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The relative importance of home and host innovation systems in the internationalisation of MNE R&D: a patent citation analysis

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Abstract

This paper examines the phenomenon of home base augmenting (HBA) R&D and home base exploiting (HBE) R&D. It has three novelties. First, we argue that any given R&D facility's capacity to exploit and/or augment technological competences is a function not just of its own resources, but the efficiency with which it can utilise complementary resources associated with the relevant local innovation system. Just as HBA activities require proximity to the economic units (and thus the innovation system) from which they seek to learn, HBE activities draw from the parent's technological resources as well as from the other assets of home location's innovation system. Furthermore, we argue that most firms tend to undertake both HBE and HBA activities simultaneously. Second, we use patent citation data from the European Patent Office to quantify the relative HBA vs. HBE character of foreign-located R&D. Third, we do so for European MNEs located in the US, as well as US MNEs located in Europe. Our results indicate that both EU (US) affiliates in the US (EU) rely extensively on home region knowledge sources, although they appear to exploit the host country knowledge base as well. The HBA component of US R&D in Europe in chemicals, electronics and petroleum refining is stronger than their European counterparts, as is the case for European R&D activities in the US in engineering.

Keywords: internationalisation, R&D, innovation systems, multinational enterprises, patent citation analysis, knowledge flows, Europe, US.

1. INTRODUCTION

The growing significance of the international R&D activities of multinational enterprises (MNEs) over the last two decades has been cause for comment for those concerned with technology and innovation policy. It has been suggested – and this view is primarily one associated with European scholars - that the internationalisation of R&D by domestic firms might result in a 'hollowing out' of domestic capabilities, as firms decrease domestic R&D activities while increasing foreign activities (e.g., European Technology Assessment Network 1998). This is regarded as indicative of a weakening domestic competitiveness of the home location. In the US, on the other hand, concern has been with much the opposite phenomenon: the potential loss of competitiveness of US firms and the 'national knowledge base' due to the increasing local R&D presence of foreign-owned MNEs (e.g., Dalton et al. 1999).

The evidence regarding R&D internationalisation by MNEs is varied, heterogeneous and ambiguous. It is true that large MNEs play a dominant role in the innovative activities of their home countries and control or own a large part of the world's stock of advanced technologies[1]. These same MNEs undertake a growing share of their total production activities in host locations. A majority of overseas R&D activities of MNEs are associated with adapting and modifying their existing technological assets in response to demand conditions ('home-base exploiting R&D', or HBE). On the other hand, evidence clearly suggests that this is intermediated by industry level effects[2] (e.g., Lall 1979, Patel 1996), and there is considerable inertia in the internationalisation of R&D. That is, firms have not internationalised their innovative activity proportionally to the growth in their overall production activities (Zanfei 2000, Patel and Pavitt 1999). This non-internationalisation is associated – *inter alia* – with the complex nature of systems of innovation, and the embeddedness of the MNEs activities in the home environment (see e.g., Narula 2002), and the need for internal cohesion within the MNE (Blanc and Sierra 1999, Zanfei 2000). Thus, the R&D intensity of MNEs overseas activities tends to be quite low.

Over the last decade there is evidence of a growing significance of overseas R&D activities by MNEs in order to augment their existing assets by specifically establishing R&D facilities ('home-base augmenting R&D', or HBA) to absorb and acquire technological spillovers, either from the local

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[1] In 1993 five large multinational companies, (Akzo Nobel, DSM, Philips, Shell and Unilever) perform slightly more than half of total Dutch business R&D (Netherlands observatory of science and technology. Science and Technology Indicators, 1996). In the United States five multinational companies (General Motors, Ford Motors, International Business Machines, Lucent Technologies and Hewlett–Packard) account for 20 per cent of the US R&D expenditure in the manufacturing sector (Science and Engineering indicators, 2000). Siemens, Bayer and Hoechst AG performed 18 per cent of the total manufacturing R&D expenditures in Germany in 1994 (Kumar, 1998). In 1997 three multinational companies (Shell, Glaxo Wellcome and Smithkline Beecham) accounted for more than the 30 per cent of the overall UK R&D investment in manufacturing (R&D Scoreboard DTI, 2000).

[2] For instance, Dalton and Serapio (1999) report that R&D of US MNEs performed abroad is concentrated in four sectors: pharmaceuticals, motor vehicles, electronic and electrical equipment, and industrial machinery (including computers).

knowledge base (public infrastructure or to benefit from agglomerative effects in a specific sector), or from specific firms (see e.g., Dunning and Narula 1995, Cantwell and Janne, 1999, Patel and Vega 1999, Kuemmerle 1996). The HBE vs. HBA classification is not a case of R&D facilities performing one or the other: any given facility *ceteris paribus* performs both HBE and HBA (Zander 1999), because technology leadership changes over time, and because products and processes require multiple technological competences.

This literature also points us in the direction that any given R&D facility's capacity to exploit and/or augment technological competences is a function not just of its own resources, but the efficiency with which it can utilise complementary resources associated with the relevant local innovation system. That is, there are formal and informal linkages between geographically co-located firms, and the opportunities for learning are associated with a myriad of economic actors. In other words, there is often an important local component, i.e., that spillovers are stronger within a small geographical unit (see, e.g., Jaffe *et al*., 1993, Jaffe and Trajtenberg, 1996, Sjöholm, 1996, Maurseth and Verspagen, 2001). This is one of the reasons that HBA activities require proximity to the economic units (and thus the innovation system) from which they seek to learn. In this paper we take a similar 'macro' view of HBE R&D. When firms engage in HBE activities overseas, they draw not just from the technological resources of the parent company, but directly and indirectly from the assets of innovation system of the entire home base region.

Much of the extant empirical work on HBE and HBE activities of MNEs has tended to concentrate on foreign-owned R&D in the US. A novelty of this paper is that we attempt to empirically test the extent of the HBE and HBA component of the R&D activities of both European MNEs in the US, and US MNEs in Europe, and their interaction with the two respective innovation systems. To this end we will carry out an analysis of the citation patterns of patents originating from foreign-based R&D facilities to both home country and host country patents.

To address this issue we conduct patent citation analysis using a database on patents applied by 117 European and US MNEs from 1976-1996, considering Europe and US as two regional blocks. Unlike most previous studies on internationalisation of R&D utilising patent citations, which have relied on USPTO data, this paper uses European Patent Office (EPO) data. The paper is organized as follows. In the next section we discuss the dynamics of asset-augmenting R&D activities and the conditions that determine the extent and nature of knowledge spillovers, and their acquisition. In section 3 we discuss the advantages and disadvantages of using patent statistics and we describe the procedure used to build the database. A descriptive look at the data is also provided. Finally in section 4 we present the methodology to test our research questions and the results of our analysis. Section 5 provides some conclusions.

