active in the IT hardware, chemicals, pharmaceuticals, electronics and non-electrical machinery industries during 1995-2002. The firms originate from 11 different home countries (US, Japan and 9 European countries). The location of firms' R&D activities is derived from address

[1] A partial exception is Narula (2002). His case studies of Norwegian firms suggested that the nature of the innovation system of a firm's home country, and the level to which the firm is embedded in it, may play an important role in creating inertia in R&D internationalization decisions.

information of patent inventors. Our analyses show that the home country bias is higher for firms active in scale intensive technologies, diversified technology portfolios, strongly embedded home operations, and little experience in conducting international R&D operations. Technology leadership leads to a smaller home country bias, except when IPR protection is very high at the firm's home country.

## Theoretical Background

The centralization vs. decentralization framework of Pearce (1989) can be used as context for examining global R&D investments by multinational firms (Serapio and Dalton, 1999). In this framework, a distinction has been made between (1) centripetal forces that support a tendency to centralize R&D in the firm's home laboratory and (2) centrifugal forces that pull corporate R&D to facilities outside the home country.

One reason to centralize firms' R&D activities at home relates to the realization of economies of scale and scope. The indivisible nature of R&D 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; Herschey 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). The potential for knowledge spillovers is especially large when firm technologies are technologically related (Leten et al, 2007). Technologically diversified firms could enjoy a synergy effect between different disciplines by collocating them and promoting interdisciplinary interaction (Argyres, 1996). Collocation and physical proximity are important because much technological knowledge is tacit in nature and requires personal contacts to be transferred efficiently (Patel and Pavitt, 1991). A second factor keeping R&D at home close to firms' headquarters is the fear of dissipation of R&D results and technological secrets to competitors. Since geographical proximity to rival firms increases the risk of out-going knowledge spillovers, centralising R&D activities enables firms to retain tighter control of firms' proprietary assets (Rugman, 1981; Pearce, 1999). Further, coordination of R&D activities between MNEs' laboratories becomes increasingly difficult and costly if R&D locations are globally dispersed. R&D is an activity which requires a high level of communication between the involved parties (Nobel and Birkinshaw, 1998). Efficient communication necessitates personal contacts and face-to-face interaction, which are both promoted by physical proximity and centralization.

Along with the increasing internationalisation of R&D activities by MNEs in the last decades, centrifugal forces have been drawing most attention as location determinants of R&D activities abroad. Centrifugal forces have been categorised as two major motivations of MNEs' international R&D activities in previous studies (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 major 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 type of foreign R&D is gaining importance in recent years (e.g. Florida, 1997; Kuemmerle, 1997; Ambos, 2005; OECD, 2007; Shimizutani and Todo, 2005; Von Zedtwitz and Gassmann, 2002) and can have a positive impact on the productivity of home country operations (Iwasa and Odagiri, 2004; Penner-Hahn and Shaver, 2005; Griffith et al, 2006).

Based on this theoretical background, we developed a set of hypotheses on firm-level determinants of the home country bias in R&D investments (next section). The home country bias in

R&D is defined as the difference between the actual R&D done at home and the ‘expected’ amount of home country R&D based exclusively on country characteristics.

## Hypotheses on Firm-Level Determinants of the Home Country Bias in R&D

### Economies of Scale and Scope

Economies of scale and scope play an important role in firms’ decision making of centralizing R&D activities in their home countries. First, centralization decisions are influenced by the importance of scale economies in the technology fields in which firms conduct R&D activities. R&D activities are typically characterized by high fixed costs and large scale economies, although there exist differences across technologies and industries. Kuemmerle (1998), for example, finds that the optimal laboratory size is larger for electronics firms (256 employees) than for pharmaceutical firms (167 employees). When scale economies are large, firms need to organize their R&D activities in sufficiently large laboratories to achieve the minimum efficient scale for effective research (Perrino and Tipping, 1989). Centralization of R&D activities in a single location to benefit from scale economies is mostly done in firms’ home country to benefit from the nearby presence of the corporate headquarters and main production facilities. 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 potential to realize knowledge spillovers between different technology fields (Henderson and Cockburn, 1996). This is especially the case when technologies are technologically related (Leten et al, 2007; Nesta and Saviotti, 2005). Sources of scope economies relate to the establishment of joint technology platforms, joint access to specialized equipment, and synergies in technology development. Given the tacit nature of much technological knowledge, firms can promote the realization of knowledge spillovers, and lower coordination costs, by collocating R&D activities in one central R&D facility (Patel and Pavitt, 1991; Argyres, 1996). In sum, firms which conduct R&D activities in scale intensive technologies and which have a diversified technology portfolio (and the potential to realize economies of scope) are expected to concentrate relatively more R&D activities in their home country.

