Forthcoming in Industrial and Corporate Change

Inter-firm reverse technology transfer:

The home country effect of R&D internationalisation

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Abstract

One consequence of the internationalisation of R&D may be the transfer of foreign technology from the multinational to other firms in its home country. This phenomenon, which can be termed *inter-firm reverse technology transfer* and which has not been directly analysed by either the international management or foreign direct investment literature, may have significant implications for policy – particularly in Europe. This paper is a first attempt in this direction. Patent citation analysis on a database of EPO patents granted to 17 European chemical and pharmaceutical multinationals over the period 1985-05 shows that they act as a channel for the transmission of knowledge developed in the US, to other home country firms; these results are robust to the exclusion of examiner citations. We find that this technology transfer process is explained by the degree of home country embeddedness of the multinational firm, the US subsidiaries' engagement in asset-augmenting activities, and the presence of a technology gap between the US and the home country. These results point to an alternative understanding of foreign direct R&D investment and its implications for the home country's technological activity and general competitive performance.

Keywords: reverse technology transfer; R&D internationalisation; multinational firms; patent citation; embeddedness.

Word count main text: 8,611.

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1. Introduction

Multinational enterprises (MNEs) play a dominant role in innovation activities in their home countries, and control a large proportion of the world's stock of advanced technologies. Their decisions regarding the method, location and exploitation of research and development (R&D) can greatly influence the home country's technological potential and competitiveness (Pavitt and Patel, 1999); thus, the growing internationalisation of R&D activity has been a cause of concern to policymakers. In Europe it has been suggested that the relocation abroad of R&D—particularly in the faster growing industries—is resulting in a ‘hollowing out’ of domestic capabilities and a weakening of the national innovation system (ETAN, 1998). In the US the internationalisation of industrial R&D has brought worries about a possible impoverishment of the national technology base due to the increased R&D activities of foreign MNEs (Kogut and Chang, 1991).

However, whether these concerns are justified can only be decided by evaluating the nature and extent of the R&D activity that has been relocated abroad. Policy makers may be relaxed about simple adaptations to products developed at home to suit local tastes, but should be concerned about the transfer of more substantive R&D investment. Even then, the problem is not so much the extent of the R&D performed abroad, but the extent to which the domestic economy benefits from it, if at all. Indeed foreign subsidiaries' innovative efforts may increase domestic technological competitiveness if what is absorbed abroad spills over to other home country firms.

This process, defined by Mansfield and Romeo (1980) as ‘reverse technology transfer’ (RTT), is not new (Reddaway et al., 1968), but it has mainly been examined as a means of improving the MNE’s knowledge and technology assets portfolios (i.e. intra-firm reverse technology transfer - see Mansfield and Romeo, 1980; Gupta and Govindarajan, 2000; Frost and Zhou, 2005; Singh, 2007) and its productivity (Fors, 1997; Griffith et al., 2006). But reverse technology transfer can have significant effects on the home country if the knowledge and resources that are transferred back to the parent firm spill over to the rest of the economy through linkages with domestic firms – i.e. *inter-firm RTT*.

Despite the political relevance of the potential reverse flow of knowledge from R&D activities performed abroad, this process has not received explicit research attention in the academic literature. The R&D internationalisation literature generally regards the home country as the source of an MNE’s technological advantage (e.g. Sölvell et al., 1991) and thus it assumes that internationalisation entails only outflows of knowledge. The foreign direct investment (FDI) literature mainly focuses on the impact of outward investment (primarily, foreign production) on home-country employment and balance of payments, disregarding the effects on the technology base. The effect of outward FDI on the home country’s productivity and knowledge base has also been rather ignored (van Pottelsberghe de la Potterie and Lichtenberg, 2001). For example, in a recent survey, Lipsey (2002) does not mention a single study investigating either of these issues. As Blomström and Kokko (1998: 22) acknowledge, ‘the existing literature on the home country effects of FDI has seldom referred *explicitly* to spillovers’ (emphasis added). Thus, there has been little direct investigation of inter-firm RTT. One of the few quantitative studies of this process is by Globerman *et al.* (2000), who carry out citation analysis on a sample of Swedish

patents and find that the pattern of Swedish outward FDI is a significant determinant of the knowledge flows to Sweden.

Our study aims to contribute to the research on the impact on the home country of R&D internationalisation, by testing for the presence of inter-firm RTT stemming from the activities of the US subsidiaries of 17 European chemical and pharmaceutical MNEs over the period 1985-2005. Following Globerman *et al.* (2000), we track international knowledge flows through citation analysis for a sample of European Patent Office (EPO) patents. We demonstrate empirically that the main factor favouring the realisation of technology-related externalities from outward FDI is high degree of embeddedness of MNEs in their home countries. Despite greater internationalisation, MNEs remain strongly embedded in their home countries where they are at the centre of dense networks of relationships with suppliers, customers, competitors, research institutes and universities, financial institutions and industry associations (Sally, 1994).

Section 2 describes the theoretical background underpinning the RTT process. Section 3 discusses the limitations of patent data to measure innovative activity in US subsidiaries, and of patent citation analysis to track knowledge flows. Section 4 describes the data and Section 5 illustrates the empirical approaches used to test for the presence of inter-firm RTT and reports and explains the empirical findings. Section 6 tests for the factors influencing this technology transfer process; Section 7 elaborates the results and offers some conclusions.

2. Theoretical framework

Traditionally, the main function of foreign R&D has been considered to be support for local production and sales activities through the adaptation of technology invented at home to local market conditions (e.g. Vernon, 1966). Technology transfer was seen as

predominantly from headquarters to foreign subsidiaries, and R&D was considered to be primarily asset-exploiting (Dunning and Narula, 1995), incremental and associated with demand-driven innovative activities. However, increasingly R&D activities are being located abroad to augment existing and acquire new technological assets from the local knowledge base (public infrastructure or sector specific agglomeration effects) or specific firms (Kuemmerle, 1999). The growing importance of these types of asset-augmenting (Dunning and Narula, 1995) R&D facilities is stimulating theoretical and empirical research on the processes and mechanisms through which knowledge produced in foreign R&D units is transferred back to the parent company or other foreign subsidiaries i.e. intra-firm RTT (Gupta and Govindarajan, 2000; Frost and Zhou, 2005; Singh, 2007).

The ability to acquire knowledge from pockets of excellence around the world and to manage knowledge flows within international networks of interdependent and specialised units, is now considered the main source of competitive advantage for MNEs (Bartlett and Ghoshal, 1989; Kogut and Zander, 1993). Building an evolutionary theory of the firm, Kogut and Zander (1993) define MNEs as ‘social communities that specialize in the creation and internal transfer of knowledge’ According to them ‘a MNE arises not out of the market failures for the buying and selling of knowledge but out of its superior efficiency as an organizational vehicle by which knowledge is transferred across borders’ (Kogut and Zander, 1993: 625). MNEs, therefore, are firms that are specialised in cross-border technology transfer of relatively tacit and idiosyncratic knowledge, and their survival and expansion are determined by their ability and efficiency in this task. The specific ability of MNEs to articulate tacit knowledge implies that if foreign affiliates can absorb this knowledge, the MNE will be able to codify and exploit it within the firm. This ‘encoding’ of the

knowledge makes it more easily imitable by other firms in the home country once it has been transferred back to the parent company.

Although there are barriers to the internal diffusion of knowledge associated with its characteristics, the prior knowledge of the receiving unit, and the willingness of a unit to share information with other units (Sölvell and Zander, 1995; Gupta and Govindarajan, 2000), studies on intra-firm RTT have found that even though the more traditional knowledge flows, from the centre to the periphery, continue to be dominant, reverse flows are an increasing phenomenon (Gupta and Govindarajan, 2000; Frost and Zhou, 2005; Singh, 2007). These studies show that knowledge flows from foreign units to the parent company will be more likely if foreign affiliates undertake asset-augmenting types of activities, which generate knowledge that is less context-specific and thus more useful to the rest of the organisation. In addition, Gupta and Govindarajan (2000) show that the wider the technology gap between the host and home countries, the greater the incidence of reverse knowledge flows.

