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ROLE OF HOME AND HOST COUNTRY INNOVATION SYSTEMS IN R&D INTERNATIONALISATION: A PATENT CITATION ANALYSIS

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This paper 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 asset-augmenting activities require proximity to the economic units (and thus the innovation system) from which they seek to learn, asset-exploiting activities draw from the parent's technological resources as well as from the other assets of the home location's innovation system. Furthermore, we argue that most firms tend to undertake both asset exploiting and augmenting activities simultaneously. Second, we use patent citation data from the European Patent Office to quantify the relative asset augmenting vs. exploiting 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.

Keywords: Internationalisation; R&D; Innovation systems; Multinational enterprises; Patent citation analysis; Knowledge flows; Spillovers; Asset-augmentation

JEL Classifications: F23; O32; O33

1 INTRODUCTION

Large Multinational Enterprises (MNEs) play a dominant role in the innovation systems of their home countries and control or own a large part of the world's stock of advanced technologies. These same MNEs undertake a growing share of their total production activities in host locations. A large part of overseas R&D activities of MNEs are associated with adapting and modifying their existing technological assets in response to demand conditions ('asset-exploiting R&D'). On the other hand, evidence clearly suggests that this is intermediated by industry level effects (e.g., Lall, 1979; Patel, 1996; Serapio and Dalton, 1999), and there is considerable inertia in the internationalisation of R&D. That is, firms have not internationalised

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their innovative activity proportionally to the growth in their overall production activities (Patel and Pavitt, 1999; Zanfei, 2000).

However, over the last decade, there has been 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 ('asset-augmenting R&D') to absorb and acquire technological spillovers, either from the local knowledge base or from specific firms (see, e.g., Dunning and Narula, 1995; Kuemmerle, 1996; Cantwell and Janne, 1999; Patel and Vega, 1999). The asset-exploiting *vs.* asset-augmenting classification is not a case of R&D facilities performing one or the other: any given facility usually performs both asset-exploiting and asset-augmenting (Zander, 1999), because technology leadership changes over time, and products and processes may require multiple technological competences.

This literature also points out that any given R&D facility's capacity to exploit and/or augment technological competences is a function not only of its own resources, but also of its efficiency with which it can utilise complementary resources associated with the relevant local innovation system. That is, there is often an important local component, i.e., that spillovers are stronger within a small geographical unit (see, Jaffe *et al.*, 1993; Jaffe and Trajtenberg, 1996; Sjöholm, 1996; Maurseth and Verspagen, 2002). This is one of the reasons that asset-augmenting activities require proximity to the economic units (and thus the innovation system) from which they seek to learn. This article takes a similar 'macro' view of asset-exploiting R&D. When firms engage in asset-exploiting activities overseas, they draw not only from the technological resources of the parent company, but also directly and indirectly from the assets of innovation system of the entire home base region.

Much of the extant empirical work on asset-exploiting and asset-augmenting activities of MNEs has tended to concentrate on foreign-owned R&D in the USA. A novelty of this article is that we attempt to empirically test the extent of the asset-exploiting and asset-augmenting component of the R&D activities of both European MNEs in the USA, and US MNEs in Europe, and their interaction with the two respective innovation systems. To this end, we 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. We use European Patent Office (EPO) patent application data of 118 European and US MNEs from 1977 to 1999, considering Europe and USA as two regional blocks.

The article is organised as follows. In Section 2, 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 describe the procedure used to build the database. 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-EXPLOITING AND ASSET-AUGMENTING R&D ACTIVITIES OF MNEs: A 'MACRO' PERSPECTIVE

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, neither at the same rate, nor to the same extent. Two primary types of R&D activity have been identified within this approach, namely, asset-exploiting activity and asset-augmenting activity.¹

¹ This dichotomy represents two extremes, and is an oversimplification of reality. There are a variety of intermediate types, as shown by Le Bas and Sierra (2002).

Asset-exploiting R&D occurs when firms 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 also been referred to as home-base exploiting (HBE) activity² (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.

As a large percentage of the foreign-located R&D activities of firms tends to be production-supportive (i.e., asset-exploiting), such demand-side considerations are significant. Countries with a higher involvement in foreign production also demonstrate a higher proclivity towards foreign-located R&D. However, the level of foreign R&D in any given host location is 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.

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 asset-augmenting 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 minimisation. Among the reasons for such sticky knowledge, the argument of the tacit nature of knowledge often stands out. 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). Although 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).

Although the theoretical exposition on asset-augmenting and asset-exploiting has taken a broad and macro perspective on their nature, empirical work has taken two distinct approaches. The first approach has focused on the nature of asset-exploiting R&D 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; Serapio and Dalton, 1999) or more recently using patent citation analysis (Almeida, 1996; Frost, 1998, 2001). This 'narrow' view of asset-exploiting R&D can be contrasted with a 'macro' view which has measured asset-exploiting as being *implicitly*

² Although the HBE–HBA terminology dominates in the literature, we feel that this classification scheme is less accurate, and holds to a very traditional view of the MNE as centred in a dominant home base. In fact, by emphasising the role of home bases, the HBE–HBA jargon cannot be easily made consistent with the possibility that firms are evolving towards network structures, hence reducing the importance of a single home and, by the same token, expanding the number of countries wherein the firm ends up being based. This article, therefore, will use the more accurate asset-exploiting and asset-augmenting terminology instead (see Narula and Zanfei, 2004).

