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European Chemical and
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Reverse Technology Transfer:
A Patent Citation Analysis of the European Chemical and Pharmaceutical sectors

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Abstract

One consequence of the internationalisation of R&D, particularly in high-tech sectors such as chemicals and pharmaceuticals, may be the transfer of foreign technology from the multinational to other firms in its home country. This phenomenon, which may be termed *inter-firm reverse technology transfer*, has not yet been directly analysed by either the international management literature or the literature on foreign direct investment. But its implications for policy – particularly in Europe – may be significant. Drawing on the evolutionary theory of the multinational, and on the concept of embeddedness, this paper is a first attempt at addressing this issue. We test the hypothesis of inter-firm reverse technology transfer by performing a patent citation analysis on a database of USPTO patents applied for by 24 chemical and pharmaceutical companies over the period 1980-99. Our findings suggest that multinationals act as a channel for the transmission of knowledge developed abroad to other home country firms. These results point to an alternative understanding of foreign direct R&D investment and its implications for both the home country's technological activity, and its competitive performance in general.

Keywords: Multinational firms; patent citation; embeddedness; international technology transfer.

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Introduction

Multinational enterprises (MNEs) play a dominant role in the innovation activities of their home country and control a large proportion of the world's stock of advanced technologies. Their decisions regarding the method, location and exploitation of R&D can greatly influence the home country's technological potential and competitiveness (Patel and Pavitt 1999) and so the growing internationalisation of R&D activity over the past two decades has been a cause of some concern to policy makers. In Europe some have suggested that the relocation of R&D abroad – particularly in faster growing industries – might result 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 with it worries about a possible impoverishment of the national technology base due to the increasing R&D activities of foreign MNEs.

To be able to evaluate the potential impact of relocation on the MNEs' country of origin, one must assess whether the decentralisation of R&D entails only an outflow of knowledge. Foreign affiliates can represent an inflow of technological knowledge for the home country whenever their activity is explicitly aimed at generating knowledge and gaining access to localised sources of innovation. This concept of 'reverse technology transfer', as defined by Mansfield (1984), is not new, but it has mainly been examined as a means of improving both the MNE's portfolio of knowledge and technological assets (i.e. *intra-firm reverse technology transfer* – see Frost 1998, Branstetter 2000, Gupta and Govindarajan 2000, Håkanson and Nobel 2000, 2001), and its productivity (Fors 1997, Castellani 2001, Braconier *et al.* 2002). But reverse technology transfer may also 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 its linkages to domestic firms – i.e. *inter-firm reverse technology transfer*. This process has been less well researched: Globerman *et al.* (2000) find evidence of positive feedback effects of outward FDI in Sweden on both MNEs and SMEs. Other studies on the impact of outward FDI on domestic productivity growth (i.e. Pottelsberghe and Lichtenberg 2001) and on export performances (i.e. Nachum *et al*. 2001) can also be regarded as empirical evidence on the effects of reverse technology transfer, although they do not analyse this phenomenon directly, i.e. at the micro level.

This paper aims at contributing to the empirical and theoretical literature on *inter-firm reverse technology transfer*. In particular it investigates whether multinationals act as a channel for the transmission of knowledge developed abroad to other home country firms. If the multinational organization plays a role in the reverse technology transfer process, then it follows that firms located in the multinational's country of origin should show a learning advantage over firms located in other countries. Technological knowledge may diffuse more rapidly and easily in the home country where the multinational lies at the centre of a dense network of relationships with suppliers, customers, competitors, research institutes and universities, financial institutions, and industry associations. MNEs are strongly embedded in the home country where they are committed to long-term, usually historically defined, relationships with a range of external actors (Sally 1996).

This brings us to our research questions.

Do firms located in the MNE home country benefit from the technological knowledge developed in foreign subsidiaries of their national champions? Which home country firms benefit more from this technology transfer process?

To test our research questions we carried out a citation analysis on the patents granted by the United States Patent and Trademark Office (USPTO) to US subsidiaries of 24 European chemical and pharmaceutical MNEs over the period 1980-1999 using data from the NBER patent citations data file (Hall *et al*. 2001). Patent citations represent a link to previous innovations or pre-existing knowledge upon which the inventor builds. When an inventor cites another patent, this indicates that the knowledge contained in the cited patent has been useful in the development of the citing patent. Patent citation can thus be an indicator of knowledge flows, although with some limitations. We would therefore expect that firms located in the home country of the multinational show a higher propensity to use knowledge developed in US subsidiaries of their national 'champions'. [1]

We examine the *inter-firm reverse technology transfer* process in the chemical and pharmaceutical industries because of the increasing internationalisation of R&D activities by MNEs operating in these sectors. In particular we investigate the role played by European MNEs in transferring technology from the United States. As shown by a number of studies (Shan and Song 1997, Sharp 1999, Senker 1998, Allansdottir *et al.* 2002) chemical and pharmaceutical European companies have been particularly engaged in tapping into the US knowledge base, the source of many new products and technological competences, especially in biotechnology. This strategy might therefore represent a potential for reverse technology transfer, which might benefit other firms located in Europe and enhance the competitiveness of Europe in fast growing technological areas.

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[1] For example, technology transfer from an R&D laboratory set up or acquired by Bayer in the US to other firms operating in Germany, via Bayer's headquarters.

The selection of these two sectors is also based on methodological grounds. One of the major limitations of using patents and patent citations data is that they might not capture the firm's innovation activity. However this drawback does not appear to be so severe for chemical and pharmaceutical companies as shown by studies based on survey data (see Arundel and Kabla 1998, and Brouwer and Kleinknecht 1999).

The paper is organized as follows. In Section 1 we discuss the theoretical background underpinning the reverse technology transfer process. We present the database and discuss some of the limitations of using patent citation analysis in Section 2. Section 3 contains an analysis of the innovation activity of MNEs in our sample in order to assess the nature of their foreign-based R&D effort. In Section 4 we present the methodology used to test our research question and we provide a descriptive look at the citation data. In Section 5 we describe the econometric model and comment on the results. Finally, in Section 6, we provide policy suggestions drawing from the empirical evidence.

1. Internationalisation of R&D activities and knowledge flows

The internationalisation of multinationals' R&D has been driven by a myriad of factors, the most prevalent of which is the need to adapt existing products and processes to different demand and market conditions across locations. Such facilities have been termed 'home-base exploiting' (HBE) (Kuemmerle 1996) or 'asset-exploiting' (Dunning and Narula 1995). However, over the last decade supply factors have became an increasingly important motivation for carrying out R&D abroad (Kuemmerle 1999, Serapio and Dalton 1999, and Patel and Vega 1999). With these 'home-base augmenting' (HBA) (Kuemmerle, 1997) or 'asset-seeking' (Dunning and Narula 1995) R&D facilities MNEs aim to absorb and acquire technological spillovers, either from the local knowledge base (public infrastructure or agglomeration effects in a specific sector), or from specific firms.

Recent empirical evidence has emphasised that, although the HBE sites remain important, the HBA nature of foreign-based R&D investment is becoming significant, particularly in technology-intensive sectors (Shan and Song 1997, Kuemmerle 1999, Serapio and Dalton 1999, and Patel and Vega 1999, Criscuolo *et al.* 2003).

