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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 29 chemical and pharmaceutical companies over the period 1980-99. Our findings suggest that multinationals, especially in the pharmaceutical sector, 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 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).

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 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 spills 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. Pottelberghe 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.

In this paper we investigate this technology transfer process in the chemical and pharmaceutical industries. European MNEs operating in these industries have been particularly engaged in tapping into the US knowledge base, the source of many new products and technological competences, especially in biotechnology (Shan and Song, 1997, Sharp 1999, Senker 1998, Allansdottir et al. 2002). While this strategy seems to have helped European-owned multinationals to retain their competitive advantage and enhance the relevant capabilities, the competitiveness of Europe as a geographic region seems to have deteriorated (Gambardella, Orsenigo and Pammolli, 2000). This is consistent with European MNEs having been successful in managing the internal reverse technology transfer process, but the knowledge transferred not diffusing to other home country firms. From a policy perspective the potential for inter-firm reverse knowledge transfer is the most relevant issue; this may be all the more so in biotechnology, where the existence of a technology gap between Europe and the US poses a serious threat in term of loss of economic growth potential and social progress.

The first objective of this study is to examine the flow of technological knowledge from US subsidiaries to firms located in Europe. In particular, we want to assess 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 European 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).

To address this issue we carry out a citation analysis on the patents applied to the United States Patent and Trademark Office (USPTO) by US subsidiaries of 29 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'.

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 of the citation data. In Section 5 we describe the econometric model and comment 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 are 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, 1997) 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, such as biotechnology, computers and telecommunications (Shan and Song, 1997, Kuemmerle, 1999, Serapio and Dalton, 1999, and Patel and Vega, 1999).

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 most favourite location of HBA facilities 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 into 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 biotech industry explains both spatial agglomeration and the need for geographical proximity to benefit from localised spillovers. While the marginal cost of transmitting codified knowledge on geographic distance, the marginal cost of transmitting tacit knowledge increases with distance (Audretsch and Feldman, 1996). [1]

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-borders 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 raises two questions:

1. To what extent and under what conditions does the knowledge accumulated in subsidiaries located in centers of excellence diffuse among the different units of the multinational organisation?

2. To what extent and under what conditions can local firms in the multinational home country have access to this knowledge?

The first research question deals with the diffusion of knowledge 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 (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 buying and selling of knowledge but out of its superior efficiency as an organizational vehicle by which knowledge is transferred across borders" (p. 625).

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[1] 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.

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 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 HBE type of facilities are still the dominant strategy.

The novelty of HBA R&D investment might also explain the lack of interest so far in the second research question, the existence of *inter-firm reverse technology transfer* from asset-seeking R&D facilities to the home country's firms.[2] 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

[2] 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.

find strong evidence of this technology transfer process in those chemical companies that, compared with pharmaceutical companies at least, 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 themselves social structures 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 a 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]

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 (Smith and Powell, 2002). This implies that the reliance on MNEs as a channel for international technology transfer might fade away as a the knowledge frontier in biotechnology evolves (for a discussion Pammolli and Riccaboni, 2001).

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 biotechnology is tacit in nature and tend to be spatially concentrated, thus the presence of foreign affiliates might be a necessary condition for international technology transfer in this technological area. The home part of the multinational might be the 'technological gatekeeper' of their home country biotechnology 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 voluntary or

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

involuntary outside the firm's boundaries. The MNE's embeddedness in the home country is the main factor allowing this to occur.

We will explore the existence of inter-firm reverse technology transfer using a database on patenting activities of 29 chemical and pharmaceutical European MNEs. Before explaining the methodology adopted to address this research question we illustrate the characteristics of our dataset.

2. Description of the database and limitation of patent citations

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 patent 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 29 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

[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.

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 from limitations.

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 protect and define their knowledge base in view of future collaboration with other firms. Results of basic research, however, tend not to be patented and therefore this study will analyse mainly the process of reverse technology transfer in applied research.

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. One may assume, however, that codified knowledge flows of patent citations go hand-in-hand with more tacit aspects of knowledge flows through for example face to face contacts and scientists rotation (Almedia and Kogut 1999, Verspagen and Schoenmakers, 2000).

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 on 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 no-local partners might have led firms to seek patent protection both in Europe and in the US.

Before looking in the details to 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 is 11,672, which corresponds to almost 21 per cent of the total number of patents granted to the multinational companies in our sample. As we pointed out before, the bulk of R&D activity is carried out in the home country (66.78 per cent of patents originates 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 28.1% and the mean is 28.4% and the standard deviation is 14.6%.