The emphasis in these studies is on the MNE rather than other home country firms and institutions. But, as Globerman (1994) points out, there may be some public effects associated with these private effects of outward FDI (i.e. effects on the home country as a whole) if the benefits of these activities are not completely captured by the MNE.¹ One obvious social benefit is improved technological performance and

¹ Although this study focuses on the benefits from relocating R&D abroad, there are some negative externalities from this type of outward FDI. E.g., there could be a reduction in the investing MNE's home country knowledge intensive activities, the so called 'hollowing out' effect (ETAN 1998), or successful imitation by foreign competitors of technologies and innovations. As a result of potential leakage effects from the presence of home country affiliates in foreign markets, MNEs may suffer reduced sales in both the foreign and home markets, which may provoke decreased demand for the products of other home country firms. Furthermore, the home country may lose its control over a key technology and with it, its position in the international market. Most public policy concern over outward FDI and particularly outward R&D FDI, focus on these two negative effects, disregarding the

international competitiveness more generally, of the home country. The foreign activities of MNEs may provide access to foreign technologies and, therefore, may represent a channel for transferring knowledge back to the home country.

Externalities from outward FDI will occur when the MNE does not completely internalise all the gains derived from the investment firms (Globerman, 1994; Blömstrom and Kokko, 1998). First, *vertical* outward FDI can lead to positive productivity spillovers in high-tech industries if the structural shift to high value-added activities allows the home country firms to progress along their learning curves and become more competitive. Second, the expansion abroad of domestic MNEs may increase the productivity of home-country MNE suppliers through economies of scale deriving from *horizontal* outward FDI. To the extent that these activities are characterised by economies of scale, the increase in foreign sales may also stimulate an increase in R&D expenditure by the parent company providing, in turn, a source of potential spillover effects for other home country. Thirdly, and more directly, positive externalities may derive from *inter-firm RTT*, i.e. from R&D activities performed abroad aimed at tapping into foreign centres of excellence and creating new technological assets that build on localised sources of knowledge. The physical presence in foreign markets facilitates faster and/or improved understanding of the new technologies being applied in those markets, since foreign affiliates have the opportunity to assimilate the tacit knowledge involved in the use of these innovations. However, Caves (1974) observes that there are other channels through which technology can be transferred across borders such as the international movement of knowledge, international trade in capital goods and licenses. Therefore, it is important to stress that the role of MNE affiliates in the transfer of knowledge from

potential social benefits that may derive from such investment.

foreign markets back to the home country will be more important in those emerging technology fields characterised by tacit knowledge. Indeed, tacit knowledge is one of the main factors explaining the localised nature of R&D spillovers and determining the extent to which foreign affiliates, which are close to the sources of host country innovations, can act as vehicles for technology transfer to other home country firms.

There are various ways that knowledge accumulated abroad might 'leak' out of the MNE to other home country firms and institutions. The most obvious are those identified in the inward FDI-related spillovers literature (for a review see Blömstrom and Kokko, 1998), namely labour mobility, demonstration effects and backward and forward linkages. But there are others such as strategic alliances, licensing, informal sharing of know-how, and communication at conferences and fairs. For instance, as the result of its R&D investment abroad, an MNE may promote the adoption of a new production process or technology by its home country suppliers. Spillovers can occur as the result of a scientist or manager with work experience in a foreign affiliate, moving to another home country firm. And home country firms may get to know about and, most importantly, learn how to apply technologies developed abroad, through strategic alliances or other forms of co-operation with an MNE. As the evidence on localised knowledge spillovers (Jaffe et al., 1993) and the empirical literature on inward FDI shows, most of these spillover channels work best if the agents involved in the knowledge exchange are geographically and socially proximate, in other words if they are locally embedded.

The incidence of inter-firm RTT depends on a number of factors. First, there must be a pool of knowledge in the host country that MNE can tap into. Thus, the greater the difference in the levels of technological proficiency of the host country and home country firms, the higher will be the potential for RTT. Second, technology sourcing

will be higher in the case of asset-augmenting R&D activity, and very low when R&D efforts are focused on the adaptation of products and processes for the local market. Third, and most importantly, technological knowledge should flow, voluntarily or involuntarily, outside the firm's boundaries, which is dependent on the embeddedness of the MNE in the home country.

Although the increasing cross-border activities of MNEs might seem to be rendering them 'stateless' corporations (Ohmae, 1990), they remain firmly rooted in their home countries. As Sölvell and Zander (1995) note:

In the home base, the global firm can be characterised as an *insider*, where it is linked to other firms in both formal and informal networks ... *These linkages with geographically and culturally close actors are seen as of a certain quality and intensity, different from linkages that cut across national borders.* They provide the channels for rapid dissemination of information and knowledge, and provide a basis for cooperation leading to continuous stream of small and large improvements. For example, *key facilitators of information flows* would include personal relationship due to schooling and military service, mobility of employees between competing firms, norms of behaviour supporting continuity and long-term relationships, or quasi-familiar ties between firms. (emphasis added)

The strong embeddedness of MNEs in their home country is also reflected in the fact that their international operations and strategies are shaped by their home country's socio-cultural and institutional legacy, as underlined by Pauly and Reich (1997).

3. Method: Patenting and patent citation analysis

Following the studies by Globerman *et al.* (2000) and a number of other studies within the international business literature (e.g. Almeida, 1996; Frost, 2001; Singh, 2007), we track international knowledge flows using patent citations. The legal purpose of patent citations is to indicate which parts of the knowledge described are claimed in the patent and which parts are attributable to earlier patents. So, in principle, when a patent cites another patent, this indicates that the knowledge embodied in the cited patent has been useful in some way for developing the new

knowledge described in the citing patent, and that the citing patent has no claim over that particular knowledge (Jaffe et al., 1993). In other words, and for the purposes of this study, it is an explicit record of knowledge flows and use of received knowledge.

However, there are some limitations to the use of patent citations to capture knowledge flows. First not all inventions are patented: firms can use other methods to protect the returns from R&D investment. However, in the chemical and pharmaceutical sectors, studies using data from innovation surveys (see Arundel and Kabla, 1998) have showed that both large and small and medium sized enterprises (SMEs) have high patenting propensity, and thus patents are appropriate to measure their innovative activities. Second, patent citations are an incomplete measure of knowledge flows because they capture only those flows that result in a novel and patentable technology and, therefore, cannot be used to make inferences about tacit forms of knowledge, learning via imitation or reverse engineering. Consequently, in capturing only patent activity the results from this study provide a conservative estimate of RTT.

If knowledge flows can occur without generating citations, there may also be citations that do not represent actual knowledge sources utilised by the inventor in the development of the invention. This source of noise is due to the fact that, although suggested by the inventor together with his/her legal adviser, the final decision about which patents to cite lies ultimately with the patent examiner. Recent studies have compared inventor and examiner citations, for both EPO (Criscuolo and Verspagen, 2008) and USPTO (Alcacer and Gittleman, 2006) patents, and found that inventor citations are more localised than examiner citations, which suggests that inventor citations are more likely than examiner citations to indicate knowledge flows. Thus,

by excluding the noise introduced by examiner citations we should be able to test for the presence of inter-firm RTT more accurately.

Because there can be interventions by patent attorneys and/or the inventors may be ignorant of a patent until after their own invention development (Jaffe et al., 1998), not all inventor citations capture knowledge flows. However, a recent study by Duguet and MacGarvie (2005) provides evidence supporting the use of EPO patents as a measure of knowledge flows. These authors found that citations to other patents were positively and significantly correlated with firm's engagement in R&D collaboration, licensing of foreign technology, mergers and acquisitions and equipment purchases. Thus, despite their limitations in capturing real knowledge flows, the evidence from this study goes some way towards justifying the use of EPO patent citations as a reasonable proxy for knowledge flows.

4. Data

Our primary data source is the Organisation for Economic Cooperation and Development (OECD) EPO patent citation database (Webb et al., 2005) which contains detailed information on EPO patent applications, patent citations to other EPO and non-EPO patents, citations to non-patent documents, and the citation categories assigned by the EPO examiner in the patentability search report. Following Criscuolo and Verspagen's (2008) strategy, we exploit this information to identify inventor citations (i.e. citations in the 'D' category). We assign each EPO patent to a European NUTS2 region and a US state, using the geographical classification of the inventor address in the OECD REGPAT database (Maraut et al., 2008).

We also exploit a dataset developed by Thoma and Torrisi (2007) of EPO patent applications from 1,404 European publicly listed companies, which are representative of the most R&D-intensive sectors in Europe and account for 70% of total business

R&D in these European countries on average.² In this dataset patents are assigned to companies, based on information on ownership links between parent companies and subsidiaries provided by Bureau Van Dijk's Amadeus dataset, for 1997-2005. All corporate structure changes due to mergers, acquisitions and spin-offs during the period 1997-2005, are tracked through the Bureau Van Dijk's Zephyr dataset.