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

associated with the technological resources of the *entire* home location (see 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 efficiencies (as the 'narrow' approach has largely done). At the macro level, the discussion on asset-exploiting *vs.* asset-augmenting activities bears important similarities to the debate on the local nature of technological spillovers in the economics literature (e.g., Jaffe *et al.*, 1993, 1998; Jaffe and Trajtenberg, 1996; Maurseth and Verspagen, 2002). Here the issue is whether or not knowledge spillovers between firms, or from (semi-) public knowledge institutes to firms, depend on geographical distance. The earlier-mentioned studies find that both in the USA and in 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 earlier), and 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 asset-augmenting R&D activities are similar and consistent in acknowledging the significance of localised knowledge. If knowledge spillovers are indeed localised, one may expect that local knowledge bases tend to differ with regard to focus and quality. Then, the only efficient way for a firm to tap into a local knowledge base would be to be physically present in such a local environment, which is indeed what we have defined as asset-augmenting activities. This similarity suggests that we may use the techniques that are proposed in the literature for tracing localised spillovers, in order to search for interactions between the local knowledge base and foreign-owned R&D activity, and hence identify asset-augmenting *vs.* asset-exploiting R&D activities (cf. Almeida, 1996; Frost, 2001). This is what we will attempt to do in the empirical section of this article.

However, the two views are different in examining asset-exploiting activities. A MNE's 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 and suppliers, who are often inextricably linked to the MNE and its innovatory activity. Thus, in this article, we take the view that when a firm engages in asset-exploiting R&D activities abroad, it seeks to exploit not only its own technological assets, but also 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, 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 are expensive and time consuming, and are tempered by a high level of integration with the innovation system in the home location. 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 (see Zanfei, 2000 for a discussion).

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 inter-related technological assets required for this diversification strategy (Narula, 2002). The point we are trying to raise is that complex centripetal and centrifugal forces underlay the kinds of R&D activities, which a firm undertakes, and where these are located. It is rare that firms undertake either asset-augmenting or asset-exploiting R&D overseas in exclusion of the other (Zander, 1999).

It is axiomatic that asset-augmenting 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, asset-augmenting activities have been hypothesised 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 Granstrand *et al.*, 1997; Granstrand, 1998). 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 multitechnology-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 asset-augmenting and asset-exploiting activities simultaneously.

Large firms tend to engage in both asset-augmenting and asset-exploiting 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. Finally, 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 asset-exploiting R&D. Thus, an MNE in a given location may (1) not only be seeking to internalise spillovers from non-related firms, but also be engaging in intra-firm knowledge transfers within the same multinational group and (2) engage in both asset-exploiting and asset-augmenting activities simultaneously.

This brings us to the following research question: To what extent do foreign affiliates in technology-intensive sectors display asset-augmenting R&D activities relative to asset-exploiting 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 and data on 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 methodological point of view, the current citation analysis study differs from the previous ones on the source of the patent data. Although Almeida and Frost used US patent data, we will use data on patents filed with the 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 US subsidiaries of non-US companies means that there will be an over-estimation of the role of domestic R&D for the former and foreign R&D for the latter' (p. 148).

The characteristics of the dataset and the trends that emerge in terms of patent and patent citations activities of these firms are discussed in Section 3.

3 THE DATASET

Unlike patent counts, patent citations are relatively new as indicators of technology. Although the use of patent data as a technology indicator has a long tradition, they are not, however, undisputed. 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, at the level of individual multinational firms, patent statistics are available for a longer time period than R&D statistics. The main disadvantages are simple patent counts do not take into account differences in the quality of innovations, many patents do not lead to innovations and the propensities to patent an innovation may differ between sectors and firms.

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. However, from an economic point of view, 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, 1998) for USPTO patents. 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 EPO (Bulletin CD and REFI tapes). There is one major difference between the EP and USPTO regarding the description of the state-of-the-art 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, although 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. As 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 with European patents. On the other hand, citations on EPO patents 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 as 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 flows.

It should be emphasised that knowledge flows are a much broader concept than is captured by patent citations (US or European). In terms of the distinction introduced by Griliches (1992), patent citations focus on a specific form of pure knowledge spillovers. Rent spillovers, which reflect the fact that intermediate input prices do not embody completely the product innovations or the quality improvements resulting from R&D activities, 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 firms 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. However, one may assume that the codified knowledge flows of patent citations go hand-in-hand with more tacit aspects of knowledge flows. According to the 'knowledge conversion' model by Nonaka and Takeuchi (1995), there is a strong interaction between codified and tacit knowledge during the creation of new technological assets. Tacit knowledge can therefore be converted into some forms of codified knowledge that can be incorporated in patent documents. Indeed, this ability to codify and 'articulate' knowledge represents one source of firms' sustainable competitive advantage (Hedlund, 1994; Teece and Pisano, 1994). According to Kogut and Zander (1993, p. 637), '... firms invest in ways to reduce the tacitness of technology by encoding its use and replications in rules and documentation'.