What is perhaps more 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

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

that are location specific. If US subsidiaries are carrying out HBA R&D activities we should observe an evolution of their patenting activities towards new technological fields that are near the specialization of the host state.

Frost (1997) 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. We calculated these distances using patents aggregated in 36 different technological categories.[6]

Table 1. Phi-square measures between US subsidiaries and headquarters of most technological 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**

From table 1, 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.[7] In particular biotechnology (class 435, 800) appears among the top three technology classes of specialization of the US 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,

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

[7] 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.

Zeneca).

To assess whether US subsidiaries try to specialise in host state areas of expertise we calculate, following Frost (1997), what percentage of US affiliates' patents are in fields where the host state has a revealed technological advantage.[8] We compare this with the proportion of US subsidiaries' patents in technical areas where the MNE home country is specialised.

Table 2 Locational specialization of U.S. subsidiaries patenting activities

	Home country		Host state	
Parent company	**1980-87**	**1988-99**	**1980-87**	**1988-99**
BASF AG	76.71	77.66	57.53	64.36
Bayer AG	74.51	57.27	70.00	56.82
Ciba-Geigy AG	66.13	63.89	61.29	62.64
Glaxo Wellcome PLC	65.00	71.43	35.00	54.17
Henkel KgaA	71.59	79.78	51.14	59.55
Hoechst AG	75.00	74.32	59.62	51.89
ICI PLC	50.00	59.05	64.52	54.29
Rhone-Poulenc S.A.	43.66	69.30	69.01	59.29
Roche Holding AG	55.77	65.79	63.46	55.41
Sandoz AG	62.90	58.16	62.90	58.16
SmithKline Beecham PLC	66.67	79.59	55.56	61.22
The BOC Group PLC	40.38	59.71	44.23	46.04
Average	**68.03**	**74.18**	**63.12**	**62.17**

The average pattern shown in Table 2 reveals an increasing trend in the proportion of US subsidiaries' specialization towards field of home country expertise, and a stable pattern towards fields of host state specialization. However US subsidiaries of six MNEs have substantially moved their technical activities towards areas of host state specialization.

We can 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, and that these R&D activities are of the HBA type. These findings support the hypothesis of a potential reverse technology transfer

[8] We calculate the revealed technological advantage as $RTA_{in}= \left(P_{in} \Big/ \sum_i P_{in} \right) \Bigg/ \left(\sum_n P_{in} \Big/ \sum_{in} P_{in} \right)$, 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.

both intra-firm and inter-firm.

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. As anticipated earlier, we did not expect a higher number of citations to US subsidiaries patents by European inventors.

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.[9]

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.

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 (5.7 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.

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

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

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

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

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 have never patented in the US directly but be are 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.

Unfortunately we are unable to identify the assignees of 173 citations. We eliminated them from our sample, leaving us with 5601 observations including intra-group citations. As shown in Table 3, 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 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.

Table 3. Descriptive statistics

	Percent citations	Total no. of citations	Average citation lag
Intra-country*	29	1219	5.37
Intra-group	20	1130	4.85
US MNEs*	14	636	6.05
EU MNEs*	74	3293	5.58
Domestic*	16	543	5.68

* Intra-group citations excluded in the calculation

Finally, we analysed to what extent European firms are building on knowledge generated from HBA facilities. Adopting the approximation used before, 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. These findings are already indicative of a strong potential for the reverse technology transfer hypothesis, which the empirical analysis will test.

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 patent, while controlling for other important variables, such as the technological characteristics of the cited patent, 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 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 citation rate between the European MNE's American subsidiaries and the firms, located in Europe, who cite them. As extensively explained by Hall *et al.* (2001), one of the central difficulties in using patent citations is correcting for different factors that may change citation intensities over time and across sectors. 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. To correct for these effects we adopt the so called 'fixed-effect approach' (Hall *et al*. 2001) and deflate the number of citations by citing firm i to patents applied by multinational j by the average number of citations received of patents in the same year-class cohort as the cited patent. With this procedure we remove from the citation count the variability arising from year, technology class and year-class fixed effects.

The dependent variable (CR_{ijtn}) is therefore the number of citations (C) received by firm j in each separate year (t) and class (n) from firm, i, divided by the average for that year and class (AVC_{tn}):[10]

$$CR_{ijtn} = \frac{(C_{ij})_{tn}}{AVC_{tn}} \forall i \neq j .$$

Unfortunately we are not able to identify with certainty the patent activity of each subsidiary because of the aforementioned practice of assigning patents to the headquarters, even if developed in other locations.[11] We therefore repeat the analysis with different average citation rate measures, where the cited firm j corresponds to the following entities: the overall US part of the multinational j (i.e. all US affiliates of Bayer AG), and the single assignee (i.e. Bayer Corporation). In the first case we do not distinguish among different American subsidiaries, while in the second one, we take

[10] We exclude intra-group citations (where i=j) from our analysis, since *inter-firm* technology transfer is the phenomenon we are investigating.