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

*Hypothesis 1b: The home country bias in R&D is stronger for technologically diversified firms.*

**Embeddedness in the Home Country Innovation System**

The extent to which firms are embedded in their home country innovation system is expected to affect their R&D investment decisions. The capacity of firms to innovate is not limited to the boundaries of the firm but also depends on external knowledge sources such as customers, suppliers, other firms, public institutions and universities (Chesbrough, 2003; Cassiman and Veugelers, 2002). External knowledge is transferred to firms not only through formal, but also informal mechanisms (Gertler et al., 2000; Frost, 2001). Moreover, not only direct ties but also indirect ties matter (Gertler et al., 2000). This requires firms to know local actors, share information and knowledge, and cultivate mutual trust in the local technical community (Criscuolo and Autio, 2008; Furman, 2003; Frost, 2001). 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 (Lane and Lubatkin, 1998). Once linkages to a local innovative community are developed in the home country, a firm can maintain the local network at a low cost, whilst constructing linkages with new technical communities in other countries is time-consuming and costly. As a result, firms may become 'locked in' the innovation system of the home country, and conducting R&D abroad becomes a less attractive option (Narula, 2002). 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 (Allen, 1977). International management studies point out that the integration of globally dispersed R&D activities of MNEs requires substantial coordination and communication efforts (Nobel and Birkinshaw, 1998; De Meyer, 1991). However, communication between different R&D sites may be hindered by obstacles such as geographic, cultural and temporal distances (Sosa et al., 2002). Although recent developments in information and communication technologies have somewhat reduced this problem (Argyres, 1999; Howells, 1995), effective coordination still requires face-to-face contacts (Singh, 2008) and coordination costs remain an important restriction against conducting globally dispersed R&D activities. When coordination costs in a firm's international R&D network are large we expect firms to be less motivated to undertake global R&D activities and concentrate R&D activities 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 positions in an industry 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 implement a technology sourcing strategy due to a lack of sufficient absorptive capacity (Penner Hahn and Shaver, 2005; Song and Shin, 2008). Recent firm-level empirical analyses on strategic interaction confirmed that technology leaders conduct more foreign R&D activities than technology laggards (Berry, 2006). On the other hand, firms conducting foreign R&D activities near rival firms risk leakage of their core technologies due to outgoing knowledge spillovers. These risks are greatest in countries with weak intellectual property rights protection (Branstetter et al, 2006; Belderbos et al., 2008). R&D activities, if conducted in countries with weak IPR, often implies weak external links and a strong reliance on internal complementary know how developed at home countries (Zhao, 2006). Since technological dissipation is more serious for technology leaders, they are most responsive to the strength of Intellectual Property Rights regimes in home and host countries (Belderbos et al., 2008). If IPR protection is relatively strong in a firm's home country, foreign R&D becomes a less attractive option for technology leaders. In sum, we expect absorptive capacity arguments to dominate over knowledge concerns only when technology leaders are located in home countries with relatively weak IPR regimes. This leads to the following hypothesis:

*Hypothesis 4: The home country bias in R&D is weaker (stronger) if a firm is a technological leader in its industry and IPR protection in the home country is relatively weak (strong).*

### International R&D Experience

Firms' experience in foreign R&D is expected to impact on R&D globalization decisions. According to the evolutionary view of the firm, international experience is a primary source of organizational learning in multinational firms (Kogut and Zander, 1993; Belderbos, 2003). Exposure to foreign R&D learns firms how to cope with foreign environments and how to transfer knowledge across borders within the multinational firm's R&D network. Firms that have developed technology transfer management skills are likely more efficient in transferring proprietary technologies between headquarters and foreign affiliates. This helps the firm and its affiliates to develop location-specific R&D capabilities and integration into local knowledge networks, increasing access to foreign technological knowledge and reducing dependence on innovation in the home country. We therefore expect the home country bias in R&D will be lower for firms with more international R&D experience.