Our primary data source is the EPO database on patent applications. We select all patent applications, whether they have been granted, rejected (or withdrawn), or are still under review. 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. For these firms, we use information on linkages originally compiled by Wilfred Schoenmakers on the basis of the Dun and Bradstreet Linkages database, version 1998 (see Verspagen and Schoenmakers, 2004). Table I gives a summary of the number of firms in the sample and the industries they operate in according to their principal product group.

We regroup the sectors into five: chemicals, electronics (semiconductors, computers and electronics), industrial machinery and transportation (motor vehicles and parts, and industrial

TABLE I Sectoral distribution of MNEs in the database and in the sample analysed.

<i>Sector</i>	<i>EU MNEs</i>	<i>US MNEs</i>
Included in the analysis		
Chemicals	10	4
Electronics		
Computers and office equipments	0	5
Electronics and electrical equipments	7	6
Electronics and semiconductors,	0	2
Industrial Machinery and transportation		
Industrial and farm equipments	4	2
Motor vehicles and parts	9	5
Petroleum refining	8	12
Pharmaceuticals	4	6
Total in the sample	42	42
Excluded from the analysis		
Aerospace	2	6
Metals	5	1
Scientific, photo and control equipments	0	2
Telecommunications	9	9
Overall	58	60

TABLE II EPO applications by affiliates during 1985–1987 and 1995–1997.

<i>Sectors</i>	<i>EU MNEs' affiliates in the US</i>				<i>US MNEs' affiliates in the EU</i>			
	<i>1985–1987</i>	<i>As percentage of all EU MNEs patents</i>	<i>1995–1997</i>	<i>As percentage of all EU MNEs' patents</i>	<i>1985–1987</i>	<i>As percentage of all US MNEs' patents</i>	<i>1995–1997</i>	<i>As percentage of all US MNEs' patents</i>
Chemicals	691.3	9.2	848.3	11.6	199.1	11.8	221.3	13.9
Electronics	254.6	4.3	1323.3	12.3	490.3	11.1	966.5	14.0
Industrial machinery and transportation	169.8	5.3	142.9	2.3	246.4	25.7	702.9	35.4
Petroleum refining	331.0	20.9	250.9	17.5	96.0	8.4	119.1	14.6
Pharmaceuticals	507.9	25.7	873.4	49.4	248.5	17.2	389.5	16.5

farm and equipment), petroleum refining and pharmaceuticals (see Appendix A for a list of companies used in our statistical analysis). Aerospace, metals, telecommunications, and scientific, photo and control equipments will not be considered because they have too few observations (citations and/or patents) to be of use in the statistical analysis.

We did consider the possibility of running our analysis classifying patents according to their technological field using, for example, the classification provided in OST (1998) and used in the study by Le Bas and Sierra (2002). However, the size of our sample does not permit us to use a technological classification fine enough – Le Bas and Sierra have 30 separate fields – to provide us with insights into the technological dimension of the firms' internationalisation strategies. Rather than to use an arbitrarily coarse two-digit classification (see, for example, that proposed by OST, 1998, p. 474), we decided instead to compare industries rather than technologies. However, we acknowledge that the knowledge base of large firms is much more diversified than their product range and, therefore, the results presented in this article are only indicative of a more complex phenomenon.

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.

Table II shows the number of patents applied for by EU (US) affiliates in the US (EU) in two sub-periods 1985–1987 and 1995–1997 and their share of the total number of EPO applications made by EU MNEs (US MNEs). The data suggest two important trends worth noting. First, across most sectors and for both European and American affiliates, there has been a generally upward trend in the number of patents, as well as the percentage of patent applications made by our sample of firms attributable to research in the foreign location. The largest increase has been for EU MNEs in pharmaceuticals: almost 50% of all EU MNEs patents can be attributed to their US subsidiaries. Secondly, there is a substantial difference in the number of American affiliates' patents and European affiliates' patents, which will have to be taken into account in the patent citation analysis.

Table III shows the number of citations made by patents applied for by these subsidiaries between 1995 and 1997 to home country and host country patents and their shares over the total number of citations made to patents in our dataset. In all sectors, apart from petroleum refining, EU MNEs subsidiaries appear to draw more heavily on home country's knowledge sources. This is also the case for US MNEs, although in chemicals and in industrial machinery and transportation, the proportion of citations to host country patents is significantly higher than the one to home country patents. Although illustrative, we cannot infer much from these figures because, as we explain in Section 4, we need to control for a number of other variables.

TABLE III Geographical origin of patents cited by affiliates during 1995–1997.