From the Thoma and Torrisi's dataset we extracted EPO patent applications with priority years between 1985 and 2005, by the US subsidiaries of 17 of the largest European chemical and pharmaceutical MNEs in 2005 (see Appendix A for list of companies). These two sectors were selected on methodological grounds, as explained above, and because of the increasing internationalisation of R&D activities by MNEs in these industries. A number of studies (e.g. Shan and Song, 1997) show that European chemical and pharmaceutical MNEs exploited US knowledge to acquire the technological competences for many new products, especially in biotechnology. The US is the preferred location for asset-augmenting activities not only because of its technological infrastructure, but also because of the large number of small specialist research firms that are extremely dynamic and embedded in networks of collaborative relationship with universities, large firms and public and private research centres in the US (Gambardella et al., 2000). European MNEs are attracted to these biotech clusters for the benefits that can be gained from the external economies generated by the concentration of production and innovation activities, and for the access they give to high skilled workers and the research of 'star' academic scientists.

4.1. Preliminary analysis of the citation data

² By Europe, here we mean the 15 European Union member countries (prior to May 2004), plus Norway, and Switzerland.

We identified 18,328 EPO patent applications from the set of US subsidiaries and, from the OECD/EPO database, extracted 16,701 citations to this sample of patents, in EPO patents with priority years after 1990.³ From these citations we selected those in patents with at least one inventor located in a European country, which accounted for 6,724 citations. If we exclude intra-firm citations, we have a sample of 4,805, of which 714 are inventor citations. Among these 4,805 citations, we identified 1,449 *home-country citations*, i.e. citations made by a patent with at least one inventor located in the country of origin of the cited subsidiary (e.g. citations made by patents invented in Germany to patents granted to a US affiliate of Bayer).⁴ Similarly, among the set of 714 citations included by inventors we found 249 *home-country citations*.

Using the OECD REGPAT database, we derived a similar indicator at the regional level. We identified the NUTS2 region in the home-country where patents owned by the cited MNE originate and then searched among the 4,805 citations for those citing patents with at least one inventor from one of the home-country regions identified. To take the example of Bayer, we consider a citing patent invented in Germany to be a *home-region citation* if the citing patent was invented in one of the 41 NUTS2 German regions from which Bayer's patents originate.

³ Because EPO patents do not capture to the same extent as USPTO patents (Criscuolo, 2006), US subsidiaries' R&D activities, we searched in the OECD EPO database for EPO equivalents of USPTO and WIPO patents, i.e. EPO patents protecting the inventions with the same priority numbers as USPTO or WIPO patents. It is likely that US subsidiaries apply first to USPTO or WIPO before subsequently filing at the EPO. Thus, it is possible that an EPO citing patent refers to a USPTO or WIPO document rather than an EPO patent. Substituting USPTO and WIPO cited patents with their EPO equivalents improves our measurement of inter-firm RTT, although we cannot completely compensate for the fact that EPO data do not fully measure the innovative efforts of US subsidiaries.

⁴ For companies such as AstraZeneca and Sanofi-Aventis, which are the result of mergers between two MNEs with headquarters in different countries, a citation made by a patent with at least one inventor located in either of the two countries of origin, to patents owned by these MNEs, is considered a *home-country citation*.

We also identified three groups of citing firms with different international profiles:

- 1) subsidiaries or headquarters of European MNEs with US operations;
- 2) subsidiaries of US MNEs;
- 3) domestic firms defined as firms without subsidiaries in the US, universities, public research institutes, government bodies and private inventors .

For those citing firms not included in the Thoma and Torrisi's dataset, we checked the names of the assignees manually, using several sources (LexisNexis Corporate Affiliations directory, Bureau Van Dijk's Zephyr database, and company websites) in order to assign the citing firm to one of the above three categories. This was done to control for the fact that MNEs might have acquired the knowledge developed in the US either directly through their presence in the US or indirectly through their organisational networks. Domestic firms and institutions would most probably be reliant on their linkages with relevant MNEs to access technological knowledge accumulated in the US. It is for this group of organisations that MNEs may be an important channel for international transfer of knowledge. Figure 1 shows the alternative technology transfer channels for firms with US operations to access knowledge developed there.

***** INSERT FIGURE 1 *****

Table 1 reports the breakdown of *home-country* and *home-region citations* across the three groups of firms. A large proportion of citations are contained in patents applied for by European MNEs, but almost 30% of all citations originate from domestic firms or institutions and 30% of these are in patents whose inventors are located in the home country of the cited subsidiary. When we examine the sub-sample of citations included by the inventor, on average, the share of *home-country citations* is higher than in the entire sample (35% vs 30%). This appears to be driven by the

greater proportion of *home-country citations* among European MNEs and domestic firms. Conversely, there are fewer *home-region inventor citations* in the sample of inventor citations than in the entire sample and particularly in the case of European MNEs.

These figures suggest that citation patterns differ across these three groups of firms and depend on whether the home region or the home country is used as the geographical unit of analysis. They also show that both multinational companies in the home-country of the cited subsidiary and domestic firms appear to benefit from this RTT process, but this needs to be statistically tested. We use two methods to test for whether a US subsidiary facilitates the diffusion of knowledge to other home-country firms: the matching method, which tests whether the frequency of *home-country* and *home-region citations* is higher than a reference baseline probability, and a citation-level multivariate regression analysis, which enables us to directly control for other determinants of the citation pattern.

5. Testing for the presence of inter-firm RTT

5.1. The matching method

This method builds on the approach originally proposed by Jaffe, Trajtenberg and Henderson (1993) and subsequently applied by Almeida (1996) in the context of knowledge flows among foreign subsidiaries and domestic firms. Figure 2 shows that the approach consists of constructing a set of citing patents invented in Europe, each citing at least one of the originating patents.

/***** INSERT FIGURE 2 AROUND HERE *****/

To test for the presence of inter-firm RTT we need to examine how many of these citing patents are invented in the home-country of the cited MNE. To be able to infer that the observed frequency of home-country match is greater than would be

expected given the existing geographical distribution of R&D activities in the relevant technical field and time period, we match each citing patent to a control patent with the same priority year and the same 4-digit International Patent Class (IPC) which does not cite the originating patent. We compare the frequency of home-country matching between control patent and corresponding cited patent with that in the sample of citing patents.

To test whether there is a statically significant difference between the two proportions of *home-country citations* we use a t statistic to test for the difference between two independently drawn binomial proportions, which is derived as follows:

$$t = \frac{p_o - p_c}{\sqrt{\frac{p_o(1-p_o)}{n_o} + \frac{p_c(1-p_c)}{n_c}}}$$

where p_o and p_c are the proportions of *home-country citations* in the sample of citing patents and control patents, respectively, and n_o and n_c are the number of citations in the two samples. A positive and significant t -statistic value indicates that *home-country citations* are higher than would be expected among a sample of citing patents invented in Europe with similar temporal and technology profiles.

Table 2 reports the results of the matching procedure at country and regional levels, and using one and four matched control patents. Across all samples the t -statistic is significant at the 0.01 level, which indicates that there is a higher proportion of *home-country* and *home-region citations* in both the entire sample and the sub-sample of inventor citations, than in the control sample.

These findings suggest that home-country firms benefit from the R&D activities conducted in the US by domestic MNEs, and these benefits are particularly stronger for home-country firms located in the same region as the national subsidiaries of the investing MNE. Indeed, the difference between p_c and p_o is higher

at regional than at country level for both the entire sample and the sample of inventor citations. This indicates that some of the mechanisms through which knowledge is transferred from the investing MNE to other home-country firms, such as labour mobility, informal know-how sharing, or demonstration effects, operate at the regional level as suggested by the literature on localised knowledge spillovers (Jaffe et al., 1993).

5.2 Citation-level regression analysis

To test the robustness of the results from the matching method we carried out a citation-level multivariate regression analysis following the approach proposed by Singh (2007). This method allows us to directly control for alternative explanations of the observed citation patterns such as the technological characteristics of the cited patent, the technological specialisation of the citing firm's country and, most importantly, the citing firm's international profile. This method consists of estimating the probability of citation between two patents extracted from a pool of potentially citing and cited patents. In our study the number of potentially cited patents corresponds to the entire US subsidiaries sample's patents, regardless of whether or not they have been cited by a European inventor.