The increasing number of HBA facilities set up by Europe's leading chemical and pharmaceutical multinationals in the United States can be attributed to the comparative advantage that the US has in the new biotechnology areas relative to the more traditional pharmaceutical fields. The US is the preferred location for HBA activities not just because of its technological infrastructure per se, but also because of the existence of a large number of small specialist research firms which are extremely dynamic and embedded in networks of collaborative relationship with universities, large firms and both public and private research centres (Gambardella *et al*. 2000). European multinationals are attracted to these biotech clusters in order to benefit from the external economies generated by the concentration of production and innovation activities, and to get access both to highly skilled workers and to the research of ‘star’ academic scientists. The tacit nature of knowledge in the new technological areas, such as biotechnology, explains both spatial agglomeration and the need for geographical proximity to benefit from localised spillovers. While the marginal cost of transmitting codified knowledge does not depend on geographic distance, the marginal cost of transmitting tacit knowledge increases with distance (Audretsch and Feldman 1996).[2]

The internationalisation of R&D activity and above all the creation of HBA type R&D sites reinforces the role of multinational firms in promoting cross-border knowledge flows. MNEs have the ability to access local knowledge in multiple locations and, thanks to their international R&D network, are able to leverage scientific and technological knowledge through the integration and cross-fertilisation of geographically dispersed capabilities (Zander and Sölvell 2000).

This increasing importance of HBA activities has led researchers to investigate to what extent knowledge diffuses inside the multinational firm and in particular from the foreign-based R&D facilities to the home part of the multinational (*intra-firm reverse technology transfer*). MNEs have to ensure that the knowledge acquired abroad is then transmitted to the rest of the multinational. The evolutionary theory of the multinational (Chesnais 1988, Cantwell 1989, Kogut and Zander 1993) and the more recent knowledge-based theory of the firm (Grant 1996) has emphasized the strategic role of knowledge in the creation and sustainability of a firm’s competitive advantage. Kogut and Zander define MNEs as “social communities that specialize in the creation and internal transfer of knowledge” and according to them “an MNE arises not out of the market failures for the

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[2] However, merely establishing R&D activities abroad for the purpose of tapping into pools of scientific knowledge does not necessarily mean that firms will be successful in doing so. The acquisition of complementary assets that are location specific requires the creation and development of strong linkages with external networks of local counterparts. This is expensive and time consuming, and is tempered by a high level of integration with the innovation system in the home location. As pointed out by Zanfei (2000) the decentralisation of R&D activities in foreign subsidiaries leads to a delicate trade-off between the autonomy of the subsidiaries and their integration into the rest of the multinational company.

buying and selling of knowledge but out of its superior efficiency as an organizational vehicle by which knowledge is transferred across borders" (p. 625).

However, technology transfer, even within the firm, is far from being an automatic process, especially when the flow of knowledge goes from the periphery to the centre. There are barriers connected to the characteristics of the technological knowledge to be transferred, to the prior knowledge of the receiving unit and also on the motivational disposition of the subsidiary (see Kogut and Zander 1993, Szulanski 1996, and Gupta and Govindarajan 2000). The more the knowledge is complex, context specific and tacit in nature, the more difficult it is to transfer it. The successful diffusion of knowledge requires of the receiving units a certain degree of absorptive capacity, i.e. "the firm's ability to identify, assimilate, and exploit knowledge from the environment" (Cohen and Levinthal 1989). But there are also motivational barriers: affiliates might be reluctant to transfer knowledge to other units of the MNE because this would imply losing an "information monopoly" within the company and the status of "centre of competence" for a specific area (Cyert 1995).

Nonetheless the empirical literature on *intra-firm reverse technology transfer* (Frost 1998 and Håkanson and Nobel 2000, 2001) seems to find evidence supporting the existence of such a process. Frost's (1998) study on the patenting activities of foreign subsidiaries in the US between 1980-90 shows that foreign affiliates work as a conduit for technological diffusion of localised knowledge to their headquarters, although their contribution remains modest compared to the technological flow from the headquarters to the subsidiaries. This is in line with other empirical analyses (for instance, Dalton and Serapio 1999) showing that the HBA nature of foreign-based R&D activities has became significant only recently and that the HBE type of facilities are still the dominant strategy.

The increasing importance of HBA R&D investment might also explain the lack of interest so far in the *inter-firm reverse technology transfer* process from asset-seeking R&D facilities to the home country's firms. This process implies that there is a feedback effect from outwards R&D investment: subsidiaries abroad internalise localised technologies and transfer these back to the MNE's operations in the home country and over time this body of knowledge becomes available to other home country firms. We expect that this process would be mainly confined to those (high-tech) sectors where there is an important component of HBA foreign-based R&D activity and that its effects might only be evident after some time. We therefore do not expect to find strong evidence of this technology transfer process in those chemical companies that, compared to pharmaceutical companies, have tended so far to establish HBE laboratories where technology platforms developed in the home country are the bases for local product development (Zedtwitz and Gassmann 2002).

The existence of *inter-firm reverse technology transfer* can mainly be attributed to the high degree of embeddedness of MNEs in their home country. The concept of embeddedness as understood by Granovetter (1985) implies two elements. One is that economic organizations are embedded in social structures and in networks of linkages with other economic units. The second is that these relationships become social structures themselves which evolve with time. 'Embeddedness thus implies that business firms, and the network which they form, are both socially and historically constructed' (Halinen and Törnroos 1998, p. 189). As argued by Sally (1996), the MNE's degree of embeddedness in an external network can differ quite substantially.

> "At one extreme, MNEs can be weakly embedded in national economies which are still strongly 'dis-intermediated', that is where MNE relations with external actors are brittle and frequently at arm's length. At the other extreme is strongly national embeddedness, in which MNEs are deeply interwoven in the institutional knitting of the economy in question, committed to organised long-term, usually historically defined, relations with a range of external actors" (p. 71).

For the multinational firms it is in the home country where their core productive and innovative activities are concentrated, where their linkages with external actors are strongest, but also historically defined (Pauly and Reich 1997). Their role in the diffusion of technological knowledge acquired abroad relies on the fact that multinational companies are 'spatially embedded' (Halinen and Törnroos 1998) in their home country, they are at the centre of networks that have evolved over a long time-span, and they are rooted in various social structures. These aspects of embeddedness, i.e. mutual trust, long lasting relationships and constant interaction, are extremely important for the process of knowledge diffusion inside a local network; knowledge diffuses over physical distances primarily through formal connections to well-situated partners (Saxenian 1994). In particular, potential channels for the realisation of the reverse technology transfer process are the international mobility of researchers previously employed in the foreign R&D facility, the licensing of foreign developed technologies, strategic alliances between the headquarters and the home country firms (involving knowledge accumulated overseas), suppliers and customers linkages between the home based of the multinational and other home country agents.[3]

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[3] The existing literature on the geographical localization of spillovers (i.e. Jaffe *et al.* 1993, and Verspagen and

Of course, home country firms might access knowledge developed abroad by other means, especially if they are themselves part of a company with units in the foreign location. In the empirical analysis we try to control for this, looking at the home country firm's international presence.