Sectors	<i>Citations made to</i>							
	<i>EU MNE's affiliates in the US</i>				<i>US MNE's affiliates in the EU</i>			
	<i>Home country patents*</i>	<i>Percentage of total</i>	<i>Host country patents†</i>	<i>Percentage of total</i>	<i>Home country patents*</i>	<i>Percentage of total</i>	<i>Host country patents†</i>	<i>Percentage of total</i>
Chemicals	41.9	30.5	8.3	6.1	7.9	23.3	14.6	42.8
Electronics	55.3	38.1	25.3	17.5	61.6	39.7	37.3	24.0
Industrial machinery and transportation	7.2	50.7	4.0	28.2	6.3	13.8	17.5	38.7
Petroleum refining	5.0	13.1	5.4	14.2	3.9	28.3	1.8	12.8
Pharmaceuticals	52.1	20.4	22.9	9.0	10.8	8.6	6.9	5.6

*Patents owned by EU MNEs invented in the EU.

†Patents owned by US MNEs invented in the US.

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, including Switzerland, (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 I). 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.

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.

Secondly, 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 citation counts 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 rates in year t between the cited firms (i) and the citing firms (j) operating in sector n are calculated by using the following formula:

$$CR_{i-j,t,n} = \frac{(NC_{i-j,t,n}/NP_{j,T-t}NP_{i,t,n}) \times 1000}{NC_{TOT-TOT,t}/NP_{TOT,t}} \quad (1)$$

where $NC_{i-j,t,n}$ represents the total number of citations received by the patents of the firm group i , applied in year t , where firm group i operates in sector n , by the patents of the firm group j ; $NP_{i,t,n}$ denotes the number of potentially cited patents, which is equal to the patents of the firm group i , applied in year t ; $NP_{j,T-t}$ is the number of potentially citing patents, which is equal to the number of patents of firm group j between time t and last period of observation ($T = 1999$); $NC_{TOT-TOT,t}$ represents the number of citations made by the total number of patents in the sample to patents applied at time t and $NP_{TOT,t}$ is the total number of patents of all firms in the sample in year t .

The denominator in Eq. (1) divides the number of citations received by all the patents in the sample applied in year t over the number of patents applied in the same year. Thus, it represents the average citation rate of patents applied in year t by all firms in our sample operating in all sectors under analysis. With this procedure, we remove from the citation count the variability arising from the yearly fixed effect. The numerator in Eq. (1) measures the actual citation rate

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, $q/(p+q)$.

between two company groups, for example, European subsidiaries in the US (*i*) and US MNEs (*j*), taking into account the patenting behaviour of the two firm groups.

According to the theory outlined earlier, asset-augmenting 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 asset-exploiting R&D activity, the knowledge generated in the home region is implemented in the host region, and this would be reflected in more intense citations to patents from the home region. Note that this interpretation adheres to the ‘macro’ definition of asset-exploiting activities, as explained in Section 2. The ‘micro’ view of asset-exploiting 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, e.g., Almeida, 1996; Frost, 1998, 2001). Our ‘macro’ view of asset-exploiting 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 asset-exploiting R&D activities.

Asset-augmenting activities of European (American) affiliates in the US (EU) are indicated by a high rate of citations made by EU (US) subsidiaries’ patents to US (EU) owned patents invented in the US (EU), while a high rate of citations made by these firms to EU (US) owned patents invented in the EU (US) (including intra-firm citations) indicate asset-exploiting activities. Table IV reports some descriptive data on the citation rates.

The aim of this study is to assess the extent of asset-augmenting and asset-exploiting 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 Mann–Whitney tests for two

TABLE IV Descriptive statistics.

<i>Sector</i>	<i>MNE</i>	<i>R&D activity</i>	<i>Observed</i>	<i>Median</i>	<i>Std. dev.</i>	<i>Minimum</i>	<i>Maximum</i>
Chemicals	US	Augmenting	23	0.0028	0.0009	0	0.0032
		Exploiting	23	0.0045	0.0016	0	0.0065
	EU	Augmenting	23	0.0049	0.0017	0	0.0056
		Exploiting	23	0.0052	0.0011	0	0.0047
Electronics	US	Augmenting	23	0.0023	0.0008	0	0.0033
		Exploiting	23	0.0053	0.0013	0	0.0052
	EU	Augmenting	23	0.0028	0.0008	0	0.0030
		Exploiting	23	0.0018	0.0011	0	0.0041
Industrial machinery and transportation	US	Augmenting	23	0.0025	0.0008	0	0.0032
		Exploiting	23	0.0048	0.0027	0	0.0101
	EU	Augmenting	23	0.0013	0.0011	0	0.0027
		Exploiting	23	0.0007	0.0007	0	0.0033
Petroleum refining	US	Augmenting	23	0.0023	0.0028	0	0.0118
		Exploiting	23	0.0062	0.0028	0	0.0096
	EU	Augmenting	23	0.0033	0.0015	0	0.0056
		Exploiting	23	0.0048	0.0023	0	0.0081
Pharmaceuticals	US	Augmenting	23	0.0034	0.0030	0	0.0126
		Exploiting	23	0.0081	0.0032	0	0.0130
	EU	Augmenting	23	0.0085	0.0026	0	0.0102
		Exploiting	23	0.0106	0.0059	0	0.0234

TABLE V Testing the relative propensity to engage in asset-exploiting and asset-augmenting activities by EU MNEs.