*Hypothesis 5: The home country bias in R&D is smaller, the more experience a firm has in conducting foreign R&D activities.*

## Empirical Methods and Data

### Sample

To investigate R&D investment decisions of multinational firms, we have collected data on the technological activities of 162 R&D intensive firms over the period 1995-2002. The firms are large R&D spending Japanese, European and US firms in five industries: Engineering & General Machinery, Pharmaceuticals & Biotechnology; 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. We did not include firms which are the result of large international mergers to avoid problems related to multiple home countries[2].

Patent data are used as indicator of firms' R&D activities and their location. Patent data have the advantage of being easy to access, covering long time series, and containing detailed information on the technological content, owners and inventors of patented inventions. They also have some shortcomings: not all inventions are patented, patent propensities vary across industries and firms, and patented inventions differ in quality (Basberg, 1987; Griliches, 1990). Despite the drawbacks, patents are extensively used as indicator of the location of firms' technological activities (Patel and Vega, 1999; Belderbos, 2001; Guellec and Van Pottelsberghe, 2001; Le Bas and Sierra, 2002; 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.

In this study we draw on patent data from the European Patent Office (EPO). The choice for EPO rather than USPTO patents is motivated by two factors. First, EPO patents are on average, of a higher quality than USPTO patents (Van Pottelsberghe and François, 2006; Quillen and Webster, 2001). Second, inventor address information on USPTO patents, which is used to identify the location of R&D activities, is incomplete for a large number of USPTO patents. Patent application data are used as indicator of the firms' technological activities. Due to the long time span of patent granting decisions at the European patent office (4-6 years), the use of patent application data has advantages over grants as a source of information on the location of recent corporate technological activities

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 due to

[2] An example is the pharmaceutical firm AstraZeneca which was formed in 1999 as a merger of the British firm Zeneca and the Swedish firm Astra.

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. Using consolidated patent data is crucial to study the location of firms' R&D activities since patents may be applied for under the name of a subsidiary rather than the parent firm. On average 18 percent of the sample firms' patents were filed under a subsidiary name or name variants of the parent firm.

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 tend to use the headquarter address instead of the address of the subsidiary where the invention originated as assignee address (Deyle and Grupp, 2005; Landoni et al, 2008). If a patent lists inventors based in more than one country, the patent is assigned fully to each country. We examine patents originating in 11 home countries (US, Japan and 9 European countries) and 32 host countries. The list of host countries includes all major developed countries and the largest developing economies in South-East Asia and South-America, and South Africa.

**Empirical Methods**

To examine the determinants of the home country bias in R&D, we follow a stepwise procedure. We first estimate, for each sample firm, the extent of the home country bias in R&D by determining a benchmark value for home R&D and comparing this to the actual value of R&D conducted at home. The benchmark value of home R&D is the amount of R&D that one would expect to be conducted at home if the distribution of R&D would be fully determined by country characteristics. The difference between actual home R&D and the estimated benchmark value forms the home country bias measure. To determine the benchmark value of home R&D we need to determine the impact of country level characteristics on firms' R&D location decisions. This is done by relating the number of firms' patents in a set of 32 host countries (firm and country level analysis) to a broad set of country characteristics (such as market size, technological strengths, academic research, cost of R&D personnel, strength of and IPR regime) found to affect R&D location decisions in prior studies.[3] Yearly patent numbers are summed up per four year period (1995-1998 and 1999-2002) to ensure a greater number of positive observations at the firm and country level. This leads to a dataset with 9,760 observations. The dependent variable (number of patents of a firm in a country) is logarithmic transformed and an OLS regression is performed. Error terms are clustered at the firm level.