In the pharmaceutical industry, recent trends seem to suggest that the number of collaborations with physically distant partners is increasing as firms attempt to access cutting-edge technologies. They may not therefore draw as extensively as before on domestic sources of technological knowledge (Owen-Smith and Powell 2002). This implies that the reliance on MNEs as a channel for international technology transfer might fade away as the knowledge frontier evolves.

However, as pointed out by Veugelers and Cassiman (1999), the role of multinationals in the cross-border transfer of knowledge becomes crucial when the know-how that home country firms are trying to access is localised and "sticky". This is why it is crucial to state that this type of reverse knowledge flow only originates from asset-seeking R&D facilities. As we explained earlier, technological knowledge in new technological fields such as biotechnology is tacit in nature and tends to be spatially concentrated, thus the presence of foreign affiliates might be a necessary condition for international technology transfer. The home part of the multinational might be the 'technological gatekeeper' of their home country firms.

The extent of inter-firm reverse technology transfer depends on a number of factors. First, because technological flows are mediated by the headquarters, we have to assume that technological knowledge diffuses first within the MNE. Second, the successful diffusion of knowledge requires absorptive capacity in the receiver units (home country firms). Absorptive capacity implies the existence of prior related knowledge and a commitment to internalise external knowledge, i.e. a demand for it. Third and most importantly, technological knowledge should flow voluntarily or involuntarily outside the firm's boundaries. The MNE's embeddedness in the home country is the main factor allowing this to occur.

We explore the existence of inter-firm reverse technology transfer using a database on patenting activities of 24 chemical and pharmaceutical European MNEs. Before explaining the methodology adopted to address this research question we illustrate the characteristics of our dataset.

Schoenmakers 2000) addresses similar issues although it uses geographical proximity as the main variable explaining technology diffusion. We instead believe that when firms are the main channel for technology transfer the concept of embeddedness, which is not only spatially defined, is more appropriate.

2. Description of the database

Our primary data source is the NBER patent and citations database (Hall *et al*. 2001), that contains utility patents granted from 1963 to the end of 1999 and citations from patents granted in 1975-99. From the almost 3 million patents contained in the NBER database we select those granted between 1980 and 1999 to US affiliates of 24 chemical and pharmaceutical European MNEs. We use the address of the first inventor to identify the location of the invention and the name of his organizational affiliation ("assignee name") to relate each patent to the corporation that owns it. To be able to attribute all patents to a specific corporate group we used the Dun & Bradstreet Linkages database which contains the group ownership structure as it was in 1996. We use this structure to construct patent data for each MNE during the period 1980-99. A major drawback of this procedure is that it does not take into consideration changes in corporate structure due to mergers and acquisitions that have occurred before or after 1996. Most of the effects of mergers and acquisitions after 1996 are mitigated by the fact that there are few patent applications in the database from after this year (because the database lists patents by the year they were *granted*, finishing in 1999).[4] As pointed out by Verspagen and Schoenmakers (2000), the usual practice in most multinational companies is to assign a high proportion of patents to the parent company or the technological headquarters, and this should reduce the limitations involved in the procedure used to consolidate the patent data at the level of the group.

The point of citing other patents or referencing articles in a patent application is to comply with the legal requirement to supply a complete description of the state of the art. Citations limit the scope of the inventor's claim for novelty and in principle they represent a link to previous innovations or pre-existing knowledge upon which the inventor builds. When an inventor cites another patent, this indicates that the knowledge contained in the cited patent has been useful in the development of the citing patent. In this way they may proxy the flows of knowledge that underlie the new invention. Patent citation analysis was first proposed by Jaffe *et al*. (1993) for examining the geographical location of technological spillovers. Subsequently other authors (Almeida 1996, Frost 2001, and Branstetter 2000) have applied a similar methodology in their analysis of the geographical location of knowledge sources by foreign subsidiaries. This methodology although useful is not free of limitations.

[4] In addition this problem is minimized by the fact that we are analysing patent citations to these set of patents, which occur with a certain time lag.

Patent citations have the same disadvantages that patents have as an indicator of technological activity. The pros and cons of using US patents as an indicator of technological activity are well covered in the literature (i.e. Griliches 1992, and Basberg 1987), but two are particularly important for this study.

First, not all inventions are patented: firms can follow other means for appropriating the innovation benefits. But we contend that they are appropriate in exploring the innovation activity in the chemical and pharmaceutical sectors. Recent studies using data from innovation surveys have shown that both large and small & medium-sized firms operating in these industries have a high patent propensity (Arundel and Kabla 1998, and Brouwer and Kleinknecht 1999), and patents are more widely used than the alternative methods to protect the returns of R&D investments. In addition, dedicated biotechnology firms, which are highly engaged in R&D collaboration agreements, might have a high rate of patenting in order to protect and define their knowledge base in view of future collaboration with other firms.

Second, patent statistics are not able to account for the accumulation of un-codified knowledge and therefore patent citations might not capture the transfer and development of tacit knowledge. In addition, though suggested by the inventor, the final decision on which patents to cite in an application lies ultimately with the patent examiners. This leads to a potential source of bias due to the fact that patent citations might not reflect an actual source of knowledge used in the development of the citing patent. Unfortunately the number of citations of this sort is quite large as found out by a survey on inventors (Jaffe *et al*. 2000) and therefore citations are a noisy signal of the presence of technological knowledge flows. However they ‘can be used as a proxy for knowledge flows intensity between countries or categories of organizations’ (Jaffe *et al*. 2000, p. 218).

Finally another caveat of this analysis lies in the fact that we use data from the US patent office. This might underestimate the patenting performance of European firms, especially SME and public research institutes. However the high degree of internationalisation of these industries and the increasing propensity to collaborate with distant partners might have led firms to seek patent protection both in Europe and in the US.

Before looking in detail at the results of the patent citation analysis, we report some descriptive statistics on the patent activity of US subsidiaries and on the citations to these patents by firms located in Europe.

3. Descriptive statistics

The overall number of patents granted to US subsidiaries over the period 1980-99 was 11,672, which corresponds to almost 21 per cent of the total number of patents granted to the multinational companies in our sample. 66.78 per cent of patents originate from home country locations, but there is evidence of an increasing trend in the number of patents applied for by US subsidiaries. Some companies are more technologically active in US locations than others: more than 60% of the patent applications made by the BOC Group, for example, have come from US sites, with the figure for Roche Holding being more than 50%.[5] In general the ratio of US patents to the total number of patents granted to pharmaceutical companies increased from 14% in 1980 to 30% in 1997. The same ratio for chemical companies increased from 8% in 1980 to 27% in 1997. The median of the share of patents originating in US locations in the total number of patents granted to these firms is 0.281 and the mean is 0.284 with a standard deviation of 0.146.

We present some descriptive data on the citations to US subsidiaries patents. The total number of citations received by these patents from 1980 to 1999 is 38,887, of which only 5,783 (less than 15%) were citations made by inventors located in one European country. This is a very small number compared to the citations made by US located inventors (28,825), but big enough to carry out a consistent empirical analysis. Among the citations made by inventors resident in Europe, 1,130 are intra-group citations, which shows that patents developed by multinational companies are drawn heavily from internal sources of technological knowledge although developed in other locations.[6]

We define intra-country citations as ones made by inventors located in the country of origin of the cited subsidiary, i.e. citations in patents originating in Germany to patents applied for by a US affiliate of Bayer AG. If we exclude intra-group citations, there are 1,259 intra-country citations, which might be due to the strong embeddedness of multinationals in their home country or/and to the home country technological specialization.

