REVERSE TECHNOLOGY DIFFUSION: ON THE DIFFUSION OF TECHNOLOGICAL CAPABILITIES FROM ADVANCED FOREIGN SUBSIDIARIES TO HEADQUARTERS OF THE MNC

ABSTRACT

This paper examines longitudinal patterns in the diffusion of technological capabilities from advanced foreign subsidiaries to headquarters. Hypotheses are developed concerning the overall pace of diffusion of technological capabilities from foreign subsidiaries to headquarters, as well as differences in the pace of diffusion between capabilities emerging in either greenfield or acquired foreign subsidiaries. Cox analysis regression drawing upon of the complete patenting activity of 23 Swedish multinationals over the 1893-1990 period reveals increased pace of diffusion of technological capabilities from foreign subsidiaries to headquarters. The findings also indicate that the pace of diffusion is more rapid for acquired than greenfield foreign subsidiaries. Implications for strategy and management of the MNC are discussed.

REVERSE TECHNOLOGY DIFFUSION TO HEADQUARTERS FROM COMPETENCE-CREATING FOREIGN SUBSIDIARIES

According to recent research within the field of international business, developing and diffusing technology throughout the MNC network constitutes one of its most important policies and sources of competitive advantage (Bartlett & Ghoshal, 1989; Gupta & Govindarajan, 1991; Nohria & Ghoshal, 1997; Argote & Ingram, 2000; Piscitello, 2004; Mudambi, 2002, 2007). The general story often depicts the MNC as an increasingly interconnected and superior creature for leveraging technology domestically as well as internationally, where autonomous innovative activity by foreign subsidiaries serves as an important source for the technological development of the MNC as a whole (Pearce, 1989; Håkanson & Nobel, 1993; Nobel & Birkinshaw, 1998).

Indeed, over time foreign subsidiaries have become responsible for an increasing share of research and development in the MNC (Cantwell, 1989; Dunning, 1994; Cantwell, 1995; Zander, 1997, 1999; Cantwell & Piscitello, 2000; Frost, 2001; Cantwell & Mudambi, 2005). In the earlier phase of MNC development, foreign subsidiaries are looked upon as extensions of the parent firm using technology supplied from home and attending to adaptation work and serving local customers in foreign locations (Dunning, 1980). However, over time some foreign subsidiaries access external resources in the local environment, and became involved in local and independent technological development (Birkinshaw & Hood, 1989; Forsgren, 1989; Forsgren et al., 1992; Pearce, 1999) and although headquarters still serves as the main provider and diffuser of capabilities, foreign subsidiaries have turned into important sources of technological capabilities that are of significance for the entire multinational group (Cantwell, 1995; Papanastassiou & Pearce, 1997; Zander, 1999).

Accordingly, capability flows from foreign subsidiaries to headquarters has become increasingly important (Mansfield & Romeo, 1980; Ghoshal, 1987; Mudambi, 2002), and as a result technological capabilities emerge and diffuse more extensively from foreign subsidiaries to headquarters. In this paper focus is hierarchical reverse diffusion (Mudambi & Navarra, 2004), more specific the diffusion pace of technological capabilities from foreign subsidiaries to headquarters.

Earlier studies on reverse diffusion within MNCs has emphasized the questions why and how reverse transfer can benefit headquarters (Piscitello & Rabbiosi, 2007), highlighting determinates and obstacles of such flows (Szulanski, 1996; Gupta & Govindarajan, 2000). Previous research has also addressed organizational mechanisms used by MNCs in order to enhance reverse transfer (Foss et al., 2002; Björkman et al., 2004), and differences of greenfield and acquired subsidiaries regarding reverse transfer of technology and knowledge (Björkman et al., 2004; Bresman et al., 1999; Gupta & Govindarajan, 2000; Håkanson & Nobel, 2001), however the pace of reverse diffusion of technological capabilities has not received direct empirical attention[1].

The issue is also of managerial relevance. In today's rapid changing environment, the ability of the MNC to leverage capabilities and technology throughout its geographically dispersed network of foreign subsidiaries has become vital in order to achieve and maintain the competitive advantage and performance of the multinational group (Gupta & Govindarajan, 1991; Mudambi, 2002; 2007; Piscitello, 2004). Thus managers at headquarters need to be able to estimate the pace of reverse diffusion of new technological capabilities from foreign subsidiaries in order to coordinate a global strategy and improving processes throughout the entire multinational group (Ambos et al., 2006).