Based on the estimated coefficients of the country variables *and* values for these variables for the home country, we then predict for each firm the (logarithmic transformed) number of patents in its home country and 4-year period. This value is taken as benchmark value of home country R&D. The difference between the actual number of patents of a firm in the home country and the benchmark value (both logarithmic transformed) indicates the extent of the firm's home country bias in R&D.

After this, we relate the estimated home country R&D bias for each firm to a set of firm-level characteristics that are expected to impact on the extent of the home country bias. This analysis pools observations across the two 4-year periods and includes 311 (firm-level) observations. The regression is performed with OLS and error terms are clustered at the firm level.

[3] Home country observations are not included in this estimation.

**Country Variables**

To determine the benchmark value for home country R&D, we estimated the impact of a set of country-level variables (technological strength, academic research strength, level of IPR protection, market size and R&D labour cost) on R&D location decisions. The *technological strength* of a country in an industry is measured by the number of patents that are applied in the country in technology fields that are relevant to the firm's industry[4]. Patents of the investing firm are subtracted from these patent counts.

The *academic research strength* of a country in an industry is measured by data on scientific articles authored by residents of a country and published in the 'Web of Science' publication database.[5] Using locations of publishing institutions and the ISI science classification table, publication numbers are available at the level of countries and 240 scientific disciplines. Science fields are linked to 5 broad technology classes following the approach of Belderbos et al (2009)[6]. To construct a sector level indicator, we assigned two broad technology classes to each of the 5 industries of the sample firms based on their importance in patent portfolios of the sample firms[7]. Since the Web of Science only includes journals that are peer reviewed, adhere to standards of editorial policy, and have a threshold impact factor, the publication count can be considered a relatively accurate measure of the output of qualitative academic research at the level of countries and sectors. Host country technological and academic research strengths variables are both one year lagged to the dependent variable.

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[4] The Schmoch et al (2003) concordance table is used to identify 4-digit IPC classes that are relevant for sample industries.

[5] Papers of the document type article, letter, note and review have been selected.

[6] Belderbos et al (2009) link 'exact science' disciplines to 5 broad technology domains (electrical engineering, instruments, chemistry & pharmaceuticals, process engineering, mechanical engineering) of the Fraunhofer-INPI-OST technology classification based on descriptions of the science fields.

[7] Technology classes 'chemistry and pharmaceuticals' and 'instruments' are linked to the chemical and pharmaceutical industries. Technology classes 'electrical engineering' and 'process engineering' are linked to the IT hardware and electrical machinery industries. Technology classes ' mechanical engineering' and 'process engineering' are linked to the non-electrical machinery industry.

We used the IPR index from the Global Competitiveness Report (published by the World Economic Forum) as indicator of the country's *level of IPR protection*. 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**.** IPR data are available for the years 1995 (period 1995-1998) and 2000 (period 1999-2002)**.**

The yearly gross income levels of engineers are taken as indicator of the *labor cost of R&D personnel* in a country. Data are taken from the UBS 'Price and Earnings' reports, with 1994 wage levels assigned to period 1995-1998 and 1997 wage levels assigned to 1999-2002. Countries' *market size* is measured at the sector level as (production + import – export). Data are drawn from UNIDO industrial yearbook and OECD STAN data.

**Firm Variables**

We have collected information on a set of firm characteristics to examine the impact of these variables of the extent of the home country bias in R&D. The importance of *scale economies* in the R&D activities of a firm is measured as the weighted[8] average level of scale economies in technologies in the firm's patent portfolio. The level of scale economies in a technology field is measured by the share of large laboratories (>200 employees) in the technology field, assuming that scale intensive R&D activities are undertaken in large laboratories. Data are drawn from Ambos (2005)[9].

The level of *technology diversification* of a firm's technology portfolio is measured as the number of technology fields in a firm's patent portfolio. Hereby, we distinguish between 30 technology

[8] Weights are determined by the patent share of technologies in the 5 year patent portfolio of the firm.
[9] Ambos (2005) collected only data on laboratory sizes for overseas laboratories. As the nature of technologies does not differ significantly between domestic and foreign laboratories (Kuemmerle, 1998), we can rely on this data to create our technology level indicators of scale economies.

classes, reported in the Fraunhofer-INPI-OST technology classification. The patent portfolio of a firm consists of all patents applied for by the consolidated firm in the five years preceding the period of observation[10].