The sample of potentially citing patents is more difficult to define since, in theory, it should be equal to all patents invented in Europe. However, identifying the international profiles of all the applicants of EPO patents invented in Europe would require manually checking for the names of the assignees in different databases to identify the home countries of the ultimate owners and to establish whether the citing firm had a subsidiary in the US. Here, the set of potentially citing patents is all those patents owned by the sample of 1,404 European firms in the Thomas and Torrisi's dataset whether or not they cite patents in our US subsidiaries sample. Since this

dataset excludes private inventors, universities, European subsidiaries of US MNEs, and small European SMEs we added all patents owned by these applicants that cite the set of originating patents.

Having defined the set of potentially citing patents - 310,690, and cited patents - 18,328, we identified all potentially citing-cited pairs, in other words, we created a dataset with millions of observations in which the number of actual citations is extremely small. In this case estimating the probability of citation using a traditional logit model would significantly underestimate the probability of a positive outcome (King and Zeng, 2001).

We apply a choice-based sampling procedure, which includes all actual citations ($y = 1$) and randomly extracts a set of matched control patent pairs that do not cite each other ($y = 0$). The matching procedure adopted the following criteria: the control patent pair belongs to the same 4-digit IPC as those in the original citation pair; the control citing patent was applied for after the original cited patent; the control cited patent was applied for in the same year as the original cited patent; the patents in the control pair are not owned by the same MNE. King and Zeng (2001) recommend between two to five non-occurring events for every occurring event. We include 4 control citations for each observed citation. This resulted in a dataset containing 24,024 citation pairs of which 4,805 are actual citations and 19,219 are control citations. A similar procedure was used to derive a dataset with 3,566 citing-cited pairs added by the inventor, which included only the 714 actual citations.

The use of choice-based sampling introduces bias in the estimated model, which can be corrected using a weighted exogenous sampling maximum-likelihood estimator (WESMLE) (King and Zeng, 2001). Tomz's (2001) Stata procedure was used to estimate this so-called rare event logit model.

Since both citing and cited patents can have more than one inventor, and these inventors might be located in different countries and regions, we consider all possible combinations between the citing and cited locations (countries or regions) and assign to each observation a given weight. Let us assume that a citing patent has inventors from m different countries and the cited patent has inventors from n different countries, we then have $m*n$ combinations of citing and cited countries, which implies a weight equal to $1/m*n$ should be assigned to each observation. The rare event logit model is estimated using these weights as importance weights. Finally, to address the fact that the same citing patent appears in the dataset more than once, we report robust errors clustered on citing patent.

5.2.1 Specification of the model

We estimate a rare event logit model using the following specification:

$$y_{ij} = \beta_0 + \beta_1 Homecetry_j + \beta_2 TYPE_j + \beta_3 TechnComp_j + \beta_4 Sametech_{ij} + \beta_5 MultipleIPC_i + \beta_6 CitePub_i + \beta_7 Averagecit + \text{citing country dummies} + \text{cited MNE dummies}$$

where the dependent variable y is a binary variable equal to 1 if patent j cites patent i applied for by our sampled US subsidiary.

To test for the presence of inter-firm RTT we need to examine whether home country firms show a learning advantage over firms located in other European countries. Therefore, we include a dummy variable (*Homecetry*) that takes the value 1 if the citing patent originates from the home country of the cited subsidiary and 0 otherwise. An odds ratio greater than 1 and statistically significant would indicate that firms located in the home country of the cited MNE are more likely than other European firms to cite US subsidiaries' patents and thus would point to evidence of inter-firm RTT.

To control for other channels of technology transfer, we included a set of dummy variables (*TYPE*) that identify the three groups of citing firms located in Europe - subsidiaries of MNEs (*MNE*), subsidiaries of European multinationals (*EUMNE*), subsidiaries of US multinationals (*USMNE*) - and the reference category domestic firms and institutions (*DomesticFirm*). If the *Homectry* variable is still significant after controlling for the international profile of the citing firm this would support the existence of inter-firm RTT in addition to other potential mechanisms for international technology transfer.

The probability of citation will also be a function of the degree of technological specialization of the country in which the citing firm is located. To account for this, we include a variable (*TechCom*), which is the share of patents originating from the citing inventor's country in the same technology class of the cited patent and in the same priority year of the citing patent.⁵ This variable is crucial for identifying RTT since, if the odds ratio of *Homectry* remains significant and greater than 1 when *TechComp* is included, then we can be sure that this effect exists over and above any technological capabilities inherent in the home country.

Because citations are more likely to occur between patents in similar technological domains, we include a dummy variable (*Sametech*) which is equal to 1 if the citing and cited patents belong to the same primary 7-digit IPC of technology. Similarly, there is evidence that the number of forward citations is positively related to the number of patent classes appearing in a patent (Fleming and Sorenson, 2004), because a patent classified in multiple technology classes is more likely to appear in

⁵ We classify patents in 30 broad technology fields using the classification scheme provided by the Observatoire des Sciences et des Techniques (OST) and the Fraunhofer Institute (FhG-ISI) (see OST, 2002 appendix A5a-1 p. 346).

the searches of other inventors and/or in examiners. We, therefore, include a dummy variable (*MultipleIPC*) which equals 1 if the cited patent has been classified in more than one IPC. Forward citations are also more likely to occur when patents build on basic research, since these have a greater impact than those patents that do not cite scientific publications (Fleming and Sorenson, 2004). We therefore include a dummy variable (*CitePub*) which equals 1 if the cited patent contains citations to non-patent documents and 0 otherwise.

To correct for truncation or ‘cohort’ effects (i.e. patents granted in 1985 may receive more citations than patents granted in 2000) and for unobserved differences in citations across technology fields we include a variable for the average number of citations received by EPO patents applied for in the same year and in the same technology class of the cited patent (*Averagecit*). Finally we include a series of country dummies for citing patent countries and a series of cited MNE dummies to account for unobserved country and cited firm fixed effects. To improve the readability of the tables, we have not included the coefficients for these control variables.

5.2.2. Results of the econometric analysis

The results of the regression analyses at the country level are presented in Table 3, which reports the odds ratios for both the estimates obtained using the entire sample of citations (Columns 1-5) and those for the sub-sample of inventor citations (Columns 6-10).

The estimates in Column 1 provide support for the presence of inter-firm RTT: the odds ratio of the *Homectry* variable is greater than 1 and statistically significant. In particular, firms located in the home country of the cited MNE are 23% more likely than other European firms to cite patents owned by the US subsidiaries of these

MNEs. The *Homectry* dummy is still significant when we control for the inherent technological capability of the country of the citing firm (*TechComp*) (see estimates in Column 2). This variable has a significant and positive impact on the probability of citation, which supports the idea that absorptive capacity is crucial in the technology transfer process.

***** INSERT TABLE 3 HERE *****

The models in Columns 3 and 4 control for whether the citing firm has a subsidiary in the US. As Figure 1 showed, it is possible that firms with US operations might gain access to technologies developed in the US through their organisational networks and, thus, that the flow of knowledge, from the US subsidiary to the home country firm, does not go through the subsidiary's headquarters, in other words it is not true RTT. In Column 3 we include a variable capturing whether the citing firm is a MNE active in the US, and in Column 4 we distinguish between the subsidiaries of US and European MNEs to check whether firm nationality makes a difference.

The fact that the *Homectry* variable is still significant and positive in these two regressions reinforces the findings related to the positive role of MNEs in cross-border technology transfer. Of interest, is that European or American MNEs are 53% and 18% less likely to cite US subsidiaries patents than European domestic firms and institutions, respectively. This suggests that multinational companies in Europe are able to monitor developments in the US through their networks of subsidiaries.

To test for whether domestic companies in the home country of the cited MNE show a learning advantage relative to other domestic firms located in other European countries, we re-ran the model for the sample of citing firms without US operations.⁶

⁶ This dataset was derived following the procedure described in the previous section, but using as the set of potentially citing patents, all those patents applied for by European domestic firms and institutions.

For this sample of firms we can rule out the presence of channels of international technology transfer other than exports, and assume that MNEs might represent an important conduit for foreign developed technologies. Estimates reported in Column 5 show that the coefficient on the *Homectry* dummy is positive and significant.