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[5] In our database Genentech is part of Roche Holding.

[6] Among intra-firm citations there are self citations, i.e. citations to patents with the same assignee, but we have decided not to eliminate them from the analysis, because the location of invention of the cited patent and the citing patent is not the same since we can be almost sure that they do not belong to the same business unit.

We calculate the mean of the citation lag, defined as the difference between the application year of the citing patent and the application year of the cited patent. As expected, the average citation lag for intra-group citations (4.8 years) is less than the overall average citation lag (5.498 years), which reflects the fact that technological knowledge flows more easily within the multinational company. Intra-country citations also occur more rapidly: the average citation lag is equal to 5.3 years.[7]

We then identify three different types of citing firms according to their international profile:

1. subsidiaries or headquarters of European MNEs: European firms with at least one subsidiary in the US;

2. European subsidiaries of US MNEs;

3. domestic firms and institutions, defined as assignees without patenting activities in the US;

According to our definition, domestic firms may have subsidiaries in other European countries but not in the US, while business units in group (1) might never have patented in the US directly but be part of a European MNE with a US subsidiary. We classified the citing assignees into these two groups to control for the fact that multinational firms could have acquired the knowledge developed in the US directly through their presence in the US or indirectly through their organizational network. In contrast, domestic firms and institutions might have to rely on their linkages with the relevant MNE in order to access technological knowledge accumulated in the US. It is for this group of firms that multinational companies might play an important role in the international transfer of knowledge.

We are unable to classify the assignees of 173 citations into any of our three citing organizational groups and therefore we eliminated these citations from our sample, leaving us with 5601 observations including intra-group citations. As shown in Table 1, only 16% of all citations (excluding intra-group citations), originate from domestic firms and institutions, and the average citation lag is longer than the overall average (calculated without intra-group citations). The low

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[7] We carried out a one-sample t-test to statistically support these conclusions. The *t*-value when H_0: mean of intra-country citation lag is equal to the sample average excluding intra-group citations is equal to –2.940 and we can conclude that the citations made by firms in the home country occur faster. When we tested the null hypothesis that the mean of intra-firm citation lag is equal to the citation lag of the overall sample we obtained a *t*-value of –6.5537 and we can conclude that the intra-firm citation lag is shorter than the sample average at 1% level of confidence.

share of citations from this group of firms might be due to the fact that European firms without activities in the US may decide to apply for patent protection from the EPO first, and only afterwards decide whether to apply to the USPTO, which would explain the longer citation lag.

*************INSERT TABLE 1 NEAR HERE ************

What is also interesting is whether the patenting activities of US subsidiaries have diverged from the patenting activities of the home country R&D facilities. As we pointed out before, the process of reverse technology transfer is connected to home-base augmenting R&D activity, with the multinational firm aiming to acquire or create completely new technological assets that are location specific. Frost (1998) measures the evolution of US subsidiaries' patenting activities with respect to the home base units using phi-square distance measures, which capture dissimilarities between vectors of patents granted to the two groups of firms[8]. We calculated these distances using patents aggregated in 36 different technological categories.[9]

*************INSERT TABLE 2 NEAR HERE ************

From table 2, we can see that on average the technological distance between the US subsidiaries and the home part of the multinational has increased over time, with some firms exhibiting a more evident pattern in this direction. These results are in line with the evolution of the three technology classes in which US subsidiaries specialise most. Although not reported, US affiliates patent in technical fields not previously emphasised by the home country R&D facilities or they specialise in different areas, maybe as a result of the MNE's acquisition strategy.[10] In particular biotechnology (class 435, 800) appears among the top three technology classes of specialization of the US

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[8] The phi-square measure is a dissimilarity index, which together with the chi-square measure is specifically for frequency count data. The main difference between these two indicators of dissimilarity is that the phi-square measure does not depend on the total frequencies of the two items whose distance is computed. The formula used is:

distance $(X,Y) = \sqrt{\left(\frac{\sum_i (X_i - E(X_i))^2}{E(X_i)} + \frac{\sum_i (Y_i - E(Y_i))^2}{E(Y_i)}\right) \Big/ N}$, where *X* and *Y* are respectively the patents applied for by the home part of the MNE and the US located subsidiaries.

[9] These are the 36 technological sub-categories in the NBER database.

[10] This is particularly true for Roche Holding with its acquisition of Genentech, i.e. biotechnology is the top technical field of Roche US subsidiaries, while it does not appear in the top three of the home base units.

subsidiaries of most companies (i.e. Solvay, Roche Holding, Glaxo Wellcome, SmithKline Beecham, Novo Nordisk A/S, Akzo Nobel N.V., Boehringer Ingelheim International GmbH, Zeneca). In addition, we analysed to what extent European firms are building on knowledge generated from HBA facilities. We count how many of these citations are towards patents in fields in which the host state is technologically specialized. We found that more than 70 per cent of these citations are to patent classes where the host state shows a standardized RTA index greater than zero.[11]

We can therefore conclude that, in line with other studies (Allansdottir *et al*. 2002, Gambardella *et al*. 2000), the US is attracting an increasing amount of research efforts by European multinationals in the chemical and pharmaceutical sectors especially in biotechnology. These R&D activities are also investigating in technological areas, which differ in part from the ones explored in home country laboratories, which could be in line with an asset augmenting R&D strategy.

4. Empirical model

What is key to answering our research question is establishing whether home country firms show a learning advantage over firms located in other European countries, i.e. do they have a higher than average propensity to cite patents applied for by foreign subsidiaries of their own national 'champions'. We test this hypothesis by carrying out a multivariate regression analysis. Such an analysis allows us to consider the relationship between the citation rate and the country of origin of the citing firm, while controlling for other important variables, such as the technological proximity of the cited and citing firms, the technological specialization of the citing firm's country, and the citing firm's international profile. For example, imagine that we found many German patents citing patents applied for by a Bayer subsidiary in the US. Before we could take this as evidence of inter-firm reverse technology transfer, we would have to rule out a number of competing interpretations. German firms might operate in similar technological areas to the Bayer subsidiary, and/or the cited

[11] We calculate the revealed technological advantage as $RTA_{in=}\left(P_{in}\Big/\sum_{i}P_{in}\right)\Big/\left(\sum_{n}P_{in}\Big/\sum_{in}P_{in}\right)$, where P_{in} stands for the number of patents granted to inventors located in *i* in field *n* (3-digit level). The host state RTA is calculated using as $\sum_{in}P_{in}$ the total number of patents granted to all US states to avoid the problem of constructing the RTA index using small number of patents.

patents might happen to be very important in that particular field. Alternatively, it could be the case that the citing firm was itself part of a multinational with business units in the US and that this was the actual conduit for the knowledge flow. Finally, Germany as a nation might be specialised in the technological field of the cited patent and therefore German firms would be the most likely firms to cite patents in this field, no matter where they came from. In other words, if the citation rate is linked to factors other than embeddedness of the MNE in its home country, we would observe a higher citation rate by home country firms, without there being any true reverse technology transfer.