*Embeddedness* of firms' R&D activities within the home country's innovation system is measured by the share of backward patent citations of firms' home country patents to patents originating in the home country[11]. Self-citations are deducted from this measure because we are interested in a firm's embeddedness to external R&D players. This variable is constructed on patents in the lagged five-year patent portfolio.

*Coordination cost*s in international R&D are measured as minus the average technology transfer efficiency between the home and host countries in which firms conduct economic activities. The technology transfer efficiency of two countries is measured by the number of cross-country patent citations over the total number of patents in both countries[12]. A greater intensity of patent citations suggests a greater ease and intensity of communication and collaboration in R&D between countries, which may be due to geographic, temporal or cultural proximity. The firm-level coordination costs measure is then calculate as the average bilateral country technology transfer efficiency values for each pair of the firm's home country and host countries where the firm has manufacturing or sales subsidiaries. Information on the firms' MNE network (location subsidiaries) is taken one-year before the period under observation. A high value on the efficiency measure corresponds to low coordination costs. We measure coordination costs therefore as minus the firm-level transfer efficiency measure.

*Technology leadership* of a firm in its industry is measured by the worldwide patent share of the firm in the two broad technology classes that are linked to the industry. This variable is calculated on

[10] Firm consolidation information for the years 1995 and 1999 are used for periods one and two respectively.
[11] A patent originates in a firm's home country if at least one patent inventor has its residence in the home country.
[12] This measure is calculated at the level of 5 broad technology classes (Fraunhofer-INPI-OST main classes). Technology classes are linked to sample industries (see footnote 7). Hence, the technology transfer efficiency measure is constructed at the level of countries (pairs) and industries. This index was originally proposed by Belderbos et al (2008).

the lagged five-year patent portfolio of firms. To examine the interplay of technology leadership and IPR protection on the home country bias in R&D, the interaction effect of technology leadership and the level of IPR protection in the home country is included in the regression model. We expect a positive interaction effect and a negative main effect for the leadership variable on the level of the home country bias in R&D.

Firms' *international R&D experience* is measured by the number of years since a firm applied for its first foreign invented patent (invented by the parent firm or a majority-owned subsidiary). Summary statistics and correlations for the main variables for (first-stage and the second-stage regressions) are provided in Appendix.

## Empirical Results

As discussed above, we have followed a step-wise approach to examine firm-level determinants of the home country bias in R&D. Table 1 contains regression results of an analysis in which firm patent counts in host countries are related to a set of country characteristics. This analysis is performed to determine the impact of country factors on corporate R&D investments and to calculate firms' home country R&D bias. The model contains, besides a set of country variables, also an indicator for the size of firms' R&D activities (number of patents in the lagged firm patent portfolio), and dummies for firms' sectors and period 2. Both the dependent and independent variables are logarithmic transformed and an OLS regression (with error terms clustered at firm level) is performed. The model is overall significant (R-squared = 0.27). All country variables have the expected signs and are significant at the 1% level. Technological strength, Market size, Academic strength, and IPR protection have positive signs; the engineering wage variable has a negative sign. The firm patent stock variable is positive and significant. A negative, and significant, effect is found for the second period dummy. As foreign R&D

activities of the sample firms did, on average, increase from period 1 to period 2, the negative dummy implies that the overall increase in foreign R&D activities of the sample firms over time is more than explained by country changes such as increases in technological strength, IPR protection and market size. Controlling for all this, there is certainly no trend towards conducting more R&D abroad. The four sector dummies show positive and significant coefficients implying sector difference in the degree of foreign R&D. The tendency to conduct R&D abroad is lowest in the chemical sector (reference group).