But while there is growing recognition of the strategic role of foreign subsidiaries as sources of new technological capabilities (Birkinshaw & Hood, 1998; Zander, 1999; Cantwell & Mudambi, 2005), and the increased importance of reverse diffusion of knowledge and capabilities within the MNC (Kogut & Zander, 1993; Gupta & Govindarajan, 2000; Mudambi & Navara, 2004; Piscitello & Rabbiosi, 2007; Yang et al., 2008) few attempts have been made to examine pace of reverse diffusion, thus the aim of this paper is to examine longitudinal patterns in the pace of reverse diffusion of technological capabilities. In particular, it is argued that over time pace of diffusion of technological capabilities from foreign subsidiaries to headquarters has increased, but also that how the subsidiary is established whether through a greenfield investment or through the acquisition of an already existing unit in the host country, has important implications for the pace of reverse diffusion of technological

[1] In this paper diffusion is concerned with the process by which a specific technological capability first emerges in a foreign subsidiary and later on in headquarters. It is measured by U.S. patent data, that is reverse diffusion is detected when after a greenfield or acquired subsidiary has been awarded a patent in a technology that is new to the entire MNC, patenting activity in the same technology is also recorded at headquarters. For more detailed information about measurement issues, see the section on research design.

capabilities. To test for this a dataset containing the complete patenting activity in foreign locations of 23 Swedish multinationals over the 1890-1990 period is used.

The findings show a statistically significant increase in the pace of diffusion from foreign subsidiaries to headquarters, suggesting an increase in the likelihood of diffusion just below 3 per cent for each additional year between 1893-1990 time period and 6 per cent between 1960-1990 time period. Thus, the results lend support for work that suggests enhanced intra-MNC diffusion and sharing of technologies within the MNC (Gupta & Govindarajan, 1991; Mudambi, 2002, 2007; Piscitello, 2004), and the increased importance of foreign subsidiaries as sources of significant technological capabilities (Birkinshaw & Hood, 1998; Zander, 1999; Frost et al., 2002). Moreover, the results reveal no statistical difference in the pace of reverse diffusion depending on whether the origin was greenfield or acquired foreign subsidiaries, however the findings do indicate that the diffusion of acquired foreign subsidiaries is more rapid.

The disposition of the paper is as follows. The next section reviews the literature on MNC internationalization and the evolution of foreign subsidiaries, and presents the hypotheses concerning the pace of reverse technology diffusion. In the subsequent section, the sample, method and data collection are discussed, after which the results from the empirical analyse are presented. The final section contains a concluding discussion, including managerial implications and issues for future research.

MNC Internationalization, and the Development of Advanced Foreign Subsidiaries, and Reverse Diffusion of Technological Capabilities

In the early phase of development of today's well-established MNCs they were dependent on home-based advantages and technologies developed at home (Hymer, 1960; Dunning, 1980; Caves, 1982), and the initial reason for making foreign direct investments (FDI) was to exploit ownership advantages (Dunning & Narula, 1995) in foreign locations. Hence, headquarters served as the main provider of technology and technological capabilities were diffused from headquarters to its subsidiaries in foreign locations, and the underlying driving force for diffusion of technological capabilities was to explore home-based advantages.

However, the internationalization of MNCs has included gradually increased commitments to foreign markets and increasingly sophisticated operations in these locations. Over time, sales and manufacturing operations in foreign locations have become more important and advanced, leading to a specialization in production (Stopford & Dunning, 1983; Dunning, 1983, 1992), and the shifting of R&D activities to foreign locations. In line with these developments, some foreign subsidiaries have developed from passive recipients of centrally developed capabilities to performing R&D activities and generating technology advancements important for the entire multinational group (Dunning, 1994; Cantwell, 1995; Nobel & Birkinshaw, 1998; Zander, 1997, 1999). Hence, over time foreign subsidiaries have come to contribute actively and significantly to the emergence and diffusion of new technological capabilities in the MNC (Hedlund, 1986; Ghoshal & Bartlett, 1988; Bartlett & Ghoshal, 1989; Sölvell & Zander, 1998; Holm & Pedersen, 2000; Andersson et al., 2002). Ultimately, some foreign subsidiaries may develop into competence-creating subsidiaries[2] (Cantwell & Mudambi, 2005) which actively contribute to the technological and renewal of the MNC, referred to as advanced subsidiaries in this paper.

Furthermore, it is suggested that the evolution of technologically advanced subsidiaries has come to change the innovation process of the MNC. What have been identified as local-for-local or innovation processes among foreign subsidiaries initially entailed the local development of new technology for use in the local market (Ghoshal & Bartlett, 1988). Over time this changed, and both local-for-global and global-for-global innovation processes came to involve innovation efforts with international implications, sometimes drawing together the collective technological capabilities residing in the multinational network to develop new and potentially path breaking technology (Hedlund & Rolander, 1990). Thus, some foreign subsidiaries were no longer responsible for only one market or region, rather they acquired more important roles within the MNC such as centres of excellence (Holm & Pedersen, 2000; Frost et al., 2002), representatives of world product mandates (Birkinshaw & Morrison, 1995), or global innovators (Gupta & Govindarajan, 1991), creating several centres of decision-making and lateral communication flows within the MNC (Dunning, 1992).