When we examine the sub-sample of citations added by the inventor (see Columns 6-10) the results are similar. In particular, for this sample of citations, which more directly tracks knowledge flows, we find odds ratios for the *Homectry* variable of the order of 1.35 (1.85), meaning that (domestic) firms in the home country of the cited MNE are 35% (85%) more likely than (domestic) firms located in other European countries to cite a US subsidiary's patent. This seems to confirm the presence of inter-firm RTT. The *MultipleIPC* dummy is never significant in these models, which suggests that inventors are less likely than examiners to carry out complex patent searches.

Finally, we estimate a set of models using regions instead of countries as geographical unit of analysis. The *Homeregion* dummy variable is equal to 1 if the citing patent has at least one inventor located in one of the NUTS2 regions from where patents owned by the cited MNE originate. The *TechComp* variable is also defined at the regional level: it is equal to the share of patents invented in the citing inventor's region in the same technology class as the cited patent, and in the same priority year of the citing patent. Results of these estimations are reported in Table 4: Columns 6-10 show the estimates obtained using the sub-sample of inventor citations.

The main findings at country level mostly hold at regional level. The most important exception is the lack of significance of the *Homeregion* dummy when we consider the sample of inventor citations by domestic firms and institutions (Column 10), which could indicate that what matters for these small domestic firms is not so

much proximity to a cited MNE's unit, but location in the home country of the MNE. This finding is line with Dickens et al.'s (1994) argument that when the concept of local embeddedness is applied to MNEs, 'local' should be interpreted as 'national' and not a small within country geographic area. As in Table 3, what seems to determine the likelihood of citation among the sample of inventors from domestic firms and institutions is the technological similarity between the citing and cited patents.

***** INSERT TABLE 4 HERE *****

6. Exploring the determinants of inter-firm RTT

The analyses so far have examined whether MNEs act as a channel for the transmission of knowledge developed abroad to other home country firms, but have not investigated what determines inter-firm RTT. We have argued that this phenomenon might arise from asset-augmenting R&D units. We have also assumed the existence of a technological gap between the host and the home locations, for this process to take place, and that knowledge that originated in the US is channelled through the parent company to other home-country firms based on their high embeddedness in the home country.

We now examine whether the above factors explain the occurrence of inter-firm RTT by estimating a rare event logit model, where the dependent variable (y) is equal to 1 if there is a citation between a patent applied for by a US subsidiary and a patent invented in the home country of the cited MNE or from one of the regions where the cited MNE patents originate, and 0 otherwise.⁷

⁷ The datasets we use to estimate these models were derived using the approach described in Section 5.2 where the set of potentially citing patents is all EPO applications by inventors located in the home country of the cited MNE.

$$y = \beta_0 + \beta_1 \text{ShareHomectryEmpl} + \beta_2 \text{ShareHomectryPats} + \beta_3 \text{ShareHomectryCoPats} + \beta_4 \text{Selfcitation} + \beta_5 \text{TechGap} + \beta_6 \text{Sophi} + \beta_7 \text{CitePub} + \beta_8 \text{PatFam} + \beta_9 \text{Sametech} + \text{cited MNE dummies} + \text{citing countries dummies}$$

The first three explanatory variables try to capture the degree of home country embeddedness of the cited MNE's manufacturing operations and core value adding activities. *ShareHomectryEmpl* is equal to the average percentage of employees in the home country over the period 1990 and 2005, using information extracted from companies' financial reports and from UNCTAD World Investment reports. MNEs with a large proportion of their manufacturing and non manufacturing activities in the home country will have strong linkages with local suppliers, trade unions, national and regional governments, and trade associations. *ShareHomectryPats* is the number of patents originating from the home-country over total patents applied for by the cited MNE. *ShareHomectryCoPats* is derived as the number of joint patent applications with other home country firms or institutions over total number of joint applications. Both these indicators measure the level of concentration of upstream activities in research, development and engineering in the home country and, therefore, capture the extent of linkages with home country universities, research institutes, consumers, suppliers and competitors. Although these three variables do not directly measure these linkages they do however provide a good proxy for their presence and strength.

The role of the MNE as conduit of the knowledge developed in the US subsidiaries is captured by a dummy variable that is equal to 1 if the cited patent has been cited by other units of the same MNE (*Selfcitation*). Although there are other ways in which MNEs can exploit the knowledge produced by US subsidiaries, which are not reflected in patent citations, self-citation has been used in previous studies to

measure intra-firm RTT (Singh, 2007). The technological gap between the home and host location is measured by the ratio of the number of patents in the same 3-digit IPC of technology of the cited patent originating from the country in which the citing firm is located, over those invented in the US in same priority year as the cited patent (*TechGap*).

The asset-augmenting nature of the R&D activities carried out by the US subsidiaries is measured by three variables: *CitePub* and *PatFam* characterising the cited patent, and *Sophi* characterising the technological leadership of the US subsidiary. *CitePub* captures the basic nature of the knowledge contained in the cited patent; *PatFam* measures the economic value of the cited patent by counting the number of patent offices where the patent is protected. Because applying for patent protection in more than one patent office is expensive, we would expect that patents that are protected in multiple offices will be economically more valuable, i.e. to have expected returns high enough to outweigh the costs of filing in more than one foreign patent office (Putnam, 1996). Asset-augmenting R&D activities tend to produce less context-specific and more basic knowledge, thus we would expect US subsidiaries engaged in this type of innovative activities to apply for patents which build on, and thus reference, scientific research and which have applicability in other countries, thus with greater economic value and, consequently, larger patent families. *Sophi* measures the distance of the cited subsidiary's innovative activity from the technological frontier. It is equal to the average across the 634 4-digit IPC, of the ratio of the forward citations received by the cited subsidiary's patents to the number of forward citations received by the average patent in that class (MacGarvie, 2006):

$$Sophi = \frac{1}{N_{it}} \sum_{n=1}^N \frac{\overline{c_{int}}}{c_{nt}}$$

where N_{it} is the number of technology classes in which the cited subsidiary has patented in year t , $\overline{c_{int}}$ is the average number of forward citations received by patents applied for by subsidiary i in year t in class n , and $\overline{c_{nt}}$ is the average number of forward citations received by patents in class n in year t . This variable captures the importance and value of patents applied for by the US subsidiary relative to the overall average, correcting for the differences in citation frequencies across technological classes. A value of *Sophi* greater than 1 suggests that the subsidiary is a technology leader; a value less than 1 suggests the firm is a technology follower.

As in previous models, we include a variable measuring the technological similarity between the citing and cited patent defined at the 7-digit IPC (*SameTech*), the average number of citations received by EPO patents applied for in the same year and in the same technology class of the cited patent (*Averagecit*), citing inventor country and cited MNE dummies.

Table 5 compares the means and standard deviations of the main explanatory variables, across the sample of home country (inventor) citations and control (inventor) citations, highlighting several significant aspects. First, on average the level of embeddedness of the cited MNE is higher among the sample of home country citations. Second, US invented patents cited by home country firms on average are more likely to be also cited by other units of the MNEs that own them; they are also more likely to include references to scientific publications and to be protected in more patent offices. Third, foreign subsidiaries cited by home country firms seem to be fairly heavily involved in cutting-edge research: on average the *Sophi* variable is greater than 1 for the sample of home country citations and higher than the corresponding average for the control citations.

***** INSERT TABLE 5 HERE *****

6.1 Results of the econometric analysis

Table 6 reports the odds ratios for the rare event logit models estimated at country and region level, for the entire sample of citations and for the sample of inventor citations. Across all models the technological leadership of the cited subsidiary has a positive and significant effect on the likelihood of a *home country* or *home region citation*. Based on the estimates in Column 1, we find that for one standard deviation increase in the *Sophi* variable and holding all the other variables constant, the odds for home country citation are 1.37 times higher. Also, the other two variables capturing the asset-augmenting nature of the R&D activities of US subsidiaries (*CitedPub* and *PatFam*) appear to have a positive and mostly significant effect on the likelihood of a *home country* or *home region citation*.

***** INSERT TABLE 6 HERE *****

The extent of home country embeddedness also appears to positively and significantly affect the likelihood of *home country citation*. The proportion of joint co-patenting activity with other home country firms and institutions is consistently significant and positive across all the models as is, in most models, the share of employment in the home part of the MNE. The proportion of patents originating from the home country of the cited MNE, although positive, does not always reach significance. The pattern is similar for the *Selfcitation* dummy which, although positive, is never significant for the sample of inventor citations, which might be due to the smaller sample size. When *TechGap* is significant the odds ratio is less than 1, which implies that inter-firm RTT is more likely to occur when the technological

capability of the US or the host US state, is stronger than that of home country or home region.