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Insert Table 1 about here

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Based on the estimated coefficients of the country variables *and* values for these variables for the home country, we then predict for each firm the (logarithmic transformed) number of patents in its home country and 4-year period. This value is taken as benchmark value of home country R&D. The difference between the actual number of patents of a firm in the home country and the benchmark value (both logarithmic transformed) is our indicator of the extent of the firm's home country bias in R&D. Our home country bias measure takes positive values for all the sample firms. This confirms the existence of a home country bias in R&D investments. The home country bias is on average 3.84, but ranges from 0.04 to 7.58. Hence, there is wide variation across firms in the size of the home country bias. This allows us to study (firm-level) determinants of the home country bias. Table 2 reports results of an analysis in which our firm-level home bias measure is related to a set of firm-level characteristics. In line with analyses in table 1, we do control for differences in the size of firms' technology activities. We also include the firm's share of international sales (Source: Compustat, Worldscope and annual reports) to control for differences in firms' aggregate internationalization levels. We expect that this variable will impact negatively on the size of the home country bias in R&D. Finally, we also add dummies for firms' home countries (United States is base category) and period 2. An OLS regression is performed and standard errors are clustered at the firm level.

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Insert Table 2 about here

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The overall model fit is good (R-squared = 0.80). The empirical results show positive and significant coefficients for scale economies and technology diversification. This confirms hypotheses 1a and 1b. The home country bias is larger when scale economies are important for firms' technologies and when firms have diversified technology portfolios. A positive and significant coefficient is found for the home country embeddedness variable, indicating that the home country bias is larger when firms' R&D activities are deeply embedded in the innovation systems of their home countries. Hypothesis 3 is not supported due to the insignificant coefficient for the coordination cost variable, although it is positive as expected (p-value 0.16). The main effect of technology leadership is negative and significant, while the interaction effect between leadership and IPR protection is positive and significant[13]. For high levels of IPR protection, the net effect of technology leadership becomes zero. This partly confirms hypothesis 4: technology leadership has a negative impact on the home bias when IPR protection is low in the home country, but has no impact when IPR protection is high at home. Knowledge dissipation concerns seem to offset absorptive capacity arguments when IPR protection is

[13] A specification that includes the main effect of IPR protection in the home country generated similar results.

relatively high at the home country of firms. The international R&D experience variable has a negative and significant coefficient, confirming hypothesis 5: The home country bias is lower for firms which have build up prior experience in foreign R&D activities.

The firm's patent stock variable has a positive and significant effect on the home country bias. No significant effect is found for the international sales ratio variable and the period 2 dummy. The home country bias is smallest for the United States (reference group) as all significant home country dummies (Germany, France, Finland, Sweden and the Netherlands) have positive coefficients. The home country bias is largest in the chemical industry (base category).

## Discussion and Conclusion

We have examined the extent and determinants of the home country bias in R&D using a dataset on patenting activities of 162 high R&D spending European, American and Japanese firms active in five high-tech industries for the period 1995-2002. We first estimated the extent of the home country bias in R&D of multinational firms by determining a benchmark value for home R&D and comparing this to the actual value of R&D conducted at home (both firm level). The benchmark value of home R&D is the amount of R&D that one would expect to be conducted at home if the distribution of R&D would be fully determined by country characteristics. In a second step, we have identified a set of firm-level characteristics that impact on the extent of the home country bias in R&D.

Our analyses confirm the existence of a home country bias in firms' R&D investments. All sample firms conduct more R&D at home than what one would expect from country characteristics attracting R&D investments (market size, technological and academic research strengths, R&D personnel cost, level of IPR protection). Several firm-level characteristics are found to impact on the magnitude of the home country bias. The home country bias is larger when scale economies are important for firms' technologies, when firms have diversified technology portfolios, and when firms' R&D activities are deeply embedded in innovation system of their home countries. The home country bias is smaller when firms have substantial experience in conducting foreign R&D activities. Technology leaders have a lower home country bias when their home country has low levels of IPR protection. If IPR protection is high in a firm's home country no impact of leadership is found. Knowledge dissipation concerns may thus offset absorptive capacity effects when foreign locations provide relatively weaker IPR protection than the home country. Taken together, our findings suggest that the home country bias in R&D is not only a sign of firm inertia towards foreign R&D (caused by a strong embeddedness in the home country innovation system and limited international experience), but can also partly be explained as a rational response to economic and environmental factors such as scale and scope economies, absorptive capacity and IPR protection.