[2] Previous empirical studies have produced a number of typologies of foreign research and development units (e.g. Ronstadt, 1978; Pearce, 1989; Håkanson & Nobel, 1993; Kummerle, 1997; Nobel & Birkinshaw,1998). These typologies are mainly concerned with differences in the degrees of technical sophistication across foreign subsidiaries, and this paper is only concerned with advanced foreign subsidiaries, that is, subsidiaries which actively contribute to the technological and strategic renewal of the MNC, and correspond to competence-creating subsidiaries (Cantwell & Mudambi, 2005).

Over time, managerial attitudes within the MNC have also changed, and there has been a shift towards more geocentric managerial attitudes, fostering a duty to share useful knowledge and help solve problems anywhere in the world (Perlmutter, 1969). This incorporates the exchange of skills and knowledge and rotation of personnel throughout the multinational network. Thus, the geocentric approach reflects a more collaborative and balanced two-way communication between headquarters and subsidiaries, and as a consequence the potential diffusion of capabilities and practices throughout the MNC network. This is in sharp contrast to the ethnocentric attitudes, typically prevailing in the early internationalization and development phases of the MNC. The effects on organizational design were seen in high volumes of unidirectional communication and information flows from headquarters to subsidiaries, often in the form of orders, commands, and advice. The general attitude among headquarter managers would be to "manufacture the complex products in our country and keep the secrets among our trusted home-country nationals" (Perlmutter, 1969: 11).

Indeed, at the very general level, and in obvious simplification of differentiated attributes among individual firms of different historical and national origin, the evolution of advanced foreign subsidiaries, change in innovation processes on the MNC, drawing upon the collective capabilities within the MNC, and change in managerial attitudes, have coalesced in the formation of the "modern" MNC (Hedlund, 1986; Doz and Prahalad, 1991) where intra-MNC diffusion is becoming increasingly significant. The ability of the MNC to leverage knowledge from geographically dispersed foreign subsidiaries is perceived as a must for firm success (Bartlett & Ghoshal, 1989; Kogut & Zander, 1992; Hedlund, 1994), and diffusion of capabilities globally are viewed by several scholars as the main reason of the existence of MNCs (Kogut & Zander, 1992, 1993; Doz et al., 2001; Andersson et al., 2007). Accordingly, reverse diffusion is argued to have increased while it allows the MNC to draw upon the knowledge and capabilities residing in its network and take advantage of the scope economies of learning within the entire multinational group (Ghoshal & Bartlett, 1988; Yamin, 1999).

Moreover, it is likely that technological capabilities not only diffuse more extensively but also that they diffuse more rapidly within the modern MNC. In terms of the international exploitation of innovations and new technologies, it has been argued that enhanced international competition and shortened product life cycles have contributed to increasingly rapid transfer of technology within the multinational network. Mansfield and Romeo (1980) found that the mean age of 65 U.S. technologies transferred to overseas subsidiaries in developed countries was six years, but also that transfer speed had increased somewhat between the 1960s and 1970s[3]. Moreover, because of the interdependence of foreign R&D operations in the more modern MNC reverse diffusion is becoming increasingly important for headquarters to coordinate a global strategy (Ambos et al., 2006). Hence, the expectation in the current paper is that over time the pace of reverse diffusion of new technological capabilities is likely to have increased within MNCs, that is, new technological capabilities that emerge in the more modern MNC would experience more rapid diffusion from foreign subsidiaries to headquarters (Hedlund, 1986; Bartlett & Ghoshal, 1989).

> *Hypothesis 1: Over time, there has been an increase in the pace by which technological capabilities emerging in foreign subsidiaries are diffused to headquarters.*

The Influence of Entry Mode on Reverse Diffusion of Technological Capabilities

During the last decades, acquisitions have generally been the preferred mode of international expansion (Hood & Young, 1979; Dunning, 1988; Holm & Pedersen, 2000). The shift in entry mode from greenfield investments to the use of acquisitions have been found to have a considerable effect on the overall share and profile of foreign technological activity in the MNC (Zander, 1999; Puranam et al. 2006). Acquired subsidiaries are more likely to act in asset-seeking ways, thus developing more substantial technological capabilities and having a greater strategic impact than greenfield establishments (Cantwell & Mudambi, 2005). One of the main reasons for acquisitions is fast penetration of foreign markets and rapid access to new knowledge assets and thereby an enlargement of the MNC’s technological base (Prahalad & Hamel, 1990; Hitt et al., 1996) together with an increase in potential recombination of technological capabilities within the multinational group (Hedlund, 1986; Hedlund & Ridderstråle, 1995).