2. ASSET-AUGMENTING R&D ACTIVITIES OF MNES AND INTERNALISING KNOWLEDGE SPILLOVERS

Studies on the internationalisation of R&D have linked the theories that underlay the location of international production to explain the location of the R&D activities of firms. R&D can be said to internationalise for broadly the same motives as traditional elements of the value added chain, although not at the same rate, nor to the same extent. Two primary types of R&D activity have been identified within this approach.

First, firms internationalise their R&D because of the need to improve the way in which existing assets are utilised. That is, firms may seek to promote the use of their technological assets in conjunction with, or in response to, specific locational conditions in a foreign locale. This has been dubbed as asset-exploiting R&D (Dunning and Narula 1995) or home-base exploiting (HBE) activity (Kuemmerle 1996). Locational conditions may require some level of modification to the product or processes in order to make them more appropriate to local conditions, or in some cases, to create peripheral products. In such activities, the technological advantages of the firm primarily reflect those of the home country.

Since a large percentage of the foreign-located R&D activities of firms tends to be production-supportive (i.e., HBE), the demand-side considerations are significant. Countries with a higher involvement in foreign production also demonstrate a higher proclivity towards foreign-located R&D. The level of foreign R&D in any given host location is however, also dependent on the kinds of value adding activity undertaken there. In general, the more embedded the foreign subsidiary, and the greater the intensity of the value-adding activity, the greater the amount of R&D activity. Such activities lead to a duplication of its home base activities, since the host location is acting as a substitute for activities it may have wished, *ceteris paribus*, to undertake at home (Zander 1999), but find that it can undertake these more efficiently elsewhere.

The second broad classification is that of strategic asset-seeking activity (Dunning and Narula 1995) or home-base augmenting (HBA) activity (Kuemmerle 1996). In such kinds of investments, firms aim to improve their existing assets, or to acquire (and internalise) or create completely new technological assets through foreign-located R&D facilities. The assumption in such cases is that the foreign location provides access to location-specific advantages that are not as easily available in the home base. In many cases the location advantages sought are associated with the presence of other firms. The investing firm may seek to acquire access to the technological assets of other firms, either through spillovers (in which case the firm seeks benefits that derive from economies of agglomeration), by direct acquisition (through M&A), through R&D alliances, or by arms-length acquisition.

There are several reasons why such HBA R&D activities would be hard to achieve from the home base. As suggested by Von Hippel (1994), when the knowledge relevant for innovative activities is located in a certain geographical area and it is very "sticky"[3], the R&D activity should take place at that site, according to the principle of cost minimization. Foreign affiliates engaged in HBA activities are attracted to these technological clusters in order to benefit from the external economies and knowledge spillovers generated by the concentration of production and innovation activities. Among the reasons for such sticky knowledge, the argument of the tacit nature of knowledge often stands out. The tacit nature of technology implies that even where knowledge is available through markets (technology markets generally tend to be under-developed or non-existent), it still needs to be modified to be efficiently integrated within the acquiring firm's portfolio of technologies. In addition, the tacit nature of knowledge associated with production and innovation activity in these sectors implies that "physical" or geographical proximity is important for transmitting it (Blanc and Sierra, 1999). While the marginal cost of transmitting codified knowledge across geographic space does not depend on distance, the marginal cost of transmitting tacit knowledge increases with distance. This leads to the clustering of innovation activities, in particular at the early stage of an industry life cycle where tacit knowledge plays an important role (Audretsch and Feldman, 1996).

Thus, summarising, HBE activities are primarily associated with demand-based activities, with the internalisation of technological spillovers as a secondary issue. HBA activities, on the other hand, while often reported as a much smaller phenomenon in terms of international R&D expenditure (Patel and Vega 1999, Gerybadze and Reger 1999, Niosi 1999), are primarily undertaken with the intention to acquire and internalise technological spillovers that are host location-specific. HBE activity, broadly speaking, represents an extension of R&D work undertaken at home, while HBA activity represents a diversification into new scientific problems, issues or areas.

Examining HBE and HBA from a 'macro' perspective: why firms may engage in HBA and HBE simultaneously

While the theoretical exposition on HBA and HBE has taken a broad and macro perspective on the their nature, empirical work has taken two distinct approaches. The first approach has focused on the nature of HBE as an intra-firm process. That is, the foreign-located R&D seeks to adapt and use technologies associated with the parent company. These studies have generally been based on surveys (Florida 1997, Kuemmerle 1999, and Serapio and Dalton 1999) or more recently using patent citations analysis (Almeida 1996, and Frost 1998, 2001). This 'narrow' view of HBE can be contrasted with a 'macro-view' which has measured HBE as being *implicitly* associated with the technological resources of the *entire* home location (se e.g., Dunning and Narula 1995).

This distinction is very important, especially where the primary objective is to seek to determine the economy-wide effects of internationalisation of R&D, rather than to determine the MNE-specific

[3] Von Hippel (1994) defines stickiness as the incremental expenditure required to transfer that unit of knowledge.

efficiencies (as the ‘narrow’ approach has largely done). At the macro-level, the discussion on HBE vs. HBA activities bears important similarities to the debate on the local nature of technological spillovers in the economics literature (e.g., Jaffe *et al*., 1993, Jaffe and Trajtenberg, 1996, 1998, Jaffe *et al*., 1998, Maurseth and Verspagen, 2001). The issue here is whether or not knowledge spillovers between firms, or from (semi-) public knowledge institutes to firms, depend on geographical distance. The above quoted studies find that both in the U.S. and Europe, such a relationship indeed exists. Thus, knowledge spillovers tend to be more intense between parties that are located close to each other in space. Various explanations have been offered for this finding, such as the tacit nature of knowledge (as discussed above), but also the existence of spillovers due to a common pool of resources in a region (e.g., skilled labour, educational institute or specific scientific equipment).

The ‘narrow’ and ‘macro’ views of HBA R&D activities are similar and consistent in acknowledging the significance of localized knowledge. If knowledge spillovers are indeed localized, one may expect that local knowledge bases tend to differ with regard to focus and quality. The only efficient way for a firm to tap into a local knowledge base would then be to be physically present in such a local environment, which is indeed what we have defined as HBA activities. This similarity suggests that we may use the techniques that are proposed in the literature for tracing localized spillovers, in order to search for interactions between the local knowledge base and foreign-owned R&D activity, and hence identify HBA vs. HBE R&D activities (cf. Almeida, 1996 and Frost, 2001). This is what we will attempt to do in the empirical section of this paper.

However, the two views are different in examining HBE activities. An MNEs knowledge base is not simply a function of its own activities in the home location, but of its home location’s innovation system. There are complex interdependencies between economic actors in any given location, and because the MNE parent is often highly embedded in its home location, these linkages determine its knowledge base and the efficiency with which it can leverage its technological assets. Economic actors include both non-firm organisations as well as suppliers, who are often inextricably linked to the MNE and its innovatory activity. Thus, in this paper, we take the view that when a firm engages in HBE R&D activities abroad, it seeks to exploit not just its own technological assets, but those associated with its home country innovatory milieu.