<i>Sector</i>	<i>U</i>	<i>Two-tail p-value,</i> <i>Prob(diff = 0)</i>	<i>Right one-tail p-value,</i> <i>Prob(diff > 0)</i>	<i>Inference</i>
Ho: Asset-exploiting = Asset-augmenting				
Chemicals	0.013	0.990	0.501	Exploiting = Augmenting
Electronics	-1.019	0.308	0.408	Exploiting = Augmenting
Industrial machinery and transportation	-1.422	0.154	0.372	Exploiting = Augmenting
Petroleum refining	0.943	0.345	0.585	Exploiting = Augmenting
Pharmaceuticals	2.805	0.005	0.753	Exploiting > Augmenting

independent samples aimed at testing whether or not the various citation rates differ using data from the overall period 1977 to 1999.⁵

Our first set of tests analyses the citation behaviour of American (European) subsidiaries in Europe (the US) in order to establish in which sectors the asset-augmenting effect predominates the asset-exploiting 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 asset-augmenting and asset-exploiting activities, i.e., there is no bias towards citing patents originating from European firms or towards citing patent originating from the US firms. The Mann–Whitney test measures whether or not these two citation rates differ significantly. In particular, we perform a two-tailed Mann–Whitney to test the null hypothesis of equal medians between the two populations of citations made by EU subsidiaries patents to EU owned patents invented in the EU and citations made by EU subsidiaries patents to US owned patents invented in the US (Table V). Table V also reports the results of a right one-tailed test to see whether the difference between the two populations' medians is positive. This indicates whether the asset-exploiting component of European owned R&D activities in the US dominates the asset-augmenting component.

We cannot reject the null hypothesis in all sectors except pharmaceuticals. The 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 asset-exploiting or asset-augmenting. In pharmaceuticals, the European affiliates show a statistically significant bias towards citing the home country knowledge base, which is indicative of a strong asset-exploiting component.

We carry out similar tests for the citation behaviour of US subsidiaries' patents. These results are reported in Table VI. We find that in all sectors we could reject the null hypothesis, i.e., on average US R&D facilities located in Europe draw upon home country sources more than on host country sources.

Summarising, we can say that our evidence indicates that asset-exploiting activities remain important especially for foreign R&D investment of US MNEs in Europe. However, the evidence also indicates that asset-augmenting activities are now an important aspect of foreign-based R&D in both the US and Europe. In four of the 10 cases, asset-augmenting and asset-exploiting were in balance. That is to say, there are a number of cases where citation rates to home country and intra-firm patents were equal to the citation rates to host country patents. However, the asset-augmenting component did not dominate in any of the sectors under analysis. The significance of asset-augmenting activities is in line with previous studies. For example, Le Bas and Sierra found that in 22 technological fields out of 30, the asset-augmenting

⁵ We use the Mann–Whitney test instead of the parametric *t*-test because the sample distribution of citation rates is not normally distributed.

TABLE VI Testing the relative propensity to engage in asset-exploiting and asset-augmenting activities by US MNEs.

<i>Sector</i>	<i>U</i>	<i>Two-tail p-value,</i> <i>Prob(diff = 0)</i>	<i>Right one-tail p-value,</i> <i>Prob(diff > 0)</i>	<i>Inference</i>
Ho: Asset-exploiting = Asset-augmenting				
Chemicals	4.113	0.000	0.871	Exploiting > Augmenting
Electronics	5.497	0.000	0.995	Exploiting > Augmenting
Industrial machinery and transportation	3.044	0.002	0.774	Exploiting > Augmenting
Petroleum refining	2.679	0.007	0.741	Exploiting > Augmenting
Pharmaceuticals	2.830	0.004	0.775	Exploiting > Augmenting

strategy was the dominant one. For Europe as a whole, Le Bas and Sierra found that, in general, the asset-augmenting effect was very significant, especially for MNEs from small countries.

Our second set of statistics tests the extent to 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 'asset-augmenting or asset-exploiting intensive'. We apply the same two-sample Mann–Whitney test for equality of medians. First, we compare the asset-exploiting component of European R&D investment in the US with their US counterpart. We test both the hypothesis that European and US subsidiaries operating in the two regions exhibit the same propensity to cite home country firms (where the home country differs per group of firm, of course) and the hypothesis that the asset-exploiting component of European R&D investment in the US is stronger than the American counterpart.

The results are documented in Table VII. We find that for chemicals and petroleum refining, we cannot reject the null hypothesis, i.e., for these sectors, we find that US affiliates are building on the host region knowledge base as much as European affiliates. In contrast, US R&D activities in industrial machinery and transportation and in electronics rely more heavily on their home knowledge competences than their European counterpart. This may be interpreted as a greater tendency towards asset-exploiting activities in the case of US firms. The opposite is true for pharmaceuticals, where we find that the European R&D facilities in the US are building on home-country technological sources.