Compared to conventional diffusion of technology from headquarters to abroad, reverse transfer is more complex (Yang et al., 2008), because a subsidiary may need to convince headquarters that its capabilities are important and will contribute positively to the operations of headquarters or other actors of the MNC; while headquarters is only interested in capabilities beneficial from their perspective (Gupta & Govindarajan, 2000; McDonald et al.,

[3] Zander (1991) observed that among Swedish multinationals the average time to comprehensive transfer of manufacturing technology related to important innovations has been about eight years.

2005). Moreover, due to the principle-agent relationship of headquarters and subsidiaries, headquarters dedication to learn from its subsidiaries is less compared to the obligation of subsidiaries to learn from the parent firm (Kogut & Zander, 1993; Gupta & Govindarajan, 2000). Hence, reverse diffusion can be viewed as a complex process, where the foreign subsidiary may need to persuade headquarters that its capabilities will be beneficial and fit the need of headquarters (Yang et al., 2008).

Certain factors are nevertheless suggested to ease the process of reverse diffusion within the MNC. Normative integration between headquarters and subsidiaries are argued to facilitate the diffusion of innovations, and typically it is suggested that subsidiaries sharing the overall strategy, goals and values of the MNC generate higher degrees of reverse diffusion (Bartlett & Ghoshal, 1989). Accordingly, diffusion of capabilities from foreign subsidiaries to headquarters will be higher when there are shared beliefs and values between headquarters and a subsidiary (Ghoshal et al., 2004). Moreover, knowledge relevance and absorptive capacity is argued to positively influence reverse diffusion of capabilities (Yang et al., 2008; Cohen and Levinthal, 1990). According to Schulz (2003) knowledge relevance can be defined as “the degree to which external knowledge has the potential to connect to local knowledge”. Drawing upon relevance theory the more the sending unit’s knowledge has implications for the receiving unit and the easier it is for the receiving unit to obtain these implications, the higher degree of relevance. For a given degree of willingness to send and receive knowledge, the more the knowledge is connected and relevant, the more effective transfer (Yang et al., 2008), hence the more knowledge overlaps between a subsidiary and headquarters the more likely it is that headquarters takes interest in and understands the subsidiary’s knowledge. Taken together this suggests that the pace of diffusion of technological capabilities would be more rapid from greenfield than from acquired foreign subsidiaries, because greenfield subsidiaries can be expected to be generally more integrated with and similar in terms of technological base to headquarters than acquisitions (Yamin, 1999).

On the other hand, acquisitions that are perceived as strategically important from a headquarters perspective have a positive influence on reverse diffusion of knowledge (Yang et al., 2008). Headquarters often have a special interest in acquired subsidiaries and their technological capabilities, especially if they are perceived to be strategically important, as they are relatively more likely to contribute with significantly new technological capabilities important for the entire multinational group (Zander, 1999; Björkman et al., 2004; Gupta &

Govindarajan, 2000) than greenfield subsidiaries, and are often acquired because of their technological assets and future growth potential (Doz & Prahalad, 1991; Hitt et al., 1996). Follow, this suggests that the diffusion of technological capabilities could be faster to headquarters from acquired subsidiaries than from foreign greenfield subsidiaries.

Previous findings studying reverse diffusion of knowledge of greenfield and acquired subsidiaries have found mixed results (Björkman et al., 2004; Bresman et al., 1999; Gupta & Govindarajan, 2000; Håkanson & Nobel, 2001). According to Gupta and Govindarajan (2000) there is no difference in technology flows from greenfield and acquired subsidiaries to headquarters. However, other findings indicate that reverse knowledge transfer is higher for greenfield compared to acquired subsidiaries (Yamin, 1999) and mixed results have been found when controlling for the role of the subsidiary (Mudambi et al., 2007). Thus, two competing hypotheses are concerned with the pace of which technological capabilities diffuse from greenfield and acquired foreign subsidiaries to headquarters:

> *Hypothesis 2a: The pace of reverse diffusion of technological capabilities will be higher from greenfield compared than from acquired foreign subsidiaries.*

> *Hypothesis 2b: The pace of reverse diffusion of technological capabilities will be higher from acquired compared than from greenfield foreign subsidiaries.*