Likewise, on a more macro-level, when firms engage in R&D in a foreign location to avail themselves of complementary assets that are location specific (and include those that are firm-specific or institution-specific, which the laboratory in question seeks to use through collaboration), they are essentially aiming to explicitly internalise several aspects of the systems of innovation of the host location. However, developing and maintaining strong linkages with external networks of local counterparts is expensive and time consuming, and is tempered by a high level of integration with the innovation system in the home location. Such linkages are both formal and informal, and will probably have taken years – if not decades – to create and sustain. Frequently, the most significant issues are the ‘know-who’. Government funding institutions, suppliers, university professors, private research teams, informal networks of like-minded researchers take considerable effort to create, and once developed, have a low marginal cost of maintaining. Even where the host location is potentially superior to the home location – and where previous experience exists in terms of other value adding activities – the high costs of becoming familiar with, and integrating into a new location may be prohibitive. Keep in mind that firms are constrained by resource limitations, and that some minimum threshold size of R&D activities exists in every distinct location. As such, to maintain more than one facility with a threshold level of researchers must mean that the new (host) location must offer significantly superior spillover opportunities, or provide access to complementary resources that are simply not available anywhere else, and which cannot be acquired by less risky means more efficiently.

However, the high costs associated with integrating into the host location's systems of innovation – in contrast to the low marginal cost of maintaining its embeddedness in its home location's innovation system – creates an 'inertia' whereby firms are reluctant to expand internationally (Narula 2002). These costs must be tempered by supply-side considerations, the development of these technologies benefits from diversity and heterogeneity in the knowledge base, which might come from competitors, from interaction with customers and from other complementary technologies. A single national innovation system is often unable to offer the full range of interrelated technological assets required for this diversification strategy (Narula, 2002). The point we are trying to raise is that the complex centripetal and centrifugal forces underlay the kinds of R&D activities a firm undertakes, and where these are located. It is rare that firms undertake either HBA or HBE overseas in exclusion of the other (Zander 1999).

It is axiomatic that HBA activities will be located where opportunities for internalising spillovers are highest, and this implies seeking proximity to 'technology leaders', and given that firms tend to concentrate their more strategic R&D activities in their home location, this high level of competence is often reflected in the associated system of innovation. Thus, HBA activities have been hypothesized to be associated with locations that exhibit a technological or comparative advantage, relative to other locations, and particularly relative to the home location of the MNE seeking these assets (Dunning and Narula 1995, Patel and Vega 1999, Le Bas and Sierra, 2002). It is worth noting that technology leaders are not always synonymous with industry leaders. It is important to realise that firms – particularly in technology intensive sectors – increasingly need to have multiple technological competences (see e.g., Granstand 1998, Granstand, Patel and Pavitt, 1997). Even where products are mono-technology-based, the processes used to manufacture them often utilise several technologies.

However, taking a macro, innovation systems approach requires us to remember that because products are multi-technology based, one firm may be marginally ahead in one technology, and its competitor in another, but on a macro-level, both may have equally 'powerful' innovation systems. Furthermore, even within any given technology (and in particularly for technology intensive sectors), technology leadership changes rather rapidly. This is another reason that firms may engage in both HBA and HBE activities simultaneously.

Some important caveats should be noted. Establishing R&D activities abroad for the purposes of internalising spillovers does not necessarily mean that firms will be successful in doing so. There are a wide variety of factors that determine the MNEs efficiency in internalising spillovers. There are complex – and sometimes contrary – forces that influence their ability to do so both at the micro and macro levels. First, there are firm- and technology-specific forces. In particular, the need to seek diversity of knowledge, technologies and capabilities to remain internationally competitive, and demand issues such as information and proximity to markets.

Another micro-level determinant is associated with the difficulties of managing cross-border R&D activities. It is not sufficient for the foreign affiliate to internalise spillovers if it cannot make these available to the rest of the MNE – there needs to be internal proximity between overseas R&D and the rest of the MNE (Blanc and Sierra, 1999). A dispersion of R&D activities across the globe requires extensive coordination between them – and particularly with headquarters – if they are to function in an efficient manner with regards to the collection and dissemination of information. This acts as a centripetal force on R&D, and accounts for a tendency of firms to locate R&D (or at least the most strategically significant elements) closer to headquarters.

Such growing complex linkages, both of networks internal to the firm, and those between external networks and internal networks, require complex coordination if they are to provide optimal benefits (see Zanfei 2000 for a discussion). Such networks are not only difficult to manage, but also require considerable resources (both managerial and financial). It is no surprise, therefore, that external technology development is primarily the domain of larger firms with greater resources, and more experience in trans-national activity (Hagedoorn and Schakenraad 1994).

Large firms tend to engage in both HBA and HBE activities, because any given subsidiary has a need for a variety of technologies, and any given host location may possess a relative technological advantage in one area, but be relatively disadvantaged in another. Lastly, MNEs tend to also engage in production activities (whether in the same or another physical facility) in the host location, and this prompts a certain level of HBE activity. Thus, an MNE in a given location, (1) may not only be seeking to internalise spillovers from non-related firms, but may also be engaging in intra-firm knowledge transfers within the same multinational group, and (2) may engage in both HBE and HBA activity simultaneously.

This brings us to the following research question: To what extent do foreign affiliates in technology-intensive sectors display HBA R&D activities relative to HBE activities, i.e., to what extent do they draw upon local sources of knowledge rather than home country knowledge?

Following Almeida (1996) and Frost (2001), we address this issue using patent citation analysis. This paper follows their example by examining patent citation data from both European foreign affiliates operating in the US and US foreign affiliates active in Europe. Our data set allows us to analyse the technological sourcing behaviour of foreign affiliates operating in two geographical regions with different technological advantages and characteristics.

In addition, from a more methodological point of view, the current citation analysis study differs from the previous ones on the source of the patent data. While Almeida and Frost used US patent data, we will use data on patents filed with the European Patent Office (EPO). Using EPO data has the advantage of not having a home country bias (OST, 1998), which instead cannot be ruled out using USPTO data. As pointed out by Patel and Vega (1999) "using US patent data for US companies and for US subsidiaries of non-US companies means that there will an over-estimation of the role of domestic R&D for the former and foreign R&D for the latter" (p. 148).

The empirical analysis below will use a database on patenting activities of European and US MNEs active in high-tech sectors. Before explaining the methodology adopted to address this research question we illustrate the characteristics of our dataset and the trends that emerge in terms of patent and patent citations activities of these firms.