The dependent variable is the number of citations made by firm (*j*) located in Europe to patents applied for by the European MNE's subsidiary (*i*) at time *t* and in technological class *n*, denoted by C_{ijtn}, where *i* is not a subsidiary of *j* (i.e. we exclude intra-group citations from the analysis). We identify each cited firm *i* as a pair of assignee name and state of the first inventor (for instance Bayer Corporation - NY state) and the citing firm *j* as a pair of assignee name and country of the first inventor (for instance L'Oreal SA - France)[12]. We decided not to aggregate the data at the level of the firms because we wanted to control for the technological characteristics of the innovation activity of the cited subsidiary, we instead aggregated citations to the level of the cited firm in year *t* and class *n*.

Since we are analysing forward citations to a set of patents applied for between 1980-97 we need to correct for different factors that may change citation intensities over time and across sectors (Hall *et al.* 2001). The most obvious is the truncation effect or 'cohort effect': patents applied for in 1980 may receive more citations than patents applied for in 1995, simply because of their longer citation history. In addition, the increasing trend observed in the USPTO data in both patent applications and the average number of citations received by patents may introduce another potential bias. And finally the number of citations a particular patent receives may vary across technology classes. In order to control for the variability arising from year and technology class fixed effects we introduce

[12] In this way we should capture the patenting activity of a specific foreign subsidiary and control for the aforementioned practice of assigning patents to the headquarters, even if developed in other locations. The information contained in the NBER database on the address of the inventor was not useful in identifying the exact location of the cited US inventor (the ZIP code was missing for most patents in the sample). Similarly we should also be able to identify the patenting activity of a particular citing firm, although not with the same degree of certainty because if an inventor has an address outside the US only the country of residence is provided.

year and technology dummies in the regression.[13]

We regress the dependent variable on a number of control variables to take account of the factors discussed above:

$$\begin{aligned} C_{ijtn} = {} & \beta_0 + \beta_1 Homecountry + \beta_2 \ln(P_{jt}) + \beta_3 \ln(P_{it}) + \beta_4 PROX_{ij} + \beta_5 SOPH_{it} + \\ & \beta_7 TYPE_j + \beta_8 PHARMA + \beta_9 RTA_n + \text{year dummies} + \\ & \text{tech. class dummies} + \text{country dummies} + \varepsilon_{ijtn} \end{aligned} \qquad (1)$$

Homecountry is a dummy variable which takes the value of 1 if the citing patent assigned to firm *j* originates from the home country of the cited subsidiary. A positive and statistically significant coefficient indicates that the citation rate to US subsidiaries' patents is higher for firms located in the same country as the headquarters of the multinational cited. This dummy variable is supposed to pick up the inter-firm reverse technology transfer process.

$\ln(P_{it})$ denotes the logarithm of the number of patents applied for by the cited firm *i* in the application year *t*, which represents the number of potentially cited patents. $\ln(P_{jt})$ is the logarithm of the number of patents applied for by the citing firm *j* between year *t* and the final year of the sample (1997). This variable defines the number of potential citing patent.[14] Citations between two firms depend on their patent activities and therefore we expect a positive sign on the coefficients of both of these variables.

$PROX_{ij}$ is a technology distance measure between the cited firm *i* and the citing firm *j* which is given by the degree of similarity in their patent portfolio, as in Jaffe (1986). More precisely, the distance in the technology space between two firms *i* and *j* can be approximated by the un-centred correlation coefficient of the vectors, *F*, of patent counts in each of the 36 technology classes over the sample period:

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[13] The technological class *n* corresponds to one of the 36 two-digit technological categories contained in the NBER dataset. We adopted this technological classification because the 3-digit patent class would have implied too many technological dummies and not enough degree of freedom in the regression.

[14] Strictly speaking, the number of potentially citing patents should be equal to the number of patents applied for by the citing firm starting from the *granting* year of the cited patents, since in the USPTO patents are publicly available only when they have been granted. Considering that the average lag in the sample between application and granting year is less than 2 years, our variable can be considered a good approximation.

$$PROX_{ij} = \frac{F_i F_j^{'}}{\sqrt{(F_i F_i^{'})(F_j F_j^{'})}}.$$

This proximity measure is bounded between 0 and 1 and is closer to unity the greater the degree of overlap in the firms' research interests. We introduce this variable to control for the fact that firms operating in similar activities have a higher probability of citing each other's patents and we would expect it to be positively related to the citation rate.

$SOPH_{it}$ measures the distance of the cited firm's innovative activity from the technological frontier and it is equal to the average across the 36 technological classes of the ratio of the forward citations received by the cited firm's patents to the number of forward citations received by the average patent in that class (MacGarvie 2002).

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

Where N_{it} is the number of technological classes in which the cited firm has patented in year t, $\overline{c_{\text{int}}}$ is the average number of forward citations received by patents applied for by firm i in year t in class n, $\overline{c_{nt}}$ is the average number of forward citations received by patents in class n in year t. This variable is supposed to account for the importance and value of patents applied for by the cited firm relative to the overall average, correcting from the differences in citation frequencies across technological classes. We do not have specific expectations about the sign of this coefficient. On the one hand, we should expect a greater number of citations to patents of firms doing cutting edge innovation, but on the other hand the lack of technological congruence between the activity of the citing firm and the cited firm might negatively affect the citation frequency.

PHARMA is a dummy variable which is equal to 1 if the cited patent belongs to a multinational company in the pharmaceutical sector. We assigned a firm to one of the two sectors according to its principal product group. This dummy is included to control for sector specific effects and we expect it to be significant and positively related to the citation rate, because of the stronger HBA component of foreign-based R&D activities of pharmaceutical companies.

$TYPE_j$ stands for a set of dummy variables which identify the different groups of citing firms: European multinationals (*EUMNE*), US multinationals (*USMNE*) and domestic firms and institutions (*EU*). In the empirical analysis we also investigate the relationship between the citation rate and the multinational nature of the citing firm, introducing a dummy variable (*MNE*) which is 1 if the citing firm is a European or American multinational and zero if it is a domestic company. Finally we reclassify the firm as being multinational only if it has a patent originating from an US location and introduce a dummy variable (*USR&D*) which takes the value of 1 if this condition is verified.[15] This is designed to control for other channels through which the technology transfer may have occurred. At the same time it allows us to investigate whether domestic firms in the home country can benefit from this reverse knowledge transfer process.

RTA_n is a dummy variable which takes the value of 1 if the standardised RTA index of the country of residence of the citing inventor is positive in the technological class of the cited patent, and 0 otherwise. This variable controls for the technological specialization (and the absorptive capacity) of the country where the citing firm is located. We should expect a positive coefficient. This variable is crucial in identifying reverse technology transfer, since, if *Homecountry* remains significant and positive when *RTA* is included, then we can be sure that this effect exists over and above any inherent technological capabilities of the home country.

Finally we include year and technology dummies for each of the 36 classes to control for year and technology class fixed effects and country dummies for each country where a citing patent originates to control for unobserved country specific fixed effects. Table 3 summarizes descriptive statistics for the data used to estimate the model and in the appendix we report the autocorrelation matrix.