[11] The information contained in the NBER database on the address of the inventor was not useful in identifying the exact location of the invention: the ZIP code was missing for most patents in the sample.

as the cited firm the subsidiary to which the cited patent has been assigned.[12]

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

$$\begin{aligned}\ln(CR_{ijtn}) &= \alpha_0 + \alpha_1 Homecountry + \alpha_2 \ln(P_{jt}) + \alpha_3 \ln(P_{is}) + \alpha_4 PROX_{ij} + \alpha_5 CLASS + \alpha_6 CITREC \\ &+ \alpha_7 TYPE_i + \alpha_8 PHARMA + \alpha_9 RTA_n + \alpha_{10} HBA_n + \text{year dummies} + \text{country dummies} + \varepsilon_{ijtn}\end{aligned} \quad (1)$$

Homecountry is a dummy variable which takes the value of 1 if the citing patent assigned to firm *i* 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.

$\ln(P_{is})$ denotes the logarithm of the number of patents applied for by the citing firm *i* in the application year *s*. $\ln(P_{jt})$ is the logarithm of the number of patents applied for by the cited firm *j* in the application year of the cited patent. 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 citing firm *i* and the cited 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 sub-categories over the sample period: $PROX_{ij} = \frac{F_i F_j^{'}}{\sqrt{(F_i F_i^{'})(F_j F_j^{'})}}$. 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.

CLASS is another dummy variable which is equal to 1 when the citing patent and the cited patent belong to the same technological class. As with the technological distance measure, we assume that

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[12] This second case has a slightly smaller sample size because some patents are assigned directly to the headquarters of the multinational, despite the inventor's address being in the United States. These patents cannot therefore be assigned to a specific subsidiary and are dropped.

the citation rate should be positively related to this independent variable. This variable is supposed to account for the similarities in the technological activity of the citing and cited patent.

CITREC measures the number of citations received by the cited patent, deflated by the average number of citations received by patents in the same year-class cohort. Because the number of citations received by a patent is an indicator of its technological significance, we introduce this variable to control for the importance of the cited patent.

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 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 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. 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 multinationals only if they have 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.[13] This is designed to control for other channels through which the technology transfer may have occurred.

RTA_n is a dummy variable which takes the value of 1 if the standardised RTA index of the citing firm's home country 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.

[13] 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.

HBA_n is equal to 1 if the cited patent is in a technological area in which the US host state is specialised, i.e. the US state standardised RTA index is positive. This is a proxy for home base augmenting R&D activities of US subsidiaries. According to our reverse technology transfer hypothesis, home country firms should draw from knowledge accumulated in this type of foreign-based R&D sites and therefore we expect a positive and significant coefficient on this variable.

Finally we include time dummies to control for year specific effects and country dummies for each country where a citing patent originates to control for unobserved country specific fixed effects.

Introducing some of these control variables (particularly *CITREC*) requires variation across patents rather than simply variation across firms. Therefore we cannot simply aggregate citations to the level of the firm; rather we keep as the unit of analysis the citing-patent/cited-patent pairs.

To summarise, the *Homecountry* variable captures the reverse technology transfer process, the *HBA* variable is accounting for the MNE's international R&D strategy, 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_{is} , P_{jt} , *PROX, TYPE*), but also at the level of cited patent (*CITREC*), and at the level of the country of residence of the citing inventor (*RTA*).

Table 4 Descriptive statistics

	Mean	Standard Deviation	Minimum	Maximum
$LnCijnt_{(MNE)}$	0.37	1.26	-2.90	3.25
$LnCijnt_{(Assignee)}$	-0.74	1.23	-2.90	3.20
LnP_{is}	3.16	1.86	0	6.31
$LnP_{jt\ (MNE)}$	3.86	0.99	0	5.50
$LnP_{jt\ (Assignee)}$	3.71	1.34	0	6.24
CITREC	2.68	2.87	0.70	30.51
$PROX_{ij(MNE)}$	0.31	0.28	0	0.92
$PROXij_{(Assignee)}$	0.35	0.32	0	1

Table 4 presents summary statistics and the appendix contains the correlation matrices of the different variables included in the econometric analysis. The log of the citation rate between the citing firm and both the cited subsidiary and the cited multinational is highly correlated with the number of citations received by the cited patent and somewhat correlated with the home country dummy, the technological proximity measure, and the technological specialization of the citing country.