3. THE DATASET

Unlike patent counts, patent citations are relatively new as indicators of technology. This does not mean, however, that patents are undisputed as indicators of innovation. Griliches (1990) provides a survey of the main advantages and disadvantages of using patent statistics. Patent statistics are an output indicator of innovation rather than an input indicator (such as R&D expenditures). Their main advantage is that patent statistics circumvent the issue of R&D productivity ('the number of innovations per unit of R&D'). Also, at the level of individual multinational firms, patent statistics are available for a longer time period than R&D statistics. The main disadvantages is that simple patent counts do not take into account differences in the quality of innovations, that many patents do not lead to innovations, and that the propensities to patent an innovation may differ between sectors.

Patent documents contain a detailed description of the patented innovation. In addition to the name and address of the innovator and the applicant, patent documents also contain references to previous patents, i.e. patent citations. The legal purpose of the patent references is to indicate which parts of the described knowledge are claimed in the patent, and which parts other patents have claimed earlier. From an economic point of view, however, the assumption is that a reference to a previous patent indicates that the knowledge in the latter patent was in some way useful for developing the new knowledge described in the citing patent. This is the line of reasoning offered in Jaffe *et al*. (1993), and Jaffe and Trajtenberg (1996 and 1998) for US patents (i.e. innovations patented in US). The detailed case study by Jaffe *et al*. (1998) on a limited sample of patents concludes that patent citations are a "valid but noisy measure of technology spillovers".

We will use citations between European patents as a measure of knowledge flows. Data on patents and patent citations in Europe are obtained from the European Patent Office (Bulletin cd and REFI tapes). In addition to the differences between the EPO and USPTO system that were already discussed above, there is one additional major difference between the two patent offices. This concerns the requirements to the applicant with regard to describing the state-of-the-art of knowledge in the field by means of a list of references (citations). In the USPTO system the applicant, when filing a patent application, is requested to supply a complete list of references to patents and non-patent documents. In the EPO system, the applicant may optionally supply such a list. In other words, while in the US this is a legal requirement and non-compliance by the patent applicant can lead to subsequent revocation of the patent, in Europe it is not obligatory. As a result applicants to the USPTO "rather than running the risk of filing an incomplete list of references, tend to quote each and every reference even if it is only remotely related to what is to be patented. Since most US examiners apparently do not bother to limit the applicants' initial citations to those references which are really relevant in respect of patentability, this initial list tends to appear in unmodified form on the front page of most US patents." (Michel and Bettels, 2001, p. 192). This tendency is confirmed by the number of citations that on average appear on USPTO patents. Michel and Bettels report that US patents cite about three times as many patent references and three and a half times as many non-patent references compared to European patents. One may thus conclude that although patent citations appearing in USPTO patents are mostly added by the applicant, they are a rather noisy signal of the presence of technological knowledge flows. Citations on EPO patents, on the other hand, might suffer from the problem that they are mostly added by the examiner, and thus only an indirect indication of knowledge actually used by the inventor.

Still, it is obvious that a citation link in the European case can be seen as an indicator of technological relevance. Moreover, citations in the European system may indicate potential spillovers. Although this potential may not have been realised in all cases, it is reasonable to assume that since patents are public knowledge, professional R&D laboratories would have a reasonable knowledge about existing patents in their field. This is why we argue that European patent citations are a useful indicator of knowledge spillovers.

It should be emphasised that knowledge spillovers are a much broader concept than what is captured by patent citations (U.S. or European). In terms of the distinction by Griliches introduced above, patent citations focus on a specific form of pure knowledge spillovers. Rent spillovers are completely left out. Even within the category of pure knowledge spillovers, patent citations (to the extent that they are related to spillovers) are only a part of the complete story. For example, in order for patent citations to take place, both the spillover-receiving and spillover-generating firm must be actively engaged in R&D and apply for (European) patents.

In addition, patents are an ultimate example of codified knowledge, because they require an exact description of technological findings according to legally defined methods. Thus, one can have little hope of identifying tacit knowledge flows by means of the paper trails that patent citations leave. One may assume, however, that the codified knowledge flows of patent citations go hand-in-hand with more tacit aspects of knowledge flows. However, this argument remains speculative, and one must therefore realize that our analysis will only refer to a very specific and limited form of knowledge generation activities and knowledge flows, and our data have important imperfections. The approach has, however, the advantage that we can make use of a very detailed and precise database.

Our primary data source is the EPO database on patent applications. We select all patent applications, whether they are granted, have been rejected (or withdrawn), or are still under review. The EPO database we use contains data until the end of 1999, including approximately 1.2 million patent applications. Unfortunately, for the purpose of identifying within-firm patent applications, we cannot rely upon the information that EPO supplies in the "applicant name" field. In that field, one may find personal names or names of firms or organizations. In the case of firms, however, it may be the name of an independent firm, the name of a larger conglomerate or holding firm, or the name of a subsidiary of such a larger firm. The EPO database contains approximately 180,000 unique names in the "applicants" field.

Our sample of firms is limited to large multinational firms that appeared on the Fortune 500 list in 1997, supplemented by a few large firms from the Fortune lists in earlier years. Table 1 gives a summary of the number of firms in the sample and the industries they operate in.

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

We regroup the sectors into five groups: chemicals, petroleum refining, pharmaceuticals, electronics (telecommunications, semiconductor, computers, and electronics), and engineering (motor vehicles and parts, and industrial farm and equipment). Aerospace, metals, telecommunications and scientific, photo and control equipment will not be considered because they have too few observations (citations and/or patents) to be of use in the statistical analysis. We have included only patents applied for by the multinational enterprises in our analysis, and excluded citation pairs if one of the patents did not belong to a firm in our sample. Hence, all patents applied for by other firms remain completely outside the scope of our analysis.

For these firms, we use information on linkages that was compiled by Wilfred Schoenmakers (see Verspagen and Schoenmakers, 2000). The primary source for this information on linkages was the Dun & Bradstreet Linkages database, which was used to construct a list of the subsidiaries for each of the firms in the analysis. The Dun & Bradstreet Linkages database includes only full, i.e., one hundred percent, subsidiaries. We refer to this list as the "group". The version of the Dun & Bradstreet Linkages database that was used is from late 1998, and thus represents the mother-daughter relationships at that point in time. Of course these connections have not always been like they were in 1998. Thus, when we use the mother-daughter ties of 1998 to construct patent data for groups during the period 1983-1999, the resulting data do not reflect group patent data at the time of the patent applications involved, but rather at a fixed point in time (1998).

Obviously, this is a sub-optimal procedure. An obviously better procedure would be to use yearly data from the Dun & Bradstreet Linkages database, and to construct for every year under investigation a group's database as was done for 1998. Unfortunately, this involves too much work to be feasible in terms of the resources available for this paper. However, we feel that the procedure used is acceptable for the present purposes because most multinational companies apply for the bulk of their patents under the multinational company name. In this area the changes are less pressing, i.e., mergers occur more often on a lower level.

A further practical problem results from the fact that there is not a one-to-one correspondence between the subsidiary names in the Dun & Bradstreet Linkages database and the names in the "applicant" field of the EPO database. Wilfred Schoenmakers made a pre-selection from the EPO database by searching for different parts of the names found in the Linkages data. The results from this pre-selection were then compared, usually on a one-to-one basis, to the group list from Linkages.