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

To summarise, the *Homecountry* variable captures the reverse technology transfer process and the rest of explanatory variables control for different factors that are likely to affect the citation rate between two firms, not only at the level of the firms (P_{it} , P_{jt} , $PROX_{ij}$, $TYPE_j$, $SOPH_{it}$), but also at the level of the country of residence of the citing inventor (*RTA*).

We estimate the model presented in equation (1) pooling all citations over all years in the period. In theory we could have estimated the model using panel data regression techniques but the panel would have been very unbalanced because most of the subsidiaries patents do not receive citations

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[15] It may not be enough for a multinational to have a presence in the United States in order to get a learning advantage: it may need to patent there too.

by European firms every year.

Given the discrete nature of our dependent variable we used count data models to estimate equation (1). In addition we have to account for the fact that our data are truncated at zero, because we only observe citations greater or equal to one, i.e. we have data only on European firms that cite at least once patents applied for by our sampled US subsidiaries. Given that the mean of the citation count variable is only 1.5, truncation might have an important effect on the estimates and the goodness of fit of our model.

We specify a Poisson regression to model the probability that the number of citations between the foreign subsidiary *i* and the European located firm *j* will occur *n* times as follows:

$$P(C_{ijtn}) = \frac{e^{-\lambda_{ijtn}} \lambda_{ijtn}^{\;c_{ijtn}}}{c_{ijtn}!} \quad \text{with} \quad \mathrm{E}(C_{ijtn}) = Var(C_{ijtn}) = \lambda_{ijtn} \qquad (2)$$

Where c_{ijtn} = 1,2,..*n* are the possible values of C_{ijtn} and λ_{ijtn} is the arrival rate of patent citations. The arrival rate of citations can be modelled as $\lambda_{ijtn} = \exp(\beta' X_{ijtn}) \;\; i = 1,...,n$ to obtain the following regression: $\mathrm{E}(\mathrm{C}_{ijtn} \mid X_{ijtn}) = \exp(\beta' X_{ijtn})$ where β are the coefficients and *X*'s are the covariates (with X_1 set to one).

The Poisson regression model is the basic model for analysing count data (seminal studies on the estimation of count data models are Hausman *et al.*1984, and Cameron and Trivedi 1986, for a survey of recent developments see Winkelmann and Zimmermann 1995). However some of its assumptions are very restrictive, i.e. the conditional mean and variance are equal. The presence of overdispersion, i.e. the conditional variance is greater than the conditional mean, might lead to small estimate of standard errors (Cameron and Trivedi, op. cit.). Overdispersion might not be a problem in our data since the ratio of sample mean and variance of the dependent variable is less than one. We can however test the presence of overdispersion using the regression-based test proposed by Cameron and Trivedi (1990). In this test the null hypothesis is a moment condition based on the Poisson model, i.e. H_0: Var [y_i]=E[y_i], and the alternative hypothesis is H_a: Var [y_i]=E[y_i]+α *g*(E[y_i]), which encompasses models with parameter heterogeneity. Since E[y_i] is unknown Cameron and Trivedi suggest using the prediction of the Poisson model (μ_i) as a consistent estimate. To test the null we needed to check the significance of the single coefficient of the linear OLS regression of

$$z_i = \left[(y_i - \mu_i)^2 - y_i \right] / (\mu_i \sqrt{2}) \quad \text{on either } w_1 = \mu_i / (\mu_i \sqrt{2}) \quad \text{or} \quad w_2 = (\mu_i)^2 / (\mu_i \sqrt{2}) \qquad (3)$$

We can verify the presence of overdispersion testing the Poisson model against the negative binomial model. In the negative binomial model a random component in the specification of the arrival rate λ_{ijtn} is introduced to account for an additional source of variance.

$$\tilde{\lambda}_{ijtn} = \exp(\beta' X_{ijtn} + \upsilon_{ijtn}) = \exp(\beta' X_{ijtn}) \exp(\upsilon_{ijtn}) = \lambda_{ijtn} u_{ijtn} \qquad (4)$$

where u_{ijtn} captures unobserved heterogeneity and is uncorrelated with the explanatory variables. The marginal density of C_{ijtn} can be obtained integrating with respect to u_{ijtn} :

$$\mathrm{P}(C_{ijtn}) = \int_0^\infty P(C_{ijtn} \mid X_{ijtn}, u_{ijtn}) f(u_{ijtn}) du_{ijtn} \qquad (5)$$

It can been shown that if u_{ijtn} ~ Gamma (α_{ijtn} , α_{ijtn}), then E(u_{ijtn}) = 1 and Var(u_{ijtn}) = $\sigma_{u_{ijtn}} = \alpha_{ijtn}^{-1}$ then the integration of equation (5) leads to a negative binomial regression model with

$$E(C_{ijtn} \mid \alpha_{ijtn}, \lambda_{ijtn}) = \lambda_{ijtn} \quad \text{and} \quad Var(C_{ijtn} \mid \alpha_{ijtn}, \lambda_{ijtn}) = \lambda_{ijtn} + \alpha_{ijtn}^{-1} \lambda_{ijtn}^2 = \lambda_{ijtn} + \sigma_{u_{ijtn}} \lambda_{ijtn}^2 \qquad (6)$$

If $\sigma_{u_{ijtn}} = \alpha^{-1}$ the variance-mean ratio is linear in the mean and one obtains the NEGBIN II model in the terminology used by Cameron and Trivedi (1986).

Since the Poisson model is a special case of the negative binomial case with $\alpha^{-1} = 0$, the test for overdispersion is simply a test of H_0: $\alpha^{-1} = 0$.

However the truncated nature of our dataset leads to inconsistent estimates of our coefficients as shown by Grogger and Carson (1991). This problem can be removed by using a truncated count data model which is derived from the truncated models used for continuous data. The truncated-at-zero version of the Poisson model is obtained by rescaling the probabilities of strictly positive outcomes and the new mean and variance are equal to:

$$\begin{aligned} \mathrm{E}(\mathrm{C}_{ijtn} \mid X_{ijtn}, \mathrm{C}_{ijtn} > 0) &= \frac{\lambda_{ijtn}}{1 - \exp(-\lambda_{ijtn})} \\ Var(\mathrm{C}_{ijtn} \mid X_{ijtn}, \mathrm{C}_{ijtn} > 0) &= \mathrm{E}(\mathrm{C}_{ijtn} \mid X_{ijtn}, \mathrm{C}_{ijtn} > 0) \left(1 - \frac{\lambda_{ijtn}}{1 - \exp(-\lambda_{ijtn})} \right) \end{aligned} \qquad (7)$$

5. Econometrics results

We follow the sequential modelling strategy suggested by Cameron and Trivedi (1986) and we report in table 4 the estimation results of a normal OLS regression (column 1) using the logarithm of the citation count as dependent variable, the standard Poisson (column 2) and negative binomial (column 3), and the truncated Poisson (column 4). To reduce the number of estimates to be reported we only present the results of the model using the *MNE* dummy variable to capture the international profile of the citing firm. No important differences were found in the estimates of the coefficients using the other dummy variables to control for this characteristic of the citing firm.