7. Conclusion

This study tested for the existence of an inter-firm RTT process, i.e. a technological knowledge flow from a MNE's foreign based R&D facilities to its home country firms. The findings show that these reverse knowledge flows exist even after controlling for a number of other potential explanations for the observed citation pattern. We also found that the degree of home country embeddedness, the engagement in asset-augmenting R&D activities by the US subsidiaries, and the existence of a technological gap between the host and home countries determine the occurrence of inter-firm RTT.

Our results provide an alternative view of R&D FDI. The relocation of R&D activities abroad might not necessarily entail an erosion of national technological competitiveness. Also, it may improve the overall innovative performance of the investing firm and of other home-country firms through reverse transfer of technological assets developed in the foreign locations. National governments have tended to encourage MNEs to maintain their R&D activities at home, by limiting subsidies to R&D performed at home, for example, not favouring the re-location of this investment to foreign countries, and ignoring the possibility of RTT. If there were major formal or informal barriers to overseas R&D, it is possible that both the investing firm and other home-country players could be excluded from important product and process developments, which could lead to competitive disadvantage.

Particularly in R&D-intensive and technologically complex industries, innovation sources have become much more dispersed and, in order to remain internationally

competitive, firms require access to foreign technological developments. Thus, it would be detrimental to an economy if its major companies were not able to undertake R&D activities abroad, given the high degree of specialisation in the generation of technological knowledge and the growing importance of critical pockets of excellence abroad. Indeed, it could be argued that firms should be encouraged to undertake foreign R&D investments so that other domestic firms can gain access to new technologies and knowledge.

However, to reap the greatest home country benefits from R&D performed abroad, policy makers should ensure that the multinational's R&D function is well embedded in the home country. On the one hand this could be achieved by strengthening the ties between home-country firms and institutions and the multinational firms undertaking R&D investment abroad through enhanced inter-firm cooperation and inter-firm mobility of highly qualified workers. On the other hand this goal could be achieved by maintaining and enhancing the attraction of the home country as a location for undertaking R&D activities. To increase the attractiveness of a country as a location for R&D policy makers could foster scientific excellence through the creation of both scientific and technological networks of public and private research. Such policies would also achieve the objective of attracting foreign R&D investments aiming at the creation of forefront technology.

To what extent a passive internationalisation strategy, i.e. one encouraging R&D investment from foreign firms, is better than a 'active' one, i.e. encouraging R&D investment abroad, will be country and sector specific. As pointed out by Van Pottelsberghe de la Potterie and Lichtenberg (2001) the trade-off between these two strategies is like choosing what is the best way to learn a foreign language: talking with foreigners living in one's home country or choosing to live in a foreign country.

The latter seems more appropriate if one considers also the fact that the former strategy has the problem that, to a great extent, foreign companies cannot be chosen, and in particular it is very difficult to select the amount and the quality of technology they are willing to transfer. In addition foreign companies might displace domestic R&D by competing for limited specialised resources, such as highly-skilled workers. However the ‘active’ internationalisation strategy has other drawbacks. A policy that subsidises the relocation of R&D activity abroad needs to assess to what extent the technological knowledge acquired abroad is completely internalised by the investing firm or spills over to other domestic firms, generating positive externalities for the domestic economy. Another cost of this internationalisation strategy may arise if MNEs stop interacting with the domestic innovation system and instead turn exclusively to co-operation with foreign partners. Therefore it is important to stress that a policy aiming to encourage R&D investment abroad should be coupled with a policy aiming to capture greater local benefits from these investments.

Our analysis provides reasonable, but not conclusive, evidence of RTT. Although useful, patent citation analysis has some limitations, the most serious being the use of patent citations as a proxy for knowledge flows: citations are not only included by inventors, they can be added by patent examiners. To overcome this limitation we excluded examiner citations from our estimations, and used only the sample of inventor citations, which are more likely to represent a knowledge spillover. Although we were able to test the robustness of our findings by eliminating the noise introduced by examiner citations, we were not able to identify the channels and mechanisms enabling RTT. Information on the channels and mechanisms enabling RTT would be extremely useful for formulating managerial and policy prescriptions and future work in this area would be beneficial. This research could include analysis of how a

particular product or process innovation by a foreign subsidiary abroad, diffuses within the MNE's home country and could focus on the mechanisms through which knowledge developed abroad diffuses to other home country firms, e.g. R&D collaborations, licensing agreements, strategic alliances, or inter-firm labour mobility.

Acknowledgements

The author would like to thank Stefano Brusoni, Davide Castellani, Simon Collinson, Chiara Criscuolo, Gustavo Crespi, Linus Dahlander, Alfonso Gambardella, Gerry George, Bronwyn Hall, Simona Iammarino, Anita McGahan, Rajneesh Narula, Pari Patel, Ammon Salter, Fergal Shortall, Ed Steinmueller, John VanReenen, Bart Verspagen, Reinhilde Veugelers, and participants at the 2003 meeting of the Academy of International Business and the CESPRI seminar for helpful comments. The author is also indebted to Colin Webb, Hlne Dernis and Thomas Grid for providing their datasets. Finally, financial support from the European Commission (Marie Curie Fellowship) and the Engineering and Physical Sciences Research Council's IMRC at Imperial College London is acknowledged.

Table 1 Descriptive statistics of citations made by patents invented in Europe to US subsidiaries' patents (excluding intra-firm citations)

	Entire sample				Inventor citations			
	# of citations	% Total citations	% Home-country citations	% Home-region citations	# of citations	% Total citations	% Home-country citations	% Home-region citations
Citing firms								
Units of US MNEs	698	14.7	35.1	34.8	77	10.8	24.7	25.0
Units of EU MNEs	2,681	56.4	30.2	27.7	503	70.9	36.6	19.7
Domestic firms	1,372	28.9	28.0	26.2	129	18.2	35.7	28.3
Overall	4751	100	30.3	28.3	709	100	35.1	24.2

Table 2 Testing for RTT: matching method results

Country level analysis							
	Entire sample			Inventor citations			
	Citing Patents	1 match	4 matches	Citing Patents	1 match	4 matches	
		Control Patents	Control Patents		Control Patents	Control Patents	
Number of citations	4,805	4,732	18,409	714	650	2,267	
Proportion of <i>home-country citations</i>	30.15	27.36	27.53	34.87	29.1	29.33	
t-statistics		3.01	3.551		2.299	2.737	
Regional level analysis							
	Entire sample			Inventor citations			
	Citing Patents	1 match	4 matches	Citing Patents	1 match	4 matches	
		Control patents	Control Patents		Control Patents	Control Patents	
Number of citations	4,790	4,685	17,987	713	640	2,135	
Proportion of <i>home-region citations</i>	33.46	28.6	29.3	39.87	30.62	33.4	
t-statistics		5.124	5.463		3.561	3.067	

Table 3 Testing for the presence of inter-firm RTT: rare event logistic regressions, country level analysis

	Entire Sample					Inventor Citations				
	1	2	3	4	5 [^]	6	7	8	9	10 [^]
SameTech	3.399*** (0.135)	3.425*** (0.138)	3.352*** (0.137)	3.173*** (0.133)	2.980*** (0.206)	5.005*** (0.572)	5.255*** (0.614)	5.244*** (0.616)	5.052*** (0.597)	7.469*** (2.705)
MultipleIPC	1.251*** (0.056)	1.253*** (0.056)	1.236*** (0.056)	1.272*** (0.058)	1.396*** (0.116)	0.976 (0.122)	0.952 (0.119)	0.978 (0.124)	0.992 (0.125)	1.189 (0.400)
CitePub	1.343*** (0.058)	1.348*** (0.058)	1.306*** (0.058)	1.330*** (0.059)	1.406*** (0.105)	1.537*** (0.193)	1.539*** (0.193)	1.551*** (0.194)	1.572*** (0.198)	0.989 (0.311)
Averagecit	1.514*** (0.046)	1.516*** (0.046)	1.534*** (0.047)	1.504*** (0.047)	1.409*** (0.070)	1.758*** (0.159)	1.768*** (0.162)	1.759*** (0.161)	1.740*** (0.159)	2.696*** (0.702)
Homectry	1.230*** (0.067)	1.232*** (0.067)	1.217*** (0.068)	1.177*** (0.066)	1.177* (0.103)	1.337* (0.203)	1.324* (0.201)	1.363** (0.210)	1.367** (0.212)	1.850** (0.580)
TechComp		1.019** (0.009)	1.026*** (0.009)	1.026** (0.009)	1.026* (0.015)		1.074*** (0.029)	1.076*** (0.029)	1.063** (0.029)	1.041 (0.068)
MNE			0.451*** (0.020)					0.658*** (0.093)		
EUMNE				0.412*** (0.019)					0.617*** (0.088)	
USMNE				0.819*** (0.060)					1.116 (0.252)	
Observations	30703	30703	30703	30703	8985	4661	4661	4661	4661	826
Log-likelihood	-14278.2	-14274.5	-14065.4	-13972.4	-4146.62	-2082.59	-2075.39	-2067.99	-2064.41	-345.523
χ^2	2425.745***	2433.21***	2851.449***	3037.292***	623.627***	650.16***	664.569***	679.372***	686.537***	172.469***
Count R ^{2±}	0.797	0.797	0.799	0.800	0.804	0.801	0.802	0.804	0.802	0.812
Adj Count R ^{2±±}	-0.002	0.001	0.001	0.013	0.006	0.062	0.068	0.076	0.066	0.134