Some names that were found in the pre-selection from the EPO database could not be identified using the D&B database. In many of these cases, the name found in the EPO database was partly identical to the name of the (subsidiary) firm being looked for. This may, for example, happen if the applicant name is the name of a plant, rather than the legal entity it belongs to. In order to be able to learn more about these firms, a table was constructed with the applicant names and addresses from the EPO database. In this way not only the applicant's name but also the address could be compared to the data found in Linkages. If the applicant was not found in the D&B database, but the applicant's name was almost identical and the address was identical to other daughter firms of the same multinational, then the name was included in the group list.

A final note refers to the case when companies merge, and the original company name under which they applied for a patent might be lost. This could mean that one would not find these patents, although they belong to the multinational firm under investigation. Therefore different parts of the company name were also looked for, thereby eliminating as much as possible this bias.

Figures 1 and 2 show respectively the sectoral trends in the number of patents applied for by European affiliates in the US, and American affiliates operating in Europe. Two things are worth noting. First, across most sectors and for both European and American affiliates there has been a generally upward trend, in line with the increasing internationalisation of R&D – though the underlying pattern is volatile. Second, American affiliates of European MNEs in the chemical and the petroleum refining industry are a noticeable exception: though the number of patents applied for by these subsidiaries in 1997 was a multiple of the 1980 figure, applications have nonetheless fallen steadily over the 1990s.

***** INSERT FIG. 1 and FIG. 2 HERE *******

4. STATISTICAL TESTING

In order to investigate our main research question, we apply a number of statistical tests on the patent citation data. We identified the location of the invention by looking at the inventor's address. Only addresses in the European Union (EU) or the United States (US) are taken into account in the analysis, and, when referring to the empirical data, we use the term 'foreign' to mean 'in the other region'. The region of ownership (i.e., EU or US) is identified by the location of the headquarters of the multinational group (data as in Table 1 above). Then we know for each patent from which region the owner-company stems, and in which region the invention took place.[4] We assume that patents invented abroad reflect the R&D activities of foreign affiliates.

In what follows we will use EU or US to indicate the location and ownership of patent citations. The cited patent is listed first, the citing patent second, as in CITED_CITING. Within either CITED or CITING, the first two digits indicate ownership, the last two location of the inventor. For example, citations made by patents owned by European firms invented in the US to patents owned by US firms invented in the US are indicated as USUS_EUUS.

Comparing citations between such groups of patents is quite complex because we have to take into consideration three factors that may disturb a 'fair' comparison. First, we have to control for the number of potentially citing patents. For example, if more patents are applied for by US firms located in Europe than by European firms located in the US, we may expect the raw number of citations by US owned patents in Europe to be large, even if the number of citations per patent of this type is relatively low. As we have shown previously, the number of European and US multinationals in each sector is quite different, and hence expect that controlling for the patenting activity carried out in each location is important.

Second, we need to correct for different factors that affect changes in citation intensities over time. The most obvious is the truncation effect or 'cohort effect', which implies that older patents receive more citations than younger patents because of their longer citation history. Finally, there is a potential bias connected to the increasing trend in patent applications to the EPO. This yields higher citation rates for younger patents, simply because most of the citations occur within a relatively short period after the application date of the patent.

To correct for the first potential bias we divided the citations count by the number of potentially citing patents and the number of potentially cited patents. To remove the bias introduced by the other two factors, we follow Hall *et al*. (2001) and divide by the average number of citations received by patents applied in the same year. The citation rate between the cited firms (*Pi*) and the citing firm (*Qj*) operating in sector *n* at time *t* is calculated applying the following formula:

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[4] In case of multiple inventors, we use a fractional counting method, i.e., if there are *p* inventors in the EU and *q* inventors in the US, the EU is attributed $p/(p+q)$ of the patent, and the US $q/(p+q)$.

$$(Pi\_Qj)_{tn} = \frac{\frac{(Pi\_Qj)_{tn}}{(Qj)_{T-t} * (Pi)_{tn}}}{\frac{(Mk\_Mk)_t}{(Mk)_t}},$$

where *Mk* is the sum of patents applied by all firms in the sample in both regions ($Mk = Pi + Pj + Qi + Qj$), *Qj* denotes the potentially citing patents, which is equal to the number of patents applied between time *t* (starting in 1977) and the last period of observation in our sample (*T* = 1996), and *Pi* stands for the potentially cited patents. In the denominator of our formula we use the average citation rate of patents applied in year *t* by all firms in our sample operating in all sectors. With this procedure we remove from the citation count the variability arising from the yearly fixed effect.

According to the theory outlined above, HBA foreign-based R&D is mainly aimed at exploiting the knowledge base of the host region. Therefore, one would expect a knowledge flow from business units in the host location to the foreign subsidiaries located there. Hence citations by foreign affiliates to firms in the host region would be more intensive than citations to firms in the home region. Conversely, in HBE R&D activity, the knowledge generated in the home region is implemented locally in the host region, and this would be reflected in more intense citations to patents from the home region. Note that this interpretation implies adhering to the 'macro view' on HBE activities, as explained in Section 2. The 'micro view' of HBE activities would imply that foreign-based R&D sites have a bias towards citing patents originating from their parent-company only, and not from other firms in the home-base region (see, for example, Almeida, 1996, and Frost, 1998 and 2001). Our 'macro' view of HBE activities, which takes into account the notion of innovation systems, looks instead at the total knowledge base of the home-base region, and this is why we do not distinguish citations by foreign affiliates to the parent company or other home country firms in our analysis of HBE R&D activities.

Following our notation, HBA activities of European affiliates in the US are indicated by a high rate of USUS_EUUS citations, while a high rate of EUEU_EUUS citations (including intra-firm citations) indicate HBE activities of European affiliates. For the US counterpart, HBA activities are represented by a high rate of EUEU_USEU citations, while the presence of HBE activities is detected by high USUS_USEU citations (including intra-firm citations). Table 2 reports some descriptive data on the citation rates.

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

The aim of this study is to assess the extent of HBA and HBE activities of European and American subsidiaries located in the two regions and operating in different high-tech sectors. In order to do this, we carry out a series of *t*-tests for two independent samples aimed at testing whether or not the various citation rates differ. Although we do not report details, we tested for normality of the series of citation rates and, whenever necessary, we corrected for non-normality using an adequate functional transformation.