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

From table 4 we see that under all the different specifications, the coefficient of the home country variable is positive and highly significant, which seems to confirm the hypothesis of reverse technology transfer process. Firms located in the home country show a higher propensity to cite patents developed by US subsidiaries of their national 'champions'. The role of multinational companies in cross-border technology transfer appears to be significant after controlling for the technological characteristics of the cited patent, the firms and the country where the citing firms is located.

We can notice a great variation of the estimated values of the parameters when we pass from the standard version of the Poisson and the truncated version of this model, while robust z-statistics reveal little variation in the estimated standard errors across different model specification. Table 4 shows that there is almost no difference in the estimate we found using the Poisson and Negative Binomial model. This can be attributed to the fact that our data do not present overdispersion, which is confirmed by the estimates of the OLS regression presented in equation (3). The coefficients of w_1 (t = 1.60) and w_2 (t = 1.55) are not significant at standard level of confidence. In addition the Poisson model could not be rejected against the alternative of a negative binomial model, the log-likelihood ratio test cannot reject the null hypothesis.

We can therefore estimate our model using the truncated Poisson model. Results are presented in table 5 where the specifications in columns (1)-(3) are using different dummies to capture the international profile of the citing firm and the equations in columns (4) and (5) are trying to assess whether domestic firms in the home country can benefit from the reverse technology transfer process.

Results in columns (1)-(3) confirm what we already found in table 4. The home country variable is always significant and neither the international operation of the citing firm, whether it be through a technologically active site in the US or simply through a subsidiary presence, nor the nationality of the parent company can explain by itself the citation pattern.[16] This reinforces the findings in favour of the role of the MNE in the cross-border transfer of technology, since it seems that we can discard the hypothesis that the citing firm would have acquired the citing knowledge thanks to its presence in the US.

Of the control variables, the technological specialisation of the country where the citing firm is located (RTA_n) has a high and significantly positive impact on the citation frequency, which supports the idea that absorptive capacity, i.e. prior knowledge, is crucial in the technology transfer process. The coefficient of the technological proximity variable ($PROX_{ij}$) is also significant, suggesting that firms with a similar technological portfolio are more likely to cite each other. The coefficient of the potentially cited patents variable is significant across different specifications. The coefficient of the potentially citing patents is not significant only in one case (model 2). Both the international operation of the citing firm, whether it be through a technologically active site in the US or simply through a subsidiary presence, and the nationality of the parent company (the *TYPE* variables) have a significant effect. The sectoral dummy (*PHARMA*) and the technological sophistication ($SOPH_{it}$) of the cited firm are not significant, although positive.

In model (4) the coefficient of the interaction term between the *homecountry* and the *EU* dummy captures the effect of being a domestic company in the cited MNE's country of origin relative to being a domestic company not operating in the home country.[17] This effect is not statistically significant although positive, while the coefficient of the *MNE* is positive and highly significant. This result suggests that non-multinational firms and institutes do not benefit from the reverse technology transfer process. The model in column 5 further explores this research question and, using only the sample of citations made by multinational companies, tests whether MNEs in the

[16] We tested the equality of the coefficient on the dummy variables EUMNE and USMNE and we could not reject the null hypothesis, i.e. the log-likelihood ratio test statistic is equal to 1.92 corresponding to a *p* value of 0.17 for the $\chi^2(1)$ distribution.

[17] To test whether domestic companies in the home country are accessing the knowledge produced abroad by their national champions we should have carried a regression using only the citations made by this type of firms. However due to the small number of observations in this sample the model does not converge and the LR χ^2 is not significant.

home country show a learning advantage with respect to other MNEs not operating in the country of origin of the cited subsidiary. Results reported in column 5 seem to confirm the existence of such a learning advantage, i.e. the coefficient of the *homecountry* variable is positive and highly significant.

This qualifies our findings on the reverse technology transfer process: among the firms in the home country, multinational MNE appear to be the ones building on the technological knowledge produced abroad by the sampled subsidiaries. This could be due to the fact that we are using USPTO data and therefore we are not completely capturing the activity of purely domestic firms and institutions.

As we pointed out in the description of the citation data, only a small proportion of citations to patents applied for by US subsidiaries in the sample come from patents originating in Europe. We do not wish to claim that inter-firm technology transfer is the principal source of technology transfer. However given the increasing trend in the HBA nature of foreign-based R&D activities, the role of MNEs in the transfer of knowledge back to the home country might acquire a significant dimension, especially at the early stages of emerging technologies when knowledge is ‘sticky’ and tacit.

7. Conclusion

In this paper we test for the existence of an inter-firm reverse technology transfer process, i.e. the existence of a technological knowledge flow from foreign located R&D facilities of a multinational company to home country firms. Our hypothesis is mainly based on the evolutionary theory of the multinational firms which recognises the strategic nature of knowledge in maintaining a firm’s sustainable competitive advantage. MNEs have to ensure that the technological assets acquired locally by their subsidiaries are efficiently exploited within the firm. Multinational companies are becoming specialised in transferring knowledge within the different units of the firm. Secondly, we argued that the strong embeddedness of MNEs in their home countries will make possible the realization of spillover potential from the parent company to other actors in the home country. Most of these companies, though highly internationalised, are still rooted in their country of origin where they are at the centre of historically defined social networks with a range of external actors. It is through these channels that the technology accumulated abroad might diffuse to other home country firms.

We test the reverse technology transfer process using patent citation analysis as an indicator of technological knowledge flows from US subsidiaries of pharmaceutical and chemical European MNEs to firms located in Europe. In order to test for the role of MNEs in the international transfer of knowledge, we introduce a variable, *Homecountry*, which in a very crude way takes account of embeddedness in the home country, distinguishing between home country firms and other firms.[18] Having controlled for the international profile of the citing firm, the importance of the cited patent, the patenting activity of the citing and cited firm, the technological specialization of the citing country, we found that home country firms tend to cite US patents applied for by their national 'champions' more often. However not all types of firms in the home country seem to show a learning advantage with respect to firms located in another country, MNEs are more likely than purely domestic home country firms and institutions to benefit from the reverse technology transfer process.

An important implication of these results is that the increasing trend in the transfer of R&D activities may not be completely detrimental to the home country knowledge base. The relocation of research activities to centres of excellence can have a positive feed back effect – at least on other home country firms who have the absorptive capacity to benefit from them. Policy makers have tended so far to encourage domestic multinationals to maintain their R&D activity at home and have disapproved of the re-allocation of this investment to foreign countries, ignoring the possibility of reverse technology transfer. Our findings offer an alternative understanding of foreign direct R&D investment and its implications, both for the home country's technological activity, and for its competitive performance in general. National policies on international technology transfer have so far disregarded the role that MNEs might play in this process.

Our analysis is far from being conclusive and more empirical evidence is needed to support the hypothesis of reverse technology transfer. Although useful, patent citations analysis has many limitations: above all it does not identify the channels and mechanisms through which this phenomenon occurs. This sort of information is extremely important in formulating policy prescriptions and it is in this area that future work would be beneficial.

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[18] An ideal measure of embeddedness would take into account the development and the strength of the reciprocal linkages between MNEs' business units and home country suppliers, customers, and public research institutes. These linkages might also cut across geographical borders particularly when we consider companies originated in small countries.