In addition the analysis uncovered that the home country R&D bias is large in two sets of countries. The first group of countries consists of large economies such as France and Germany. This observation is consistent with prior findings in the literature. Ambos(2005), for example, points to the latecomer status of large economies such as Germany, France and Japan in international R&D. A possible explanation for this trend may be the existence of a large domestic market in those countries for firm products and technologies. More surprisingly, the second group of countries consists of small European economies such as Finland, the Netherlands and Sweden. Although firms based in these countries are characterized by relatively high levels of R&D internationalization to compensate the weak innovation base in the home countries (e.g. Pavitt and Patel, 1999), they still locate a substantial portion of R&D at home, which is not commensurate with the relative attractiveness of their home countries.

There are several fruitful avenues for future research on the home country bias in R&D investments. First, we only analyzed firms from developed countries (Western Europe, US and Japan) in our study. As a result, home countries of the sample firms can be considered relatively similar to each other. It would therefore be interesting to expand our sample with firms from emerging economies, such as China and India, which play an increasingly important role in the world economy. The R&D endowments of these countries are quite different from these of developed countries and one may expect that home country bias in R&D might vary with the development stage of countries. Second, an interesting question for future research is whether the extent of the home country bias has implications for the productivity and financial performance of firms. Third, future work could examine changes in the size of the home country R&D bias employing datasets with longer time frames.

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# Appendix

## (1) Descriptives and Correlations for the first-stage estimation (Table 1 in text)

| Variable | Mean | Std. Dev. | Min | Max | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 Patent Count by Firm/Host country (Dependent Variable) | 0.329 | 0.880 | 0.000 | 7.054 | 1 | | | | | | | |
| 2 Technological Strength | 4.083 | 2.215 | 0.000 | 8.909 | 0.41 | 1 | | | | | | |
| 3 Market Size | 1.759 | 1.391 | -3.460 | 5.746 | 0.34 | 0.62 | 1 | | | | | |
| 4 Academic Research Strength | 1.464 | 1.636 | -4.200 | 5.710 | 0.33 | 0.79 | 0.60 | 1 | | | | |
| 5 IPR Protection | 1.805 | 0.357 | 0.441 | 2.241 | 0.24 | 0.60 | 0.34 | 0.31 | 1 | | | |
| 6 Engineering Wage | 3.535 | 0.776 | 1.194 | 4.532 | 0.20 | 0.49 | 0.34 | 0.18 | 0.78 | 1 | | |
| 7 Firm's Total Patents | 1.917 | 1.175 | 0.000 | 5.537 | 0.28 | 0.01 | -0.01 | 0.02 | 0.01 | -0.02 | 1 | |
| 8 Period 2 Dummy | 0.511 | 0.500 | 0.000 | 1.000 | 0.04 | 0.11 | 0.01 | 0.12 | 0.10 | -0.19 | 0.12 | 1 |

Note: Continuous variables are taken in natural logarithms

## (2) Descriptives and Correlations for the second-stage estimation (Table 2 in text)

| Variable | Mean | Std. Dev. | Min | Max | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 Home Country Bias (Dependent Variable) | 3.839 | 1.318 | 0.035 | 7.580 | 1 | | | | | | | | | | |
| 2 Scale Economies | 3.057 | 0.498 | 1.792 | 3.761 | 0.18 | 1 | | | | | | | | | |
| 3 Technological Diversification | 2.536 | 0.655 | 0.000 | 3.401 | 0.66 | -0.17 | 1 | | | | | | | | |
| 4 Embeddedness | 0.229 | 0.137 | 0.000 | 0.670 | 0.07 | 0.28 | 0.06 | 1 | | | | | | | |
| 5 Coordination Costs | -0.167 | 0.102 | -0.647 | 0.000 | 0.25 | 0.10 | 0.07 | -0.12 | 1 | | | | | | |
| 6 International R&D Experience | 2.374 | 0.690 | 0.000 | 3.045 | 0.35 | -0.05 | 0.52 | -0.08 | -0.09 | 1 | | | | | |
| 7 Technological Leadership | -0.754 | 1.348 | -4.730 | 2.336 | 0.77 | -0.05 | 0.77 | -0.02 | 0.07 | 0.49 | 1 | | | | |
| 8 Technological Leadership * Home IPR Protection | -1.550 | 2.787 | -10.447 | 5.065 | 0.77 | -0.05 | 0.77 | -0.03 | 0.07 | 0.48 | 1 | 1 | | | |
| 9 Total Patent Stock | 1.932 | 1.169 | 0.000 | 5.537 | 0.84 | 0.11 | 0.72 | 0.02 | 0.17 | 0.48 | 0.91 | 0.91 | 1 | | |
| 10 International Sales Ratio | 0.352 | 0.176 | 0.000 | 0.693 | -0.02 | -0.20 | -0.04 | -0.37 | 0.23 | 0.12 | 0.06 | 0.05 | 0.06 | 1 | |
| 11 Period 2 Dummy | 0.511 | 0.501 | 0.000 | 1.000 | 0.05 | 0.00 | 0.04 | 0.00 | -0.13 | 0.28 | 0.02 | 0.00 | 0.11 | 0.11 | 1 |