RESEARCH DESIGN

Sample

To test for and explore patterns of diffusion of new technological capabilities, the paper draws on the U.S. patenting activity of 23 Swedish multinationals over the 1890-1990 period. 108 of these subsidiaries were located in Europe (most importantly Germany, 15, Switzerland, 14, United Kingdom, 12, Denmark, 11, and Finland, 10), 18 in the United States, and 31 in other countries (most importantly Canada, 9, Australia, 5, Japan, 3, and Mexico, 3).The sample firms represent a quite broad spectrum of industries, including pulp and paper, motor vehicles, pharmaceuticals, and telecommunications equipment (Appendix A). According, to earlier studies these firms represent a significant number of inventions and also R&D expenditure in Swedish industry (Wallmark and McQueen, 1986; Håkanson and Nobel, 1993), however not necessarily representative of firms of other countries. On the other hand, all of the sample firms have a long exposure to international markets and international business, and should therefore serve as a useful testing ground for identifying patterns of diffusion of technological capabilities.

In order to define the sample firms and subsidiaries in a way that allows for longitudinal comparisons, a historical examination of each individual firm identified any possible name changes as well as potential changes in ownership through mergers and acquisitions. The data also consolidates any patenting by first-order, majority owned subsidiaries for the periods during which they belonged to the parent companies. These subsidiaries were identified through an extensive and systematic search into the history of each individual sample firm, using the publications "Svenska Aktiebolag – Handbok för Affärsvärlden", "Koncernregistret – KCR", and "Who Owns Whom – Continental Europe". Complimentary publications such as publications on company histories were also used in the consolidation process (for a sample of the consolidated firms, see Appendix B).

The empirical analysis covers both foreign subsidiaries that were originally established as greenfield subsidiaries and subsidiaries that were added as the result of foreign acquisitions it should also be re-emphasized that the data only include advanced foreign subsidiaries, that is subsidiaries which have once proven their capacity to contribute significantly to the technological and strategic development of the multinational group. Proof of this capacity is that the subsidiaries have been awarded at least one U.S. patent, which by definition requires inventions to be novel, non-obvious, and useful additions to the existing stock of knowledge Therefore, the insights from the current paper are limited to the MNC's growth in terms of relatively significant new additions to the technology portfolio, and the paper does not account for the potentially wide range of minor technological advancements and improvements that may have taken place in parallel in the multinational network[4] (additional methodological notes and comments are contained in Appendix C).

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[4] It may further be noted that all patents may not necessarily have been commercialized, but given equal propensities to commercialize patents among greenfield and acquired subsidiaries the results should still reveal their relative importance in terms of the ability to contribute to the technological and strategic renewal of the parent corporations.

Data and Data Collection

The study uses patents as a marker or indicator of the emergence and diffusion of technological capabilities. Patents are frequently used technology indicators, in the international business literature and elsewhere (e.g. Jaffe, 1986; Archibugi and Pianta, 1992; Almeida and Phene, 2004; Feinberg and Gupta, 2004), and possess the specific advantage in that they provide consistent and comparable information over extended periods of time. Patenting also correlates highly with alternative measures of technological activity and innovative performance, such as research and development expenditure and new product introductions. In a study comprising a large number of companies in four high-tech industries, Hagedoorn and Cloodt (2003: 1375, 1365) find "no major systematic disparity amongst R&D inputs, patent counts, patent citations and new product announcements", concluding that "future research might also consider using any of these indicators to measure the innovative performance of companies in high-tech industries".

Specifically, the present study relies on the firms' patenting in the United States. The completion of a U.S. patent application requires the recording of the nationality of the inventor (rather than the nationality of the research unit). Under the assumption that the nationality of the inventor in the majority of cases coincides with the geographical location of invention, it is therefore possible to identify where the research and development underlying the invention was carried out. Thus, for every U.S. patent registered under the name of any of the sample firms and their subsidiaries, it is know if the patent *originated* in for example Germany, the United Kingdom, the United States or any other country[5]. This is an important advantage because company-specific patenting policies (for example involving the registration of patents under the name of the parent company rather than the inventing subsidiary) could otherwise conceal the correct geographical distribution of technological activity and invention.

One advantage from using U.S. patenting data is that the general attractiveness of the large U.S. market encourages patenting of inventions that are believe to be of relatively high quality and commercial value. It thereby reduces the possibility that accidental or insignificant

[5] A small proportion of all patents in the current dataset were associated with several individuals of different nationalities. In those cases, the recorded geographical location of technological activity and invention was that of the first inventor.

inventions contaminate the results. It has been found that Swedish firms' patenting in the United States do not differ significantly from patenting in other large markets such as Germany or France (Archibugi & Pianta, 1992). One potential drawback of using U.S. patenting data is that it tends to inflate the patenting activity by U.S. subsidiaries (because they have a relatively higher propensity to patent in what is their home market). Although this increases the relative number of entries and observations that may be associated with U.S. subsidiaries, it should not affect the expected pattern in the timing between new entries.