5. Econometrics results

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 firms do not cite each other every year. We try to capture some dynamic aspects of the reverse technology transfer process estimating the model in two sub-sample periods.

We estimated equation (1) with OLS and found that there are heteroscedasticity problems. An inspection of the data shows a number of outliers, which could affect the results for certain coefficients. We decided to use robust regression techniques, which use the following procedure. Initially, the residuals from the OLS regression are analysed to give each observation a weight based on its residual's relative magnitude. A regression using weighted data is then run, this procedure of re-weighting continues until no large residuals exist.

The results from this robust regression method are shown in the table 5. Although we do not reported the coefficients, all equations have been estimated using both year dummies and country dummies. In the first 3 columns we present results of estimations where the dependent variable is the citation rate between firm *i* and the cited subsidiary *j*, while in the last 3 columns we report the results of regressing the citation rate between firm *i* and the US part of multinational *j*. The specification of equations (1)-(3) and (4)-(6) are similar, except for the fact that we use different dummies capturing different international profile of the citing firm.

From table 5 we see that under all 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.

Of the control variables, the higher quality of the patent (*CITREC*) positively and significantly affects the likelihood of being cited. As expected, the technological specialisation of the country where the citing firm is located (*RTA*) also has a high and significantly positive impact on the citation rate, 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*) is also quite high and significant, suggesting that firms with a similar technological portfolio are more likely to cite each other. A similar effect is captured by the significantly positive coefficient in the dummy *CLASS*. The number of patents applied for by the citing firm (P_{is}) is not significant (though positive) while the number of patents applied for by the cited firm (P_{jt}) has a positive and significant effect on the citation rate.

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 (the *TYPE* variables) has a significant effect. 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 their presence in the US. The results obtained confirm also that the knowledge produced in HBA-type of facilities seems to be more cited by European firms (since *HBA* is significant). Finally the significant and positive coefficient for the sectoral dummy (*PHARMA*) suggests that pharmaceutical companies have a stronger role than chemical ones in the cross-border knowledge flows, possibly because their R&D activity is much more internationalised and oriented towards HBA type of activities.

The estimation results using the citation rate between the citing firm and the cited subsidiary (columns 1-3) have a higher goodness of fit as indicated by the R squared, than then the results between the citing firms and the US part of the cited multinational (columns 4-6), though in general the coefficient values are very similar.

Table 6 and 7 show the results obtained using citations to patents applied for in two separate sub-periods, 1980-1987 and 1988-1999. The findings are supportive of the reverse technology transfer hypothesis in both sub-samples. Regarding the control variables, it is interesting to note that for the citations with a longer citation history (table 6) the firms' international profile appears to positively affect the citation rate. The citing firm being part of a US MNE has a significant and positive effect on the likelihood of accessing knowledge developed in the US, at least when we consider the cited firm to be the entire American part of the multinational. This suggests that European subsidiaries of US MNEs are in a better position to access technological knowledge developed by competitors in the US. Since this effect is not significant for the more recent cohort of cited patents (table 7), it implies either that this advantage is becoming less important or that the international profile of the firm has an impact only for less recent technological developments. The logarithm of the number of patents applied for by the citing firm is not significant under model (1)-(3) in the sub sample 1980-87 as well as the nature of the cited US subsidiary's R&D activity. Both coefficients are however positive and significant for the more recent cohort.

In summary, these results seem to support the hypothesis of inter-firm reverse technology transfer and suggest that European firms are in part benefiting from the foreign-based R&D activities of their national 'champions'. 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 a 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 takes account in a very crude way of embeddedness in the home country, distinguishing between home country firms and other firms.[14] 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.

An important implication for these results is that the increasing trend in the transfer of R&D activities especially by European pharmaceutical multinationals may not be completely detrimental to the European knowledge base. The relocation of research activities to centre of excellence in the US 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. Patent citations analysis although useful 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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[14] 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 company in the sample