Robust standard errors clustered on citing patent in brackets. Citing country and cited MNE dummy variables included

[^] Model 5 and 10 use as a set of potentially citing patents those applied for by domestic firms and institutions

[±] Proportion of correct predictions ^{±±} Improvement in correct predictions beyond what would have been achieved by simply predicting the most common outcome

*** p<0.01, ** p<0.05, * p<0.1

Table 4 Testing for the presence of inter-firm RTT: rare event logistic regressions, regional level analysis

	Entire sample					Inventor citations				
	1	2	3	4	5 [^]	6	7	8	9	10 [^]
SameTech	3.372*** (0.139)	3.391*** (0.140)	3.307*** (0.140)	3.131*** (0.135)	2.905*** (0.207)	5.231*** (0.638)	5.189*** (0.639)	5.174*** (0.642)	5.024*** (0.627)	8.077*** (3.104)
MultipleIPC	1.230*** (0.057)	1.226*** (0.056)	1.213*** (0.057)	1.244*** (0.059)	1.362*** (0.116)	0.955 (0.127)	0.947 (0.126)	0.973 (0.131)	1 (0.134)	1.374 (0.490)
CitePub	1.334*** (0.060)	1.327*** (0.060)	1.295*** (0.060)	1.315*** (0.061)	1.458*** (0.113)	1.464*** (0.197)	1.449*** (0.196)	1.466*** (0.197)	1.488*** (0.201)	0.727 (0.236)
Averagecit	1.530*** (0.049)	1.536*** (0.049)	1.548*** (0.050)	1.520*** (0.049)	1.409*** (0.072)	1.867*** (0.185)	1.835*** (0.183)	1.820*** (0.182)	1.827*** (0.182)	3.281*** (0.910)
Homeregion	1.306*** (0.073)	1.295*** (0.073)	1.287*** (0.073)	1.228*** (0.071)	1.232** (0.111)	1.512*** (0.229)	1.540*** (0.233)	1.566*** (0.239)	1.550*** (0.238)	1.329 (0.472)
TechComp		0.994** (0.003)	0.999 (0.003)	0.995** (0.003)	0.99 (0.008)		1.01 (0.008)	1.012 (0.008)	1.006 (0.008)	1 (0.031)
MNE			0.449*** (0.021)					0.676*** (0.101)		
EUMNE				0.411*** (0.019)					0.624*** (0.093)	
USMNE				0.836** (0.064)					1.326 (0.316)	
Observations	43693	43693	43693	43693	13041	6735	6735	6735	6735	1125
Log-likelihood	-19822.8	-19816.5	-19498.9	-19365.7	-5895.12	-2817.13	-2811.02	-2805.91	-2795.47	-454.796
χ^2	3551.695***	3564.39***	4199.543***	4465.997***	1032.934***	1172.175***	1184.385***	1194.602***	1215.489***	238.142***
Count R ²	0.804	0.803	0.806	0.808	0.808	0.814	0.818	0.818	0.815	0.823
Adj Count R2	-0.002	-0.008	0.009	0.019	0.008	0.088	0.104	0.106	0.092	0.146

Robust standard errors clustered on citing patent in brackets. Citing country and cited MNE dummy variables included.

[^] Model 5 and 10 use as a set of potentially citing patents those applied for by domestic firms and institutions

*** p<0.01, ** p<0.05, * p<0.1

Table 5 Descriptive statistics

Variables	Home country citations			
	No (N=6837)		Yes (N=1921)	
	Mean	St.Dev	Mean	St.Dev
ShareHomectryEmpl	43.71	13.60	46.78	12.69
ShareHomectryCoPat	22.19	17.35	25.28	16.95
ShareHomectryPats	45.62	17.29	48.64	15.33
Selfcitation	0.20	0.40	0.33	0.47
TechGap	1.37	0.95	1.32	0.70
Sophi	1.09	0.32	1.17	0.35
CitePub	0.20	0.40	0.31	0.46
PatFam	6.25	4.71	7.91	6.00
Sametech	0.20	0.40	0.46	0.50
	Home country inventor citations			
	No (N=1279)		Yes (N=405)	
	Mean	St.Dev	Mean	St.Dev
ShareHomectryEmpl	42.39	13.48	45.86	12.02
ShareHomectryCoPat	20.35	16.91	25.68	17.21
ShareHomectryPats	45.20	16.81	48.28	14.98
Selfcitation	0.19	0.39	0.26	0.44
TechGap	1.36	0.91	1.35	0.86
Sophi	1.12	0.35	1.17	0.37
CitePub	0.26	0.44	0.34	0.48
PatFam	6.71	5.09	10.57	7.42
Sametech	0.16	0.36	0.48	0.50

Table 6 Identifying the determinants of inter-firm RTT: rare event logistic regression

	Country-Level		Regional Level	
	Entire Sample	Inventor Citations	Entire Sample	Inventor Citations
	1	2	3	4
ShareHomectryEmpl	1.057*** (0.013)	1.043* (0.025)	1.051*** (0.013)	1.037 (0.028)
ShareHomectryCoPat	1.048*** (0.006)	1.069*** (0.012)	1.047*** (0.006)	1.068*** (0.013)
ShareHomectryPats	1.002 (0.005)	1.039*** (0.016)	1.008* (0.005)	1.042*** (0.017)
Selfcitation	1.505*** (0.124)	1.177 (0.268)	1.573*** (0.132)	1.232 (0.294)
TechGap	0.770*** (0.050)	1.081 (0.150)	0.975* (0.014)	1.014 (0.033)
Sophi	2.578*** (0.381)	2.544** (0.991)	2.454*** (0.363)	2.381** (0.885)
CitePub	1.797*** (0.172)	1.529 (0.428)	1.788*** (0.175)	1.467 (0.445)
PatFam	1.047*** (0.009)	1.093*** (0.024)	1.045*** (0.009)	1.079*** (0.025)
Sametech	4.044*** (0.339)	6.793*** (1.724)	3.931*** (0.335)	7.678*** (1.985)
Averagecit	1.220*** (0.083)	1.196 (0.215)	1.123* (0.076)	1.185 (0.224)
Observations	8744	1644	13281	2498
Log-likelihood	-4021.26	-725.969	-6004.38	-988.102
χ^2	1165.268***	381.48***	1732.506***	595.281***
Count R ²	0.798	0.790	0.803	0.826
Adj Count R ²	0.083	0.146	0.072	0.173

Robust standard errors clustered on citing patent in brackets. Citing country and cited MNE dummy variables included.