Table VIII reports the test results obtained when we compare the asset-augmenting nature of R&D activities undertaken in the US by European MNEs with their US counterpart. The null hypothesis in this case is that both groups of affiliates show an equal tendency to cite host country patents. We observe that chemical and pharmaceutical R&D facilities of European MNEs operating in the US tend to draw upon host country technological resources more than their American counterpart. In all the other sectors, we could not reject the null hypothesis, i.e., European subsidiaries in the US seem to exploit and build on the host country knowledge base as much as US subsidiaries in the EU.

TABLE VII Testing the relative extent of asset-exploitation activities by EU MNEs and US MNEs.

<i>Sector</i>	<i>U</i>	<i>Two-tail p-value,</i> <i>Prob(diff = 0)</i>	<i>Right one-tail p-value,</i> <i>Prob(diff > 0)</i>	<i>Inference on</i> <i>asset-exploiting</i> <i>activities</i>
Ho: EU MNEs asset-exploiting = US MNEs asset-exploiting				
Chemicals	-0.264	0.791	0.476	EU MNEs = US MNEs
Electronics	-5.17	0.000	0.034	EU MNEs < US MNEs
Industrial machinery and transportation	-4.453	0.000	0.099	EU MNEs < US MNEs
Petroleum refining	-0.792	0.428	0.429	EU MNEs = US MNEs
Pharmaceuticals	2.478	0.013	0.723	EU MNEs > US MNEs

TABLE VIII Testing the relative extent of asset-augmenting activities by EU MNEs and US MNEs.

<i>Sector</i>	<i>U</i>	<i>Two-tail p-value,</i> <i>Prob(diff = 0)</i>	<i>Right one-tail p-value,</i> <i>Prob(diff > 0)</i>	<i>Inference on</i> <i>asset-augmenting</i> <i>activities</i>
Ho: EU MNEs asset-augmenting = US MNEs asset-augmenting				
Chemicals	3.082	0.002	0.778	EU MNEs > US MNEs
Electronics	0.440	0.659	0.540	EU MNEs = US MNEs
Industrial machinery and transportation	-1.120	0.262	0.399	EU MNEs = US MNEs
Petroleum refining	1.522	0.128	0.637	EU MNEs = US MNEs
Pharmaceuticals	3.031	0.002	0.773	EU MNEs > US MNEs

5 SUMMARY AND CONCLUSIONS

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 asset-exploiting R&D. This article has tested a 'macro' approach, arguing that when MNEs engage in asset-exploiting R&D abroad, they often seek to utilise a variety of resources associated with the innovation systems of the home country, not just the parent company's MNE-specific technological competences.

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. We have further argued that few firms engage exclusively in asset-augmenting or asset-exploiting in a foreign location because technology leadership changes over time, and products and processes require multiple technological competences. Our approach in this article has been to use EPO patent citation data in order to quantify the relative asset-augmenting *vs.* asset-exploiting character of foreign-based R&D activity.

Although 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. Here, our analysis, however tentative, negates the simplistic view that asset-augmenting activity is largely a phenomenon associated with European firms' activities in the US. The US firms in Europe also engage in asset-augmenting activities to at least the same extent as their European counterparts in the US, *albeit* in different sectors. Knowledge flows are clearly bi-directional. Innovative activities of both US and European firms abroad 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. The results indicated that both European and US affiliates still rely extensively on home region knowledge sources, although the asset-augmenting component of R&D investments from Europe into the US is in many cases as strong as the asset-exploiting component. We also investigated whether European affiliates in the US have a higher propensity to both exploit and augment their assets than their US counterparts in Europe. We also examined the relative propensity for US MNEs and European to utilise asset-exploiting and asset-augmenting activities.

In deriving policy implications based on our empirical analysis, several important caveats need to be stressed. First, although our results indicate that MNEs do engage in asset-augmenting R&D activity, our sample of firms only includes many of the world's largest MNEs. These firms are among 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 firms other than the 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. Secondly, we have only considered citations among EPO patents, a subset of all patent documents cited in EPO patents. Thirdly, 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. Our analysis has been undertaken at the sectoral-level, *albeit* aggregating from firm-level data, thereby subsuming important differences within individual MNE's technological portfolios. We attempted to analyse trends in asset-exploiting *vs.* asset-augmenting by technological fields, but our limited sample size precluded our ability to use a sufficiently disaggregated technological breakdown to make a useful differentiation, as, for instance, used by Granstrand *et al.* (1997). This is an important area for future research.

Next, we have seen considerable, and statistically significant, differences between the behaviour of US and EU firms. However, the EU consists of a variety of disparate countries, each with its own innovation system. 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 might then suggest that our comparison of the EU and the US is a spurious one, because through the aggregation of 15 countries, we create such a broad generalisation so as not to be able to draw useful policy implications. However, we are confident that this is not the case, for several reasons. First, because comparisons between the US and most individual European economies are difficult to make, given the small size of many of the EU countries. By taking the EU as a unit, we are able to compare two roughly equal economic units. Secondly, there is an increasing coordination of industrial policy between EU countries, as well as EU-wide initiatives coordinated by Brussels.