Our first test analyses the citation behaviour of American (European) subsidiaries in Europe (the US) in order to establish in which sectors the HBA effect predominates the HBE one. We describe the statistical procedure for the case of European subsidiaries in the US. The null hypothesis is that European owned R&D facilities in the US carry out an identical amount of HBA and HBE activities, i.e., that there is no bias towards citing patents originating from Europe firms (EUEU_EUUS) or towards citing patent originating from US firms (USUS_EUUS). The *t*-test therefore measures whether or not these two citation rates differ significantly. In particular, we perform a two-tailed *t*-test where the null hypothesis of equal mean between the two populations of EUEU_EUUS citations and USUS_EUUS citations is tested against two alternative hypotheses:

H^1_a: mean (EUEU_EUUS) – mean (USUS_EUUS) > 0 $\Rightarrow H^1_a$: diff > 0

H^2_a: mean (EUEU_EUUS) – mean (USUS_EUUS) < 0 $\Rightarrow H^2_a$: diff < 0

The results of this test and the *t*-statistics for European MNEs in the US are presented in Table 3, where we report in brackets the *p*-values for each (i.e., one-sided) alternative. We cannot reject the null hypothesis in chemicals, electronics, and petroleum refining. European affiliates in these sectors seem to be embedded in the host country technological base to the same extent as they are in their home region, or, in other words, we do not find a strong tendency for R&D activities in these cases to be either HBE or HBA. In pharmaceuticals, European affiliates show a statistically significant bias towards citing the home country knowledge base, which is indicative of a strong HBE component. HBA activities seem to dominate in European R&D investments in the US in engineering.

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

We carry out similar tests for the citation behaviour of US subsidiaries' patents. These results are reported in Table 4. We find that for the engineering, pharmaceuticals, and electronics sectors we cannot reject the null hypothesis, i.e., on average US R&D facilities located in Europe draw upon home country sources to the same extent as host country sources. Conversely, US R&D investment in Europe in chemicals and petroleum refining industries seems to have a strong HBE-component.

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

Summarising, we can say that our evidence indicates that HBE activities remain important both for European and US MNEs. HBE is the dominating mode of foreign R&D investment in three out of ten cases in Tables 3 and 4. However, the evidence also indicates that HBA activities are now an important aspect of foreign-based R&D in the US and Europe. In six of the ten cases, HBA and HBE are in balance, i.e., we find a minority of cases where citation rates to home country and intra-firm patents higher than the citation rates to host country patents. However, there is only one case where HBA is the dominating mode. The relatively strong importance of HBA activities is in line with previous studies. For example, Le Bas and Sierra found that in 22 technological fields out of 30 the HBA strategy is the dominant one, and that US MNEs firms mostly pursue this type of R&D internationalisation strategy. For Europe as a whole, Le Bas and Sierra found that in general the HBA effect was very significant, especially for MNEs based in small countries.

Our second set of statistical analysis compares the citation behaviour of US and European MNEs patents to each other for each type of R&D activity. This tests for the extent two which firms from the two locations differ with respect to the importance of foreign vs. domestic sources of knowledge, i.e., whether US or European firms are more 'HBA- or HBE-intensive'. We apply the same two samples *t*-test for equality of means. First we compare the HBE component of European R&D investment in the US with their US counterpart. We test the null hypothesis that European and US subsidiaries operating in the two regions exhibit the same propensity to cited home country firms (where the home country differs per group of firm, of course), against the two alternatives:

H^1_a: mean (EUEU_EUUS) - mean (USUS_USEU) > 0 $\Rightarrow H^1_a$: diff > 0

H^2_a: mean (EUEU_EUUS) - mean (USUS_USEU) < 0 $\Rightarrow H^2_a$: diff < 0

The results are documented in Table 5. We can reject the null hypothesis for three of the five sectors, the exceptions being engineering and pharmaceuticals. For these sectors we find that US affiliates are building on the host region knowledge base as much as European affiliates. Contrary to this, US R&D activities in the other three sectors, i.e., chemicals, electronics and petroleum refining, rely more heavily on their home knowledge competences than their European counterpart. This may be interpreted as a greater tendency towards HBE activities in the case of US firms.

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

Table 6 reports the *t*-tests results obtained when we compare the HBA nature of R&D activities undertaken in the US by European MNEs with their US counterparts. The null hypothesis in this case is that both groups of affiliates show an equal tendency to cite host country patents. We observe that chemicals, electronics and petroleum refining R&D facilities of US MNEs operating in Europe tend to draw upon host country technological resources more than their European counterparts. In the engineering sector we can conclude the opposite, i.e. European subsidiaries in the US seem to exploit and build on the host country knowledge base to a larger extent than US subsidiaries in the EU. We conclude by saying that these findings indicate that HBA activities are not only a characteristic of European R&D investments in the US, but they are also an important component of the US R&D activities in Europe.

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

5. SUMMARY AND CONCLUSIONS

Technological change and the growing significance of MNEs are often cited as the primary driving forces of globalisation, and in this paper we have attempted to evaluate – albeit tentatively – the changing different modes of cross-border knowledge flows as a result of activities by MNEs. The internationalisation of R&D has been driven by a myriad of factors, the most prevalent of which are the need to respond to different demand and market conditions across locations, and the need for the MNE to respond effectively to these by adapting their existing product and process technologies through foreign-located ‘home-base exploiting’ (HBE) R&D. This paper has tested a ‘macro’ approach, arguing that when MNEs engage in HBE R&D abroad, one reason for this might be to seek to utilise the resources associated with the innovation systems of the home country, not just the parent company’s MNE-specific technological competences.

Supply factors have become an increasingly important motivation to engage in such ‘home-base augmenting’ (HBA) R&D abroad. This is due, *inter alia*, to the growing tendency for multi-technology products, and the fact that patterns of technological specialisation are distinct across countries, despite the economic and technological convergence associated with economic globalisation (Archibugi and Pianta 1992, Narula 1996). Other studies have shown that these patterns of technological specialisation are fairly stable over long periods (see Cantwell 1989, Zander 1995) and change only very gradually.

In general, national innovation systems and industrial and technological specialisation of countries change only very gradually, and – especially in newer, rapidly evolving sectors – much more slowly than the technological needs of firms. As a result, there is a growing mismatch between what home locations can provide and what firms require. Firms must seek either to import and acquire the technology they need from abroad, or venture abroad and seek to internalise aspects of other countries’ innovation systems. There is a third option – that of firms seeking to modify the home-country innovation system – which is expensive, and difficult to sustain in the long run (Narula 2002).

Thus, in addition to proximity to markets and production units, firms also venture abroad to seek new sources of knowledge, which are associated with the innovation system of the host region. In this case, the R&D strategy is a more active one of trying to tap into foreign knowledge bases. We have further argued that few firms engage exclusively in HBA or HBE in a foreign location because technology leadership changes over time, and because products and processes require multiple technological competences. Our approach in this paper has been to use EPO patent citation data in order to quantify the relative HBA vs. HBE character of foreign-based R&D activity. The general idea is that citations indicate knowledge flows (from the cited party to the citing party), hence the geographical location of cited and citing inventor gives an indication of where knowledge is sourced from.