*** p<0.01, ** p<0.05, * p<0.1

Figure 1 Reverse technology transfer process

Company *a* is one of the chemical and pharmaceutical MNEs in our sample; company *b* a European MNE; company *c* a US MNE; and *SME* a domestic firm

Figure 2 Research Design of the Matching Procedure

Appendix

Table A1 List of companies in the sample

Company name	Country of origin
AKZO NOBEL	NL
ASTRAZENECA	UK/SE
BASF	DE
BAYER	DE
THE BOC GROUP	UK
GLAXOSMITHKLINE	UK
HENKEL	DE
IMPERIAL CHEMICAL INDUSTRIES (ICI)	UK
KONINK DSM	NL
L' AIR LIQUIDE	FR
MERCK	DE
NOVARTIS	CH
NOVO NORDISK	DK
ROCHE HOLDING	CH
SANOFI AVENTIS	DE/FR
SCHERING	DE
SOLVAY	BE

References

- Alcacer, J. and M. Gittleman. (2006), 'Patent citations as a measure of knowledge flows: the influence of examiner citations,' *Review of Economics and Statistics*, **88**(4), 774-779.
- Almeida, P. (1996), 'Knowledge sourcing by foreign multinationals: patent citation analysis in the U.S. semiconductor industry,' *Strategic Management Journal*, **17**(Winter Special Issue), 155-165.
- Arundel, A. and I. Kabla. (1998), 'What percentage of innovations are patented? Empirical estimates for European firms,' *Research Policy*, **27**(2), 127-141.
- Bartlett, C. A. and S. Ghoshal. (1989), *Managing across borders: the transnational solution*. Harvard Business School Press: Boston, MA.
- Blömostrom, M. and A. Kokko. (1998), 'Multinational corporation and spillovers,' *Journal of Economic Surveys*, **12**(3), 247-277.
- Caves, R. (1974), 'Multinational firms, competition, and productivity in host-country markets,' *Economica*, **41**(162), 176-193.
- Criscuolo, P. (2006), 'The 'home advantage' effect and patent families: a comparison of OECD triadic patents, the USPTO and the EPO,' *Scientometrics*, **66**(1), 23-41.
- Criscuolo, P. and B. Verspagen. (2008), 'Does it matter where patent citations come from? Inventor versus examiner citations in European patents,' *Research Policy*, **37**(10), 1892-1908.
- Dicken, P., M. Forsgren and A. Malmberg (1994), 'The local embeddedness of transnational corporations,' in A. Amin and N. Thrift (eds.), *Globalization, Institutions, and Regional Development in Europe*.
- Duguet, E. and M. MacGarvie. (2005), 'How well do patent citations measure flows of technology? Evidence from French innovation surveys,' *Economics of Innovation and New Technologies*, **14**(5), 375-394.
- Dunning, J. and R. Narula. (1995), 'The R&D activities of foreign firms in the United States,' *International Studies of Management and Organization*, **25**(1-2), 39-73.
- ETAN. (1998), *Internalisation of research and technology: trends, issues, and implications for S&T policies in Europe*. European Commission Directorate General XII: Brussels/Luxembourg.
- Fleming, L. and O. Sorenson. (2004), 'Science as a map in technological search,' *Strategic Management Journal*, **25**(8-9), 909-928.
- Fors, G. (1997), 'Utilization of R&D results in the home and foreign plants of multinationals,' *Journal of Industrial Economics*, **XLV**(2), 341-358.
- Frost, T. (2001), 'The geographic sources of foreign subsidiaries' innovation,' *Strategic Management Journal*, **22**(2), 101-123.

- Frost, T. and C. Zhou. (2005), 'R&D co-practice and 'reverse' knowledge integration in multinational firms,' *Journal of International Business Studies*, **36**, 676-687.
- Gambardella, A., L. Orsenigo and F. Pammolli (2000), 'Global competitiveness in pharmaceuticals. A European perspective,' *Report prepared for the Directorate General Enterprise of the European Commission*
- Globerman, S. (1994), 'The public and private interests in outward direct investment,' in S. Globerman (ed.), *Canadian-Based Multinationals*. University Calgary Press: Calgary.
- Globerman, S., A. Kokko and F. Sjöholm. (2000), 'International Technology Diffusion: evidence from Swedish patent data,' *Kyklos*, **53**(1), 17-38.
- Griffith, R., R. Harrison and J. V. Reenen. (2006), 'How special is the special relationship? Using the impact of US R&D spillovers on UK firms as a test of technology sourcing,' *American Economic Review*, **96**(5), 1859-1875.
- Gupta, A. K. and V. Govindarajan. (2000), 'Knowledge flows within multinational corporations,' *Strategic Management Journal*, **21**(4), 473-496.
- Jaffe, A. B., M. S. Fogarty and B. A. Banks. (1998), 'Evidence from patents and patent citations on the impact of NASA and other federal labs on commercial innovation,' *Journal of Industrial Economics*, **46**(2), 183-205.
- Jaffe, A. B., M. Trajtenberg and R. Henderson. (1993), 'Geographic localization of knowledge spillovers as evidenced by patent citations,' *The Quarterly Journal of Economics*, **108**(3), 577-598.
- King, G. and L. Zeng. (2001), 'Logistic regression in rare events data,' *Political Analysis*, **9**, 137-163.
- Kogut, B. and S. J. Chang. (1991), 'Technological capabilities and Japanese foreign direct investment in the United States,' *The Review of Economics and Statistics*, **73**(3), 401-413.
- Kogut, B. and U. Zander. (1993), 'Knowledge of the firm and the evolutionary theory of the multinational corporation,' *Journal of International Business Studies*, **Fourth Quarter**, 625-645.
- Kuemmerle, W. (1999), 'Foreign direct investment in industrial research in the pharmaceutical and electronics industries: results from a survey of multinational firms,' *Research Policy*, **28**(2-3), 179-193.
- Lipsey, R. E. (2002), 'Home and host country effects of FDI,' *NBER Working Paper*
- MacGarvie, M. (2006), 'Do Firms Learn from International Trade?,' *Review of Economics and Statistics*, **88**(1), 46-60.
- Mansfield, E. and A. Romeo. (1980), 'Technology transfer to overseas subsidiaries of U.S.-Based firms,' *Quarterly Journal of Economics*, **XCIV**(4), 737-750.

- Maraut, S., H. Dernis, C. Webb, V. Spiezia and D. Guellec (2008), 'The OECD REGPAT database: a presentation,' *STI Working Paper*
- Ohmae, K. (1990), *The Borderless World*. Collins: London.
- OST. (2002), *Science et Technologie: Indicateurs*, Economica, Paris.
- Pauly, L. and S. Reich. (1997), 'National structures and multinational corporate behaviour: enduring differences in the age of globalisation,' *International Organization*, **51**(1), 1-31.
- Pavitt, K. and P. Patel (1999), 'Global corporations and national systems of innovation: who dominates whom?,' in D. Archibugi, J. Howells and J. Michie (eds.), *Innovation Policy in a Global Economy*. Cambridge University Press: Cambridge.
- Putnam, J. (1996), 'The value of international patent rights,' Yale University: Yale,
- Reddaway, B., S. Potter and C. Taylor. (1968), *Effects of U.K. direct investment overseas. Final Report*. Cambridge University Press: Cambridge.
- Sally, R. (1994), 'Multinational enterprises, political economy and institutional theory: domestic embeddedness in the context of internationalization,' *Review of International Political Economy*, **1**(1), 161-192.
- Shan, W. and J. Song. (1997), 'Foreign direct investment and the sourcing of technology advantage: an evidence from the biotechnology industry,' *Journal of International Business Studies*, **28**(2), 267-284.
- Singh, J. (2007), 'Asymmetry of Knowledge Spillovers between MNCs and Host Country Firms,' *Journal of International Business Studies*, **38**(5), 764-786.
- Sölvell, O. and I. Zander. (1995), 'Organization of the dynamic multinational enterprise,' *International Studies of Management and Organization*, **25**(1-2), 17-38.
- Sölvell, O., I. Zander and M. E. Porter. (1991), *Advantage Sweden*. Norstedts: Stockholm.
- Thoma, G. and S. Torrissi (2007), 'Creating Powerful Indicators for Innovation Studies with Approximate Matching Algorithms. A test based on PATSTAT and Amadeus databases,' *CESPRI Working Paper*: Bocconi University, Milan,
- Tomz, M. (2001), 'Relogit: Rare Events Logistic Regressions,' <http://gking.harvard.edu/stats.html>
- van Pottelsberghe de la Potterie, B. and F. Lichtenberg. (2001), 'Does foreign direct investment transfer technology across borders?,' *Review of Economics Statistics*, **83**(3), 490-497.
- Vernon, R. (1966), 'International investment and international trade in product cycle,' *Quarterly Journal of Economics*, **80**(2), 190-207.

Webb, C., H. Dernis, D. Harhoff and K. Hoisl (2005), 'Analysing European and International Patent Citations: A Set of EPO Patent Database Building Blocks,' *OECD Science, Technology and Industry Working Papers*