Finally, we have not taken into account the differences in the embeddedness of individual MNE subsidiaries, which is itself a function of a myriad of factors, or the fact that any given innovation system is a function of both the domestic and foreign-owned firms within its borders. Policies to promote innovation and learning in a given location, which necessarily include the attraction of the R&D facilities of MNEs, require a more intimate understanding of how these activities are associated with a milieu of economic actors jointly determining knowledge creation.

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References

- Almeida, P. (1996) Knowledge Sourcing by Foreign Multinationals: Patent Citation Analysis in the U.S. Semiconductor Industry. *Strategic Management Journal*, 17(Winter Special Issue), 155–165.
- Archibugi, D. and Iammarino, S. (2000) Innovation and Globalisation: Evidence and Implications. In Chesnais, F., Ietto-Gillies, G. and Simonetti, R. (Eds) *European Integration and Global Corporate Strategies*. London: Routledge.
- Audretsch, D. and Feldman, M. (1996) R&D Spillovers and the Geography of Innovation and Production. *American Economic Review*, 86, 253–273.

- Blanc, H. and Sierra, C. (1999) The Internationalisation of R&D by Multinationals: A Trade-off Between External and Internal Proximity. *Cambridge Journal of Economics*, **23**, 187–206.
- Cantwell, J. and Janne, O. (1999) Technological Globalisation and Innovative Centres: The Role of Corporate Technological Leadership and Locational Hierarchy. *Research Policy*, **28**, 119–144.
- Dunning, J.H. and Narula, R. (1995) The R&D Activities of Foreign Firms in the United States. *International Studies of Management & Organization*, **25**, 39–73.
- Florida, R. (1997) The Globalisation of R&D: Results of a Survey of Foreign-Affiliated R&D Laboratories in the USA. *Research Policy*, **26**, 85–103.
- Frost, T.S. (1998) The Geographic Sources of Innovation in the Multinational Enterprise: U.S. Subsidiaries and Host Country Spillovers, 1980–1990. Ph.D. Thesis, Massachusetts Institute of Technology (unpublished).
- Frost, T.S. (2001). The Geographic Sources of Foreign Subsidiaries' Innovation. *Strategic Management Journal*, **22**, 101–123.
- Granstrand, O. (1998) Towards a Theory of the Technology Based Firm. *Research Policy*, **27**, 465–490.
- Granstrand, O., Patel, P. and Pavitt, K. (1997) Multi-technology Corporations: Why They have 'Distributed' Rather Than 'Distinctive Core' Competencies. *California Management Review*, **39**, 8–25.
- Griliches, Z. (1990) Patent Statistics as Economic Indicators: A Survey. *Journal of Economic Literature*, **28**, 1661–1707.
- Griliches, Z. (1992) The Search for R&D Spillovers. *Scandinavian Journal of Economics*, **94**(suppl.), S29–S47.
- Hall, B., Jaffe, A. and Trajtenberg, M. (2001) The NBER Patent Citations Data File: Lessons, Insights and Methodological Tools. NBER Working Paper 8498.
- Hedlund, G. (1994) A Model of Knowledge Management and the N-Form Corporation. *Strategic Management Journal*, **15**, 73–90.
- Jaffe, A.B. and Trajtenberg, M. (1996) Flows of Knowledge from Universities and Federal Labs: Modelling the Flow of Patent Citations over Time and Across Institutional and Geographical Boundaries. NBER Working Paper, No. 5712, Cambridge Massachusetts.
- Jaffe, A.B. and Trajtenberg, M. (1998) International Knowledge Flows: Evidence from Patent Citations. NBER Working Paper 6507, Cambridge Massachusetts.
- Jaffe, A.B., Trajtenberg, M. and Henderson, R. (1993) Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations. *Quarterly Journal of Economics*, **108**, 577–598.
- Jaffe, A.B., Fogarty, M.S. and Banks, B.A. (1998) Evidence from Patents and Patent Citations on the Impact of NASA and Other Federal Labs on Commercial Innovation. *Journal of Industrial Economics*, **XLVI**, 183–205.
- Kogut, B. and Zander, U. (1993) Knowledge of the Firm and the Evolutionary Theory of the Multinational Corporation. *Journal of International Business Studies*, **Fourth Quarter**, 625–645.
- Kuemmerle, W. (1996) Home Base and Foreign Direct Investment in R&D. PhD Dissertation, Boston: HBS (unpublished).
- 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**, 179–193.
- Lall, S. (1979) The International Allocation of Research Activity by U.S. Multinationals. *Oxford Bulletin of Economics and Statistics*, **41**, 313–331.
- Le Bas, C. and Sierra, C. (2002) Location Versus Country Advantages' in R&D Activities: Some Further Results on Multinationals' Locational Strategies. *Research Policy*, **31**, 589–609.
- Maurseth, P.-B. and Verspagen, B. (2002) Knowledge Spillovers in Europe. A Patent Citations Analysis. *Scandinavian Journal of Economics*, **104**, 531–545.
- Michel, J. and Bettles, B. (2001) Patent Citation Analysis. A Closer Look at the Basic Input Data from Patent Search Reports. *Scientometrics*, **51**, 185–201.
- Narula, R. (2002). Innovation Systems and 'Inertia' in R&D Location: Norwegian Firms and the Role of Systemic Lock-in. *Research Policy*, **31**, 795–816.
- Narula, R. and Zanfei, A. (2004) Globalisation of Innovation: The Role of Multinational Enterprises. In Fagerberg J., Mowery, D. and Nelson, R. (Eds) *Handbook of Innovation*. Oxford: Oxford University Press.
- Nonaka, I. and Takeuchi, H. (1995) *The Knowledge-Creating Company*. Oxford: OUP.
- OST (Observatoire des Sciences et des Techniques) (1998) *Science and Technologie: Indicateurs*. Paris: Economica.
- Patel, P. (1996) Are Large Firms Internationalising the Generation of Technology? Some New Evidence. *IEEE Transactions on Engineering Management*, **43**, 41–47.
- Patel, P. and Pavitt, K. (1999) Global Corporations & National Systems of Innovation: Who Dominates Whom? In Archibugi, D., Howells, J. and Michie, J. (Eds) *Innovation Policy in a Global Economy*. Cambridge: Cambridge University Press.
- Patel, P. and Vega, M. (1999) Patterns of Internationalisation and Corporate Technology: Location Versus Home Country Advantages. *Research Policy*, **28**, 145–155.
- Serapio, M. and Dalton, D. (1999) Globalisation and Industrial R&D: An Examination of Foreign Direct Investment in R&D in the United States. *Research Policy*, **28**, 303–316.
- Sjöholm, F. (1996) International Transfer of Knowledge: the Role of International Trade and Geographic Proximity. *Weltwirtschaftliches Archiv*, **132**, 97–115.
- Teeces, D. and Pisano, G. (1994) The Dynamic Capabilities of Firms: An Introduction. *Industrial and Corporate Change*, **3**(3), 537–556.
- Verspagen, B. and Schoenmakers, W. (2004) The Spatial Dimension of Patenting by Multinational Firms in Europe. *Journal of Economic Geography*, **4**(1), 23–42.