While most studies have tended to concentrate on foreign owned R&D in the US, we have also examined the case of US-owned R&D activities in Europe. As we show in this paper, knowledge flows are not clearly one-way. Innovatory activities of both US and European firms utilise both sets of knowledge bases. We applied several statistical tests aimed at detecting a bias to one or another location in the citation patterns of EU and US owned MNEs. Our tests investigated whether EU (US) owned patents invented in the US (EU) tend to cite patents originating in the host region equally, or more or less heavily than patents from the domestic region. Our results indicated that both European and US affiliates still rely extensively on home region knowledge sources, although the HBA component of R&D investments from Europe (US) into the US (Europe) is many cases as strong as the HBE component. We also investigated whether European affiliates in the US have a higher propensity to utilise HBE than their US counterparts in Europe. Apart from the engineering and pharmaceutical sectors, US R&D investments in Europe appear to exploit home country knowledge sources more than their European counterparts. We also examined the relative propensity for US MNEs and European to utilise HBA activities. In the chemicals, electronics and petroleum refining sectors, R&D facilities of US MNEs operating in Europe tend to draw upon host country technological resources more than their European counterparts. In the engineering sector we concluded that European subsidiaries in the US seem to exploit and build on the host country knowledge base to a larger extent than US subsidiaries in Europe.

In deriving policy implications based on our empirical analysis, several important caveats need to be stressed. First, while our results indicate that MNEs do engage in HBA R&D activity, our sample of firms only includes many of the world's largest MNEs. These firms are amongst the world's most successful firms, and they have considerable experience - as well as resources – to efficiently exploit cross-border knowledge flows. Nonetheless, innovation systems consist of a variety of economic actors not all of which are MNEs. We have not taken into account R&D activity by other firms than MNEs in our sample in defining the knowledge base of a (host or domestic) region. In certain sectors such as biotechnology where smaller firms predominate innovatory activities, this may significantly affect the results. Second, we have utilised a high level of industrial aggregation, and within that, we focused on knowledge-intensive, mostly high technology sectors. Obviously, supply and demand imperatives vary considerably by sector and sub-sector. More mature technologies evolve much more slowly than nascent ones, and some tend to be less tacit than others. In other words, the importance of physical proximity to technology transfer varies quite considerably between technologies and products. Third, we have seen considerable – and statistically significant – differences between the behaviour of US and EU firms. Data on internationalisation of R&D indicate considerable heterogeneity between countries of the EU (Archibugi and Iammarino 2000). For instance, Belgian and Dutch firms demonstrate a much higher level of R&D internationalisation than Italian or Norwegian MNEs. This reflects the fact that the various systems of innovation – and thus industrial and technological specialisations – remain individual and distinct. The extent to which firms are embedded and interdependent on the external (but national) actors that comprise the national innovation systems determines the industrial specialisation of firms, their competitiveness and the extent to which they are embedded at home or abroad. A more holistic approach is needed, examining both exogenous (factor-endowments based aspects) and endogenous (government institutions and regulatory aspects) issues. While the nature of comparative advantages act as an exogenous factor, *a priori* creating bounds on what is possible, the industrial structure in 'reluctant' internationalising economies also tends to exhibit the effects of inward-looking economic policy orientation and a certain level of techno-nationalism, and acts (in certain instances) to constrict – or accelerate – outward activity.

Our analysis here –however tentative – negates the simplistic view that HBA activity is largely a phenomenon associated with European firms' activities in the US. US firms in Europe also engage in HBA activities to at least the same extent as their European counterparts in the US, albeit in different sectors. The internationalisation of R&D by firms does not necessarily represent a sign of declining national technological competitiveness. No country can possibly expect to provide world-class competences in all technological fields. Even the largest, most technologically advanced countries cannot provide strong innovation systems to all their industries, and world-class competences in all technological fields. The cross-border flow of ideas is something that has always been seen as fundamental to firms, and this imperative has increased with growing cross-border competition, and international production.

Some countries have regarded imported technologies as a sign of national weakness, and have sought to maintain and develop in-country competences, often regardless of the cost. The strategy of technological self-sufficiency is increasingly untenable in a globalising world. Relying on in-country competences may lead to a sub-optimal strategy, especially in this age of multi-technology products.

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Figure 1. Number of EPO patents applied for by European MNEs' affiliates in the US (3-year moving average, 1997=100)

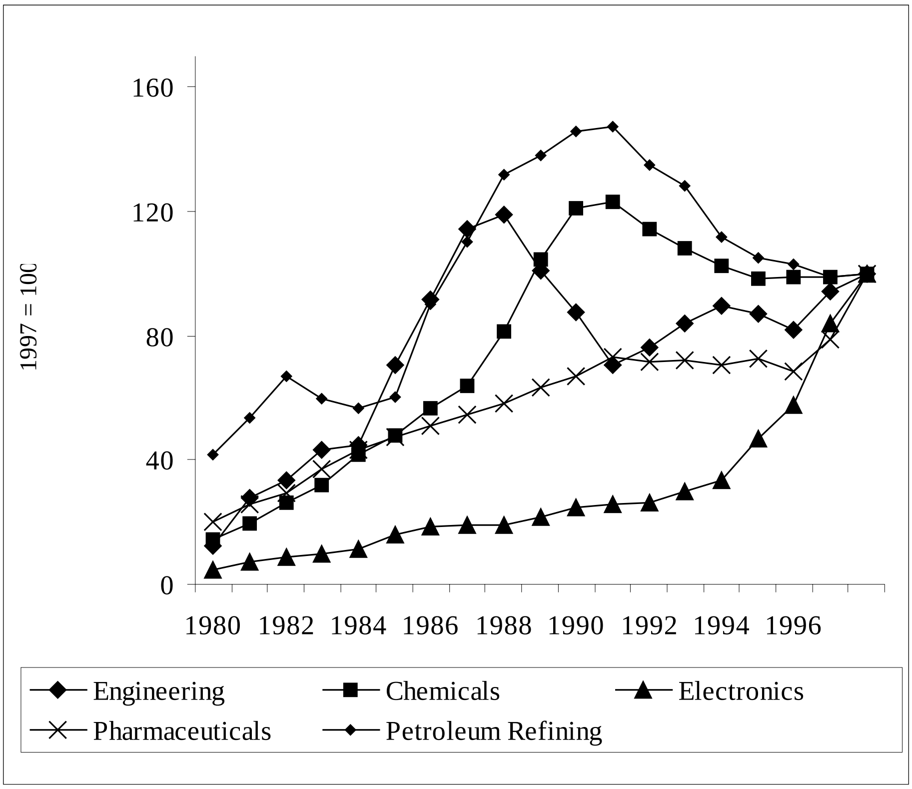

Figure 2. Number of EPO patents applied for by US MNEs' affiliates in Europe (3-year moving average, 1997=100)