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

Autocorrelation matrices

	Variable	1	2	3	4	5	6	7	8	9	10	11	12	13
1	lnCij, j=assignee													
2	lnPit	0.30												
3	lnPjt, j=assignee	0.02	0.10											
4	Citrec	0.52	0.09	-0.07										
5	Proxij, j=assignee	0.25	0.45	-0.17	0.15									
6	RTA	0.21	0.13	0.02	0.09	0.12								
7	HBA	0.08	0.07	0.13	0.05	0.00	-0.02							
8	Homecountry	0.13	0.20	0.04	0.05	0.01	0.07	0.06						
9	Class	0.15	0.01	-0.03	0.12	0.06	0.05	0.05	-0.02					
10	Pharma	0.10	0.02	0.21	0.20	-0.01	-0.02	0.12	-0.05	0.03				
11	MNE	0.13	0.32	0.06	0.05	0.14	0.03	0.03	0.08	0.02	-0.01			
12	USRD	0.23	0.58	0.11	0.10	0.25	0.04	0.06	0.10	0.00	0.01	0.50		
13	EU MNE	0.14	0.46	0.07	0.06	0.20	0.08	0.04	0.11	0.06	0.01	0.56	0.45	
14	US MNE	-0.06	-0.30	-0.03	-0.03	-0.13	-0.08	-0.02	-0.06	-0.06	-0.02	0.12	-0.14	-0.75

	Variable	1	2	3	4	5	6	7	8	9	10	11	12	13
1	lnCij, j=MNE													
2	lnPit	0.22												
3	lnPjt, j=MNE	0.23	0.07											
4	Citrec	0.54	0.09	-0.02										
5	Proxij, j=MNE	0.29	0.63	-0.23	0.29									
6	RTA	0.18	0.13	-0.02	0.09	0.15								
7	HBA	0.13	0.07	0.06	0.05	0.06	-0.02							
8	Homecountry	0.12	0.20	0.13	0.05	0.12	0.07	0.06						
9	Class	0.18	0.01	-0.03	0.12	0.09	0.05	0.05	-0.02					
10	Pharma	0.23	0.02	0.36	0.20	-0.10	-0.02	0.12	-0.05	0.03				
11	MNE	0.09	0.32	0.01	0.05	0.21	0.03	0.03	0.08	0.02	-0.01			
12	USRD	0.15	0.58	0.04	0.10	0.44	0.04	0.05	0.10	0.00	0.01	0.50		
13	EU MNE	0.10	0.46	0.00	0.06	0.33	0.08	0.04	0.11	0.06	0.01	0.56	0.45	
14	US MNE	-0.05	-0.30	0.01	-0.03	-0.23	-0.08	-0.02	-0.06	-0.06	-0.02	0.12	-0.14	-0.75

Regression Results

Table 5: Robust regression results over the period 1980-1999

	lnCij with j=assignee			lnCij with j=ult & US		
Variable	**-1**	**-2**	**-3**	**-4**	**-5**	**-6**
Homecountry	0.152	0.148	0.152	0.214	0.198	0.2
	[4.31]***	[4.19]***	[4.31]***	[5.85]***	[5.42]***	[5.47]***
Class	0.109	0.111	0.11	0.21	0.206	0.201
	[3.88]***	[3.97]***	[3.91]***	[7.21]***	[7.11]***	[6.91]***
EUMNE		0.017			-0.015	
		[0.32]			[0.27]	
USMNE		0.097			0.096	
		[1.55]			[1.49]	
LnPjt	0.136	0.141	0.131	0.053	0.057	0.059
	[14.24]***	[14.11]***	[12.14]***	[4.68]***	[4.96]***	[4.89]***
LnPis	0.077	0.077	0.076	0.253	0.253	0.254
	[5.89]***	[5.93]***	[5.84]***	[14.08]***	[14.18]***	[14.21]***
Citrec	0.216	0.216	0.215	0.203	0.206	0.206
	[41.13]***	[41.19]***	[41.06]***	[35.56]***	[36.30]***	[36.36]***
Pharma	0.095	0.095	0.095	0.306	0.277	0.275
	[2.79]***	[2.79]***	[2.79]***	[8.24]***	[7.46]***	[7.41]***
PROXij	0.364	0.362	0.365	0.657	0.645	0.645
	[7.26]***	[7.23]***	[7.28]***	[8.79]***	[8.67]***	[8.63]***
HBAn	0.063	0.062	0.062		0.188	0.189
	[2.43]**	[1.98]**	[1.98]**		[5.80]***	[5.82]***
RTAn	0.347	0.347	0.344	0.317	0.329	0.322
	[10.88]***	[10.92]***	[10.83]***	[9.57]***	[9.96]***	[9.72]***
MNE	0.039			0.014		
	[0.73]			[0.26]		
USR&D			0.049			-0.056
			[1.25]			[1.38]
Constant	-2.513	-2.506	-2.467	-2.646	-2.827	-2.819
	[3.99]***	[3.98]***	[3.93]***	[4.76]***	[5.10]***	[5.11]***
Observations	4153	4153	4153	4472	4472	4472
R-squared	0.55	0.55	0.55	0.48	0.49	0.49
F test	119.89	119.8	119.79	101.12	101.08	101.17