- Von Hippel, E. (1994) 'Sticky Information' and the Locus of Problem Solving: Implications for Innovation. *Management Science*, **40**, 429–439.
- Zander, I. (1999) How Do You Mean 'Global'? An Empirical Investigation of Innovation Networks in the Multinational Corporation. *Research Policy*, **28**, 195–213.
- Zanfei, A. (2000) Transnational Firms and the Changing Organisation of Innovative Activities. *Cambridge Journal of Economics*, **24**, 515–542.

APPENDIX A MNEs AND SECTORS IN THE SAMPLE.

Chemicals

Akzo Nobel NV
 BASF A.G.
 Bayer A.G.
 Cea-Industrie
 Montedison
 Du Pont Company Inc.
 Henkel KgaA
 Hoechst A.G.
 ICI Plc.
 Monsanto Co.
 Norsk Hydro ASA
 Occidental Petroleum Corp.
 Rhone-Poulenc
 The Dow Chemicals Co.

Industrial machinery and transportation

AB Volvo
 BMW AG
 BTR plc.
 Caterpillar Inc.
 Daimler-Benz AG
 Daimler Chrysler
 Deere & Co.
 Ford Motor Co.
 General Motors Corp.
 Fiat
 IRI
 Johnson Controls Inc.
 MAN AG
 Mannesmann AG
 Peugeot S.A.
 Renault
 Robert Bosch GmbH
 Thyssen AG
 TRW Inc.
 Volkswagen AG

Pharmaceuticals

Abbott Laboratories
 American Home Products Corp.
 Bristol–Myers Squibb Co.
 GlaxoWellcome Plc.
 Johnson & Johnson
 Merck & Co Inc.
 Novartis group

Pfizer Inc.
 Roche Holding Ltd.
 Smithkline Beecham Plc.

Electronics

ABB Asea Brown Boveri Ltd
 Compaq Computer Corp.
 Dell Computer Corp.
 Electrolux AB
 Emerson Electric Co.
 GEC General Electric Co. Plc. (Marconi)
 General Electric Co.
 Hewlett–Packard Co.
 Intel Corp.
 IBM
 Lucent Technologies
 Motorola Inc.
 Nokia Corp.
 Raytheon Co.
 Rockwell International
 Royal Philips Electronics
 Siemens AG
 Ericsson
 Texas Instruments Inc.
 Xerox Corp.

Petroleum refining

Amoco
 Ashland Inc.
 Atlantic Richfield Co.
 Chevron Corp.
 Norske A.S.
 Elf Aquitaine
 ENI S.p.A.
 Exxon Corp.
 Mobil Corp.
 PetroFina S.A.
 Phillips Petroleum Co.
 Repsol S.A.
 Shell Group
 Sunoco Corp.
 BP Plc.
 The Coastal Corp.
 Tosco Corp.
 Total S.A.
 USX Corp.

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