Although information from patents must be treated with some caution (Schmookler, 1950; Pavitt, 1988), no substantial biases are anticipated in the present study. Most of the sample firms are active in medium- to high-tech industries, where patenting is considered an important competitive device. While patenting propensity varies across the sample firms, causing variation in the number of patents associated with each firm, this does not in itself affect patterns in the emergence of new technological capabilities.

Variables

Main Variables

The first main variable of interest is the *emergence of technological capabilities*. The emergence of technological capabilities is detected when any subsidiary of the MNC is awarded a patent in a technology in which the multinational group has not been previously active. Entry into new technologies and associated technological capabilities is measured at the level of about 400 classes of technology as defined by the U.S. Patent Office[6]. At this level of aggregation, it is possible to distinguish between relatively narrowly defined technological capabilities, such as paper making and fiber preparation and pulse or digital communications. For the purposes of this paper, the classification should strike a good balance between more aggregate groups (the use of which would result in fewer identified entries into new technological capabilities) and finer levels of disaggregation.

[6] The U.S. Patent Office classification is primarily based on the nature and function of the inventions, not their primary adopters. The manual states that arts or instruments having like functions, producing like products, or achieving like effects, are classified together. The functions or effects that are chosen as a basis of classification must be proximate or essential, not remote or accidental. The categories of invention are product, process, apparatus, composition of matter, and certain varieties of plants. Accessories are generally classified with the instrument to which they are peculiar (Manual of Classification, Revision No. 1, June 1993, U.S. Department of Commerce, Patent and Trademark Office).

The emergence of technological capabilities is set to the year in which the subsidiary received its first patent in a technology that is new to the entire multinational group. It needs to be added that whereas patenting in a new technology is seen as an indicator of the emergence of new technological capabilities in the multinational group, the formation of capabilities is not a discrete event but a gradual process which typically precedes first patenting by a number of years. In more recent time, the granting of a U.S. patent has typically lagged the application by about two year (U.S. Department of Commerce, 1992), and the emergence of technological capabilities is likely to have preceded application by an additional but unknown number of years. Yet, *ceteris paribus* the information gained from the patenting records should still provide relatively consistent information about changes in the patterns of emergence of technological capabilities and the ensuing diffusion process. It is further notable that there is only information about the event that first signals the formation of technological capabilities in the multinational group, and beyond from the first recorded occurrence(s) of the diffusion of these capabilities the firms' depth of involvement within each individual technology will not be explained further[7].

The second main variable of interest is *reverse diffusion of technological capabilities*. Reverse diffusion of technological capabilities is detected when after a greenfield or acquired subsidiary has been awarded a patent in a technology that is new to the entire multinational group, patenting activity in the same technology is also recorded at headquarters[8]. Although the empirical investigation reveals patterns in reverse diffusion of technological capabilities, it is necessary to add that the main mechanisms behind diffusion remain unknown. Diffusion may have been brought about in several different and possibly overlapping ways (Wilkins, 1974), including the transfer of technology, the international mobility of individuals between a subsidiary and headquarters, knowledge exchange as part of inter-subsidiary collaboration or internationally coordinated research and development projects. In some cases, the diffusion of technological capabilities may also be the result of independent work on the same technologies by both a subsidiary and headquarters.

[7] Whereas an individual sample firm may have entered 75 new technologies and capabilities over the examined time period, 25 of which may have been recorded as diffused to other locations within the multinational group, in most cases there has been extensive activity and patenting within each individual technology. In individual sample firms such as ASEA there have been a total of close to 2,000 U.S. patents over the entire period.

[8] Headquarters is seen as synonymous with some unidentified units in the home country, typically but not always these units are R&D performed adjacent to headquarters.

While, the main source of reverse diffusion in the current study remains unknown, the main driver is probably not that of traditional transfer to exploit the technological capabilities in the local market, while the Swedish market in all probability is of insignificant size and commercial importance. Rather, drawing upon previous work reverse transfer may represent a selection process through which some subsidiaries innovations are elevated to a higher level within the MNC (Yamin, 1999) and serve as the mechanism through which headquarters can realize the economies of learning inherent in its geographically dispersed network of foreign operations (Ghoshal & Bartlett, 1988). Thus, the driver behind reverse diffusion is more likely to be enhanced headquarters innovative capacity (Piscitello & Rabbiosi, 2007), access to local knowledge, and the coordination of a global strategy (Ambos et al., 2006).

The third main variable of interest is *type of subsidiary; greenfield or acquired foreign subsidiary*. The aim of this variable was to capture potential differences in the ability or desirability to diffuse technological capabilities from greenfield and acquired foreign subsidiaries to headquarters. It was measured through a dummy variable coded 0 and 1.