Absolute value of t statistics in brackets

*** significant at 10%; ** significant at 5%; *** significant at 1%**

Table 6: Estimation results sample 1980-87

	lnCij with j=assignee			lnCij with j=ult & US		
Variable	**-1**	**-2**	**-3**	**-4**	**-5**	**-6**
Homecountry	0.169	0.166	0.171	0.197	0.194	0.199
	[3.34]***	[3.29]***	[3.40]***	[3.99]***	[3.95]***	[4.04]***
Class	0.093	0.094	0.093	0.2	0.205	0.197
	[2.31]**	[2.34]**	[2.32]**	[5.15]***	[5.28]***	[5.08]***
EUMNE		0.046			0.065	
		[0.59]			[0.88]	
USMNE		0.087			0.189	
		[0.96]			[2.16]**	
LnPjt	0.146	0.149	0.146	0.048	0.054	0.066
	[10.40]***	[10.04]***	[9.17]***	[3.18]***	[3.50]***	[4.05]***
LnPis	0.008	0.008	0.008	0.219	0.22	0.219
	[0.40]	[0.39]	[0.37]	[8.51]***	[8.56]***	[8.52]***
Citrec	0.226	0.227	0.226	0.22	0.219	0.222
	[30.98]***	[31.12]***	[30.93]***	[29.61]***	[29.55]***	[30.00]***
Pharma	0.126	0.124	0.125	0.41	0.412	0.407
	[2.34]**	[2.32]**	[2.32]**	[7.26]***	[7.32]***	[7.22]***
PROXij	0.378	0.375	0.38	0.563	0.586	0.566
	[5.28]***	[5.23]***	[5.30]***	[5.66]***	[5.87]***	[5.66]***
HBAn	0.05	0.051	0.05	0.261	0.26	0.26
	[1.13]	[1.16]	[1.13]	[6.10]***	[6.11]***	[6.08]***
RTAn	0.483	0.484	0.483	0.461	0.465	0.456
	[10.64]***	[10.64]***	[10.64]***	[10.37]***	[10.49]***	[10.27]***
MNE	0.057			0.095		
	[0.76]			[1.31]		
USR&D			0.02			-0.096
			[0.34]			[1.75]*
Constant	-2.496	-2.493	-2.438	-3.022	-3.014	-2.956
	[3.72]***	[3.71]***	[3.65]***	[4.53]***	[4.53]***	[4.45]***
Observations	2315	2315	2315	2455	2455	2455
R-squared	0.54	0.54	0.54	0.54	0.54	0.54
F test	85.51	85.48	85.51	92.46	92.4	92.94

Absolute value of t statistics in brackets

*** significant at 10%; ** significant at 5%; *** significant at 1%**

Table 7: Robust regression estimation results sample 1988-99

	lnCij with j=assignee			lnCij with j=ult & US		
Variable	**-1**	**-2**	**-3**	**-4**	**-5**	**-6**
Homecountry	0.15	0.146	0.151	0.231	0.227	0.231
	[3.11]***	[3.02]***	[3.12]***	[4.22]***	[4.14]***	[4.21]***
Class	0.094	0.098	0.096	0.16	0.166	0.159
	[2.48]**	[2.58]**	[2.51]**	[3.67]***	[3.81]***	[3.64]***
EUMNE		-0.069			-0.142	
		[0.90]			[1.62]	
USMNE		0.033			-0.019	
		[0.39]			[0.20]	
LnPjt	0.117	0.122	0.109	0.052	0.06	0.051
	[9.23]***	[9.34]***	[7.70]***	[3.14]***	[3.51]***	[2.93]***
LnPis	0.14	0.14	0.138	0.266	0.265	0.267
	[8.51]***	[8.57]***	[8.42]***	[10.43]***	[10.39]***	[10.45]***
Citrec	0.201	0.201	0.2	0.199	0.199	0.198
	[26.82]***	[26.84]***	[26.73]***	[22.53]***	[22.61]***	[22.50]***
Pharma	0.066	0.067	0.067	0.165	0.165	0.163
	[1.54]	[1.58]	[1.56]	[3.29]***	[3.29]***	[3.26]***
PROXij	0.361	0.366	0.365	0.646	0.642	0.653
	[5.26]***	[5.33]***	[5.31]***	[5.79]***	[5.76]***	[5.83]***
HBAn	0.077	0.075	0.076	0.138	0.135	0.139
	[1.75]*	[1.71]*	[1.72]*	[2.77]***	[2.71]***	[2.79]***
RTAn	0.182	0.188	0.186	0.21	0.212	0.21
	[4.18]***	[4.31]***	[4.26]***	[4.17]***	[4.21]***	[4.17]***
MNE	-0.04			-0.108		
	[0.54]			[1.27]		
USR&D			0.044	-2.635		-0.035
			[0.85]	[2.73]***		[0.58]
Constant	-2.931	-2.917	-2.997	-2.635	-2.615	-2.708
	[6.19]***	[6.17]***	[6.38]***	[2.73]***	[2.71]***	[2.82]***
Observations	1838	1838	1838	2017	2017	2017
R-squared	0.58	0.58	0.58	0.43	0.44	0.43
F test	76.28	76.2	76	44.77	44.7	44.67