Note: Continuous variables are taken in natural logarithms

**Table 1: Impact of Country Factors on R&D Location (OLS regression)**

| Variables | Coefficient | Robust S.E. |
|---|---|---|
| Technological Strength | 0.0952*** | 0.0095 |
| Market Size | 0.1314*** | 0.0124 |
| Academic Research Strength | 0.0223*** | 0.0076 |
| IPR Protection | 0.1121*** | 0.0342 |
| Engineering Wage | -0.0407*** | 0.0121 |
| Firm's Total Patents | 0.2144*** | 0.0267 |
| Period 2 Dummy | -0.0738*** | 0.0148 |
| Electronics | 0.1880*** | 0.0705 |
| Engineering and General Machinery | 0.1401** | 0.0542 |
| IT Hardware | 0.3019*** | 0.0749 |
| Pharmaceuticals and Biotechnology | 0.1834*** | 0.0578 |
| Constant | -0.9217*** | 0.1101 |
| Number of Observations | 9760 | |
| R-Squared | 0.27 | |

Notes: Robust standard errors, clustered by parent firm. ***,**,* indicate significant at the 1, 5 and 10 percent levels. Chemicals is the reference group for the Sector Dummies.

**Table 2: Firm-Level Determinants of Home Country Bias in R&D**

| Variables | Coefficient | Robust S.E. |
|---|---|---|
| Scale Economies (H1a) | 0.5456** | 0.2130 |
| Technological Diversification (H1b) | 0.3059** | 0.1241 |
| Embeddedness (H2) | 0.7933* | 0.4053 |
| Coordination Costs (H3) | 0.7181 | 0.5174 |
| International R&D Experience (H4) | -0.1228* | 0.0732 |
| Technological Leadership | -1.0813* | 0.6044 |
| Technological Leadership * Home IPR Protection (H5) | 0.5884** | 0.2924 |
| Total Patent Stock | 0.6474*** | 0.0829 |
| International Sales Ratio | -0.5267 | 0.3607 |
| Period 2 Dummy | 0.0792 | 0.0648 |
| Belgium | -0.0639 | 0.1732 |
| Switzerland | -0.0459 | 0.7557 |
| Germany | 0.5345*** | 0.1546 |
| Denmark | -0.3146 | 0.9537 |
| Finland | 0.9709*** | 0.3332 |
| France | 0.3309* | 0.1714 |
| Great Britain | -0.1366 | 0.2161 |
| Japan | 0.1462 | 0.1075 |
| Netherlands | 0.9692*** | 0.3073 |
| Sweden | 1.0131*** | 0.2572 |
| Electronics | -0.2372 | 0.1598 |
| Engineering and General Machinery | -0.2602** | 0.1270 |
| IT Hardware | -0.2970* | 0.1782 |
| Pharmaceuticals and Biotechnology | -0.4577** | 0.1903 |
| Constant | 0.6982 | 0.6193 |
| Number of Observations | 311 | |
| R-Squared | 0.80 | |

Notes: Robust standard errors, clustered by parent firm. ***,**,* indicate significant at the 1, 5 and 10 percent levels. US is the reference group for the Home Country Dummies. Chemical is the reference group for the Sector Dummies.