Control Variables

Ideally, the data ideally should have incorporated a variety of control variables capturing the external and internal environment of a subsidiary, and the organizational structure, that is degree of centralization and different control mechanisms for intra-MNC diffusion such as; incentives and evaluation program for knowledge diffusion, previous subsidiary diffusion and subsidiary size. But the length of the time period under study in combination with unavailability of data at the subsidiary level precludes the use of a comprehensive set of controls. However, a number of location, industry and market variables were included as controls.

The industry context is likely to have an influence on diffusion of capabilities within the MNC. Manufacturing industries has showed to have different patterns of knowledge flows than service based industries (Grosse, 1996; Lahti & Beyerlein, 2000), thus three industry dummy variables (coded 0 and 1) were introduced to control for industry-dependent effects on diffusion patterns. These dummy variables are expected to reflect different propensities to centralize R&D activities (Papanastassiou & Pearce, 1998) and exchange knowledge with headquarters (Randoy & Li, 1998). The first dummy variable captured firms in the automotive industry (2 firms), the second firms in processing industries such as pulp and paper and steel

(4 firms), and the third firms involved in pharmaceuticals and chemicals (4 firms). This left a mixed group of sample firms mainly active in mechanical engineering industries and often with a highly diversified product portfolio.

The potential effects of national culture on the diffusion process were controlled for by the use of culture clusters (Ronen & Schenkar, 1985). The aim of these variables was to capture cultural dissimilarities between the foreign country of a subsidiary and headquarters (which in the present sample is Sweden), which could influence both the ability and desirability of foreign subsidiaries to diffuse technological capabilities. While it is harder to establish strong ties and transfer knowledge when country boarder are crossed (Hansen, 1999; Kogut, 1991). More specific, the sample subsidiaries were divided into five different cultural clusters. The first dummy variable captured subsidiaries in the Anglo-Saxon cluster (147 foreign subsidiaries), the second subsidiaries in the Germanic cluster (63 subsidiaries), the third subsidiaries in the Nordic cluster (14 subsidiaries), and fourth subsidiaries in rest of Europe (18 subsidiaries). This left a mixed group of subsidiaries located outside Europe (6 subsidiaries).

Furthermore, size of the local market was included as a general proxy for the munificence of the local technological and business environment. Size of the local market is measured in annual GDP expressed in the log of millions of USD (constant 1990 terms), using data obtained from the GGDC total economy database (2006). It is expected that larger markets offer broader technological potential and may therefore be more important and followed more closely, leading to an earlier detection of new technological capabilities at headquarters, fostering a more rapid reverse diffusion process of technological capabilities.

Statistical Method

Variations of event history analysis (Allison, 1995) were used to analyse diffusion patterns and to test the hypotheses. In order to investigate the expected general increase in the pace of reverse diffusion, a Cox regression was employed, using the year of the first emergence of technological capabilities as the independent variable or covariate (higher numbers mean that the respective technological capabilities emerged towards the end of the 1893-1990 period) and the event of diffusion of the capabilities to headquarters as the dependent variable. A positive parameter estimate thereby signals that an increase in the year of emergence increases the hazard or pace of diffusion. The goodness of fit of the specific model is tested by the score statistic, that is the chi-square, which compares the specified model with an empty equivalent. The degrees of freedom represent the actual number of parameters specified in the model (Allison, 1995).

To investigate potential differences in the pace of diffusion for technological capabilities originally emerging either at greenfield or in acquired foreign subsidiaries, non-parametric maximum likelihood Kaplan-Meier estimates were employed. The life-table method of Kaplan-Meier estimates survivor functions following event times having probability distributions. More specifically, the survivor function is the probability that an event time is greater than *t*, where *t* can take any non-negative number. In the case of no censoring, i.e. all observations experience an event, the survivor function is simply the proportion of observations with event times greater than *t*. The method makes it possible to test the null hypothesis that survivor functions for two or more groups are identical, in the present case meaning testing for differences in the diffusion of technological capabilities originating at greenfield foreign subsidiaries versus capabilities emerging in acquired foreign subsidiaries. The Kaplan-Meier estimates is used in addition to the Cox regression analysis in order to graphically display the reverse diffusion process from greenfield and acquired foreign subsidiaries to headquarters.