Absolute value of t statistics in brackets

*** significant at 10%; ** significant at 5%; *** significant at 1%**

References

Allansdottir, A., A. Bonaccorsi, A. Gambardella, M. Mariani, L. Orsenigo, F. Pammolli, M. Riccaboni (2002), "Innovation and competitiveness in European biotechnology", Enterprise papers, N. 7, Enterprise Directorate-General, European Commission.

Almeida, P. (1996), "Knowledge sourcing by foreign multinationals: patent citation analysis in the U.S. semiconductor industry", Strategic Management Journal, Vol. 17, Winter Special Issue, pp. 155-65.

Audretsch, D. and Feldman, M. (1996), "R&D Spillovers and the Geography of Innovation and Production," American Economic Review, 86(4), pp. 253-273.

Arundel, A. and I. Kabla (1998), "What percentage of innovations are patented? Empirical estimated for European firms", Research Policy, 27, pp. 127-141.

Barney, J.B. (1986), "Strategic factor markets: expectations, luck, and business strategy", Management Science, 32 (10), pp. 1231-41.

Basberg, B. (1987) "Patents and the measurement of technological change: a survey of the literature", Research Policy, 16, pp. 131-141.

Blanc, H. and C. Sierra, (1999), "The internationalisation of R&D by multinationals,: a trade-off between external and internal proximity", Cambridge Journal of Economics, 23, pp.187-206.

Braconier, H., K. Ekholm and K.H. Midelfart Knarvik (2002) "In search of FDI-transmitted R&D spillovers: A study based on Swedish Data", Weltwirtschaftliches Archiv, Vol. 137 (4), pp. 644-65.

Branstetter, L. (2000), "Is foreign direct investment a channel of knowledge spillovers? Evidence from Japan's FDI in the United States", NBER working paper 8015, November.

Brouwer, E. and A. Kleinknecht (1999), "Innovative output and a firm's propensity to patent. An exploration of CIS micro data", Research Policy, 28, pp. 615-624.

Castellani, D. (2001) "Export behaviour, foreign direct investments and firm's productivity", Unpublished Ph.D. Thesis, University of Ancona.

Cohen, W. M. and D. A. Levinthal (1989), "Innovation and learning: the two faces of R&D", The Economic Journal, 99, pp. S.569-96.

Cyert, R. (1995), “Management of knowledge”, Global view, Newsletter of the Carnegie Bosch Institute for Applied Studies in Management, The Carnegie-Mellon University.

Dunning, J. and R. Narula (1995) “The R&D activities of foreign firms in the United States’, International Studies of Management & Organization, 25, No. 1-2, pp.39-73.

ETAN-European Technology Assessment Network (1998), “Technology policy in the context of internationalisation of R&D and innovation. How to strengthen Europe's competitive advantage in technology”, Brussels, European Commission, Directorate-General Science Research and Development.

Fors, G. (1997) “Utilization of R&D results in the home and foreign plants of multinationals”, Journal of Industrial Economics, June, Vol. XLV, No. 2, pp. 341-358.

Frost, T. S. (1998) “The geographic sources of innovation in the multinational enterprise: U.S. subsidiaries and host country spillovers, 1980-1990”, Unpublished Ph.D. thesis, Massachusetts Institute of Technology.

Frost, T. S. (2001), “The geographic sources of foreign subsidiaries’ innovation”, Strategic Management Journal, 22, pp. 101-123.

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.

Grant, R. M. (1996) “Toward a knowledge-based theory of the firm”, Strategic Management Journal, Vol. 17, Winter Special issue, pp. 109-122.

Griliches, Z. (1979), “Issues in assessing the contribution of research and development to productivity growth”, The Bell Journal of Economics, 10(1), pp. 92-116.

Griliches, Z. (1992), “Patent statistics as economic indicators: a survey”, Journal of Economic Literature, 28, pp. 1661-1707.

Granovetter, M. (1985), “Economic action and social structure: the problem of embeddedness”, American Journal of Sociology, Vol. 91, No. 3, pp. 481-510.