APPENDIX

List of companies in the sample

Company name	Country of origin	Company name	Country of origin
Akzo Nobel N.V.	NL	Imperial Chemical Industries	UK
Astra AB	SE	L'Air Liquide S.A.	FR
BASF AG	DE	Novo Nordisk A/S	DK
Bayer AG	DE	Reckitt & Colman PLC	UK
Boehringer Ingelheim International GmbH	DE	Rhone-Poulenc S.A.	FR
Ciba-Geigy AG	CH	Roche Holding AG	CH
Degussa AG	DE	Sandoz AG	CH
DSM N.V.	NL	Schering AG	DE
E. Merck Chemische	DE	SmithKline Beecham PLC	UK
Glaxo Wellcome PLC	UK	Solvay S.A.	BE
Henkel KGaA	DE	The BOC Group PLC	UK
Hoechst AG	DE	ZENECA Group PLC	UK

Correlation matrix

	Variable	1	2	3	4	5	6	7	8	9	10	11	12
1	Cijtn												
2	Homecountry	0.0493											
3	MNE	0.0655	0.0749										
4	USR&D	0.1078	0.0775	0.4944									
5	US MNE	0.0382	0.0895	0.5914	0.4347								
6	EU MNE	0.0101	-0.0448	0.1424	-0.1043	-0.7139							
7	EU*Homecountry	-0.0251	0.2235	-0.3703	-0.183	-0.219	-0.0527						
8	lnPit	0.0466	0.0535	0.0017	0.0383	-0.0054	0.0081	0.0081					
9	lnPjt	0.0557	0.3143	0.2051	0.2933	0.2649	-0.1471	0.0159	0.0493				
10	SOPHitn	-0.0003	0.0059	-0.0468	-0.0569	-0.0351	0.0025	0.0683	-0.1794	-0.0418			
11	PROXij	0.0705	0.0962	0.1117	0.2034	0.1476	-0.0843	-0.0515	-0.2626	0.1699	0.099		
12	Pharma	0.0422	-0.1005	-0.0339	-0.028	-0.0103	-0.0168	0.0002	0.2601	-0.0354	-0.0583	-0.1	
13	RTAn	0.0529	0.1391	0.0364	0.066	0.0642	-0.0472	-0.0137	0.0116	0.1459	-0.0209	0.1059	0.002

Table 1. Descriptive statistics of citations contained in European invented patents to US subsidiaries patents

	Percent	Total citations	Mean citation lag	Std. Dev. citation lag
Intra-country*	29	1219	5.37	3.341
Intra-group	20	1130	4.85	3.297
Units of US MNEs in Europe *	14	636	6.05	3.768
Units of EU MNEs in Europe *	74	3293	5.58	3.396
Domestic*	16	543	5.68	3.464

* Intra-group citations excluded in the calculation

Table 2. Phi-square measures between US subsidiaries and headquarters of most technologically active MNE

Parent company	**80-87**	**88-99**
BASF AG	0.18	0.34
Bayer AG	0.27	0.31
Ciba-Geigy AG	0.29	0.27
Glaxo Wellcome PLC	0.11	0.27
Henkel KgaA	0.37	0.28
Hoechst AG	0.29	0.26
ICI PLC	0.28	0.28
Rhone-Poulenc S.A.	0.35	0.36
Roche Holding AG	0.37	0.5
Sandoz AG	0.22	0.44
SmithKline Beecham PLC	0.38	0.38
Solvay S.A.	0.45	0.59
The BOC Group PLC	0.29	0.34
Average	**0.29**	**0.35**

Table 3 Descriptive statistics

	Mean	Std. Dev.	Minimum	Maximum
Cijnt	1.435	1.215	1	18
P_{it}	25.251	32.843	1	171
P_{jt}	1152.549	3920.28	1	31060
$SOPH_{itn}$	0.024	0.113	0	3.436

Table 4 Estimates for the citation count model

	OLS	Poisson	Negative Binomial	Truncated Poisson
Variable Name	lnCijtn	Cijtn	Cijtn	Cijtn
Homecountry	0.038	0.097	0.097	0.265
	[1.65]*	[2.18]**	[2.18]**	[2.34]**
MNE	0.085	0.166	0.166	0.663
	[4.14]***	[5.10]***	[5.10]***	[4.49]***
lnPit	0.019	0.037	0.037	0.115
	[2.60]***	[2.54]**	[2.54]**	[2.72]***
lnPjt	0.027	0.036	0.036	0.11
	[3.09]***	[2.03]**	[2.03]**	[2.00]**
SOPHitn	0.045	0.066	0.066	0.155
	[0.84]	[0.84]	[0.84]	[0.57]
PROXij	0.09	0.171	0.171	0.479
	[3.26]***	[3.27]***	[3.27]***	[3.40]***
Pharma	0.032	0.046	0.046	0.139
	[1.63]	[1.29]	[1.29]	[1.23]
RTAn	0.058	0.115	0.115	0.391
	[2.76]***	[3.21]***	[3.21]***	[3.21]***
Constant	-0.198	-0.303	-0.303	-2.452
	[2.13]**	[1.72]*	[1.72]*	[4.40]***
Observations	2891	2891	2891	2891
Log-likelihood	-1679.66	-3927.51	-3927.52	-2652.68
alpha			1.98E-06	

Year, technological fields and country dummies are included in the regressions
Robust z statistics in brackets
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 5 Truncated Poisson model estimations

Variable Name	-1	-2	-3	-4	-5
Homecountry	0.265	0.282	0.255		0.263
	[2.34]**	[2.49]**	[2.24]**		[2.29]**
MNE	0.663			0.684	
	[4.49]***			[4.36]***	
US R&D		0.59			
		[5.44]***			
EU MNE			0.635		
			[4.21]***		
US MNE			0.801		
			[4.63]***		
EU*Homecountry				0.105	
				[0.25]	
lnPit	0.115	0.107	0.117	0.123	0.115
	[2.72]***	[2.56]**	[2.77]***	[2.85]***	[2.65]***
lnPjt	0.11	0.077	0.117	0.106	0.107
	[2.00]**	[1.38]	[2.07]**	[1.92]*	[1.88]*
SOPHitn	0.155	0.197	0.144	0.209	0.196
	[0.57]	[0.78]	[0.52]	[0.82]	[0.70]
PROXij	0.479	0.39	0.499	0.491	0.461
	[3.40]***	[2.78]***	[3.59]***	[3.48]***	[3.19]***
Pharma	0.139	0.135	0.139	0.118	0.151
	[1.23]	[1.20]	[1.23]	[1.07]	[1.27]
RTAn	0.391	0.389	0.396	0.421	0.41
	[3.21]***	[3.19]***	[3.27]***	[3.40]***	[3.22]***
Constant	-2.452	-1.907	-2.51	-2.443	-1.787
	[4.40]***	[3.34]***	[4.45]***	[4.40]***	[3.05]***
Observations	2891	2891	2891	2891	2577
Log-likelihood	-2652.68	-2635.19	-2650.59	-2660.12	-2481.93
LR Chi Square	403.84***	438.81***	408.03***	388.95***	351.70***

Year, technological fields and country dummies are included in the regressions
Robust z statistics in brackets
* significant at 10%; ** significant at 5%; *** significant at 1%

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