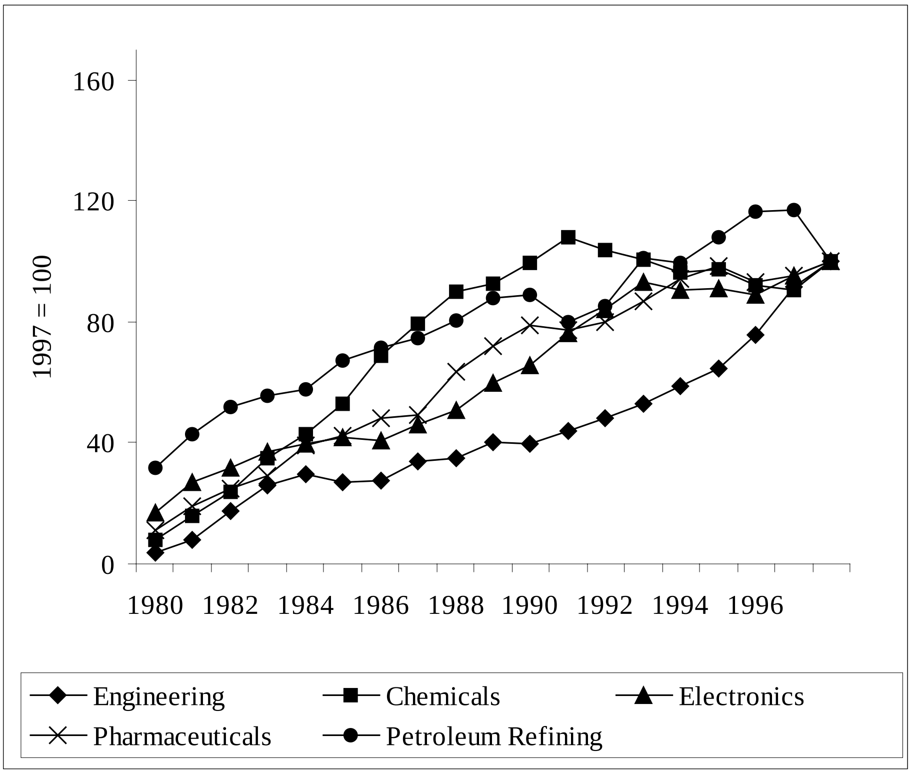

Table 1. Sectoral distribution of MNEs in the database

Sectors	EU MNEs	US MNEs
Aerospace	2	6
Chemicals	10	4
Computers and Office equip.	0	5
Electronics, Electrical equip.	7	6
Electronics, Semiconductors	0	2
Industrial and farm equip.	4	2
Metals	5	1
Motor Vehicles and Parts	9	5
Petroleum Refining	8	11
Pharmaceuticals	4	6
Scientific, Photo, Control equip.	0	2
Telecommunications	9	9

Table 2. Descriptive statistics

Sector	Citation rate	Obs	Mean	Std. Dev.	Min.	Max.
Engineering	EUEU_USEU	20	0.019	0.029	0.003	0.102
	USUS_EUUS	20	0.162	0.157	0.000	0.570
	EUEU_EUUS	20	0.067	0.043	0.000	0.163
	USUS_USEU	20	0.014	0.013	0.000	0.051
Chemicals	EUEU_USEU	20	0.105	0.076	0.037	0.345
	USUS_EUUS	20	0.021	0.015	0.005	0.058
	EUEU_EUUS	20	0.011	0.005	0.003	0.022
	USUS_USEU	20	0.089	0.077	0.000	0.373
Electronics	EUEU_USEU	20	0.021	0.033	0.000	0.155
	USUS_EUUS	20	0.022	0.009	0.013	0.048
	EUEU_EUUS	20	0.012	0.006	0.005	0.027
	USUS_USEU	20	0.013	0.010	0.002	0.044
Pharmaceuticals	EUEU_USEU	20	0.412	0.801	0.042	2.956
	USUS_EUUS	20	0.048	0.035	0.013	0.134
	EUEU_EUUS	20	0.033	0.035	0.005	0.130
	USUS_USEU	20	0.084	0.043	0.028	0.211
Petroleum Refining	EUEU_USEU	20	0.812	2.155	0.036	9.744
	USUS_EUUS	20	0.098	0.089	0.012	0.329
	EUEU_EUUS	20	0.061	0.089	0.000	0.357
	USUS_USEU	20	0.195	0.242	0.036	1.075

Table 3. HBE vs HBA by EUMNEs, two sided t-test

Ho: mean (EUEU_EUUS) = mean (USUS_EUUS)		
Sector*	Ha: diff < 0	Ha: diff > 0
Engineering	t statistics = -2.223	
	[0.016]	[0.983]
Chemicals	t statistics = -0.017	
	[0.493]	[0.506]
Electronics	t statistics = -0.649	
	[0.260]	[0.739]
Pharmaceuticals	t statistics = 1.652	
	[0.946]	[0.053]
Petroleum Refining	t statistics = 0.639	
	[0.736]	[0.263]

p values in brackets

* For industry classification see section 3.

Table 4. HBE vs HBA by USMNEs, two sided t-test

Ho: mean (USUS_USEU) = mean (EUEU_USEU)		
Sector*	Ha: diff < 0	Ha: diff > 0
Engineering	t statistics = 0.019	
	[0.507]	[0.492]
Chemicals	t statistics = 1.312	
	[0.901]	[0.098]
Electronics	t statistics = 0.510	
	[0.693]	[0.306]
Pharmaceuticals	t statistics = 1.165	
	[0.874]	[0.125]
Petroleum Refining	t statistics = 1.465	
	[0.924]	[0.0756]

p values in brackets

* For industry classification see section 3.

Table 5. HBE EUMNEs vs HBE USMNEs, two sided t-test

Ho: mean (EUEU_EUUS) = mean (USUS_USEU)		
Sector*	Ha: diff < 0	Ha: diff > 0
Engineering	t statistics = -0.885	
	[0.190]	[0.8091]
Chemicals	t statistics = -6.427	
	[0.000]	[1.000]
Electronics	t statistics = -3.2721	
	[0.012]	[0.998]
Pharmaceuticals	t statistics = -0.658	
	[0.257]	[0.742]
Petroleum Refining	t statistics = -4.038	
	[0.001]	[0.999]

p values in brackets

* For industry classification see section 3.

Table 6. HBA EUMNEs vs HBA USMNEs, two sided t-test

Ho: mean (USUS_EUUS) = mean (EUEU_USEU)		
Sector	Ha: diff < 0	Ha: diff > 0
Engineering	t statistics = 1.397	
	[0.914]	[0.085]
Chemicals	t statistics = -3.873	
	[0.002]	[0.999]
Electronics	t statistics = -1.538	
	[0.066]	[0.933]
Pharmaceuticals	t statistics = -0.905	
	[0.185]	[0.814]
Petroleum Refining	t statistics = -1.770	
	[0.041]	[0.958]

p values in brackets

* For industry classification see section 3.