Globerman, S., A. Kokko and Fredrik Sjöholm (2000) “International Technology Diffusion: evidence from Swedish patent data“, Kyklos, Vol. 53, Fasc. 1, pp. 17-38.

Gupta, A. K. and V. Govindarajan (2000) “Knowledge flows within multinational corporations”, Strategic Management Journal, 21, pp. 473-496.

Halinen, A. and J. Törnroos (1998), “The role of embeddedness in the evolution of business networks”, Scandinavian Journal of Management, Vol. 14, No. 3, pp. 187-205.

Hall, B. A. Jaffe an M. Trajtenberg (2001) “The NBER patent citations data file: lessons, insights and methodological tools”, NBER w.p. 8498.

Hakanson, L. and R. Nobel (2000) “Technology characteristics and reverse technology transfer”, Management International Review, Special Issue, 40, Vol. 1, pp. 29-48.

Hakanson, L. and R. Nobel (2001) “Organization characteristics and reverse technology transfer”, Management International Review, Special Issue, 41, Vol. 4, pp. 392-420.

Jaffe, A. B. (1986), “Technological opportunity and spillover of R&D: Evidence

Jaffe, A.B., M. and R. Henderson (1993). “Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations”, Quarterly Journal of Economics, vol. 108. pp 577-598.

Jaffe, A.B., M. Trajtenberg and M. Fogarty (2000), “Knowledge spillovers and patent citations: evidence from a survey on inventors”, American Economic Review Papers and Proceedings, vol. 90. No. 2, pp. 215-218.

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, pp.625-645.

Kuemmerle, W. (1999), “Foreign direct investment in industrial research in the pharmaceutical and electronic industries-results from a survey of multinational firms”, Research Policy, 28, pp.179-93.

Nachum L., G. Jones and J. Dunning (2001), “The international competitiveness of the UK and its multinational enterprises”, Structural Change and Economic Dynamics, 12, pp. 277-294.

Owen-Smith, J. and W. Powell (2002), “Knowledge network in the Boston biotechnology Community”, paper presented paper presented at the National Academy of Sciences STEP Board Conference on The Operation of the Patent System: Insights from New Research.

Patel, P. and M. Vega (1999), “Patterns of internationalization of corporate technology: location vs. home country advantages”, Research Policy, 28, pp.145-55.

Patel, P. and Pavitt, K. (1999), "Global Corporations & 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.

Pauly, L. and S. Reich (1997) National structures and multinational corporate behaviour: enduring differences in the age of globalisation, International Organization, 51 (1), pp. 1-31.

van Pottelsberghe de la Potterie, B. and F. Lichtenberg (2001), "Does Foreign Direct Investment Transfer Technology Across Borders?", Review of Economics and Statistics, 83(3),), pp. 490-497.

Sally, R. (1996), "Public policy and the Janus face of the multinational enterprise: national embeddedness and international production", in P. Gummett (ed.) Globalization and Public policy, Cheltenham: Edward Elgar.

Saxenian, A. (1994), Regional advantage: culture and competition in Silicon Valley and Route 128. Cambridge, Harvard University Press.

Serapio, M. and D. Dalton (1999), "Globalization and industrial R&D: an examination of foreign direct investment in R&D in the United States", Research Policy, 28, pp.303-16.

Senker, J. ed. (1998) Biotechnology and Competitive advantage, Edward Elgar.

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, pp. 267-284.

Sharp, M. (1999) "The science of nations: European multinationals and American biotechnology", International Journal of Biotechnology, Vol. 1, No.1, pp. 132-159.

Szulanski, G. (1996), "Exploring internal stickiness: impediments to the transfer of best practice within the firm", Strategic Management Journal, 17, pp. 27-43.

Veugelers R. and B. Cassiman, 1999, Importance of International Linkages for Local Know-How Flows: Some Econometric Evidence From Belgium, CEPR Discussion Paper No. 2337.

Von Hippel, E. (1994),"'Sticky information' and the locus of problem solving: implications for innovation", Management Science, Vol. 40, No. 4, April, pp. 429-439.

Zander, I. and O. Sölvell (2000), "Cross-border innovation in the multinational corporation: a research agenda", International Studies of Management and Organization, Vol. 30, 2, pp. 44-67.

Zanfei, A. (2000), "Transnational firms and the changing organisation of innovative activities", Cambridge Journal of Economics, 24, pp. 515-542.\

von Zedtwitz, M. and O. Gassmann (2002), "Market versus technology driven in R&D internationalisation: four different patterns of managing research and development", Research Policy, 31, pp. 569-588.