FINDINGS

Over the entire period 1893-1990, 249 new technological capabilities emerged in the sample foreign subsidiaries (in each case marked by the first patent in a specific class of technology as defined by the U.S. Patent Office). Out of these 249 technological capabilities, 111 were diffused within the MNC during the window of observation and 75 of these diffused to headquarters, 68 from greenfield subsidiaries and 7 from acquired subsidiaries. The overall median estimated time for diffusion to headquarters from foreign subsidiaries was 14 years (mean 14.1) between 1893-1990, however shortening the window of observation indicates a substantial increase in pace of reverse diffusion. Thus, the overall median estimated time for diffusion to headquarters from foreign subsidiaries was 7 years (mean 6.8) between 1960-1990 which suggests a substantial increase in pace of reverse diffusion over time. The correlation matrix in Table 1 reveals generally modest correlations between the covariates. The variance inflation factor (VIF) was estimated to check for potential multicollinearity issues. With no VIF scores over 3 (Hair et al.,1998), the risk of significant misinterpretations of the results due to multicollinearity appears limited.

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Insert Tables 1 about here

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Pace of reverse diffusion: A Cox regression was employed to investigate the expected general increase in the pace of reverse diffusion of the time period 1893-1990. The results reveal a statistically significant increase in the pace of diffusion (p=0.001). In other words, the later into the time period a new technological capability emerged the faster it is diffused to headquarters. The finding confirms Hypothesis 1, arguing that the pace of diffusion of technological capabilities from advanced foreign subsidiaries to headquarters goes faster over time. The parameter estimate suggests that the hazard of diffusion increases by slightly 3 per cent for each year. Additionally, a Cox regression analysis was employed investigating a shorter time period, 1960-1990, the results indicate a higher increase in the pace of reverse diffusion (p=0.01) of 6 per cent, suggesting that over time there is a substantial increase in the pace of reverse diffusion.

The variable that captures the type of subsidiary shows a 100 per cent in the pace of diffusion from acquired subsidiaries, but due to the small number of observations this difference is not statistically significant. This is also in line with the results of the non-parametric maximum likelihood Kaplan-Meier estimates, which show no clear statistical significant difference (the likelihood ratio test does not reject the null hypothesis of no difference between the groups) in survival functions between the two strata as observed in median survival times (or the time to reverse diffusion of technological capabilities). The median survival time for a technological capability that emerged in a greenfield subsidiary is 15 years (mean 15.1) versus 3, 5 years (mean 3.7) for a capability initially emerging in an acquisition. This is graphically illustrated in Figure 1, where a wider survivor function is observed for greenfield compared to acquired subsidiaries. In other words, the results indicate that the pace of reverse diffusion of technological capabilities is faster for acquired than greenfield foreign subsidiaries.

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Insert Figure 1 about here

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Furthermore, the results indicate that reverse diffusion goes faster from countries with high GDP and within the automobile industry. (62 per cent and 53 per cent increase in the likelihood of reverse diffusion respectively), however these results were not significant. Significant results are found for the dummies controlling for culture clusters, where the figures specifically suggest that reverse diffusion goes faster from locations outside Europe compared to Germanic and Anglo-Saxon countries.

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Insert Tables 2 and 3 about here

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DISCUSSION AND CONCLUSIONS

The main results suggest the presence of an increased pace of reverse diffusion, that is the diffusion from foreign subsidiaries to headquarters has become faster over the investigated time period. The findings lend support for those who have argued that the reason for why MNCs exists and succeed is there ability to efficient develop and leverage knowledge across boarders (Gupta & Govindarajan, 1991; Kogut & Zander, 1993), and that foreign subsidiaries serve as important sources of technological capabilities for headquarters and the entire multinational group (Cantwell, 1995; Pearce, 1999; Zander, 1999). Moreover, the result of an increased pace in reverse diffusion are inline with previous research arguing that enhanced international competition and shortened product life cycles have contributed to increasingly rapid transfer of technology within the multinational network (Mansfield and Romeo, 1980). The observed hazard rate suggests that the increase in pace of reverse diffusion is just below 3 per cent for each additional year between 1983-1990, and 6 per cent for each additional year between 1960-1990 indicating an substantial increase over time in the pace of diffusion of technological capabilities from foreign subsidiaries to headquarters.

Secondly, the results suggest a substantial difference in the diffusion to headquarters of technological capabilities emerging in either greenfield or acquired foreign subsidiaries. This lends some support for previous research arguing that acquisitions are often used in order to gain new technologies (Zander, 1999) and that headquarters therefore has a high interest in their technological assets and capabilities (Björkman et al., 2004). Several of the control variables showed results that were in the expected direction, however they were not significant. The diffusion pace from foreign subsidiaries to headquarters is higher from large and munificent markets, and the automotive or pharmaceuticals industry.

Two particular limitations must be emphasized when analysing the results and in the conclusions. First, the sample used in this study is restricted to a limited and non-random sample. In essence, the firms represent a large and representative proportion of Swedish MNCs, but they may not be representative of MNCs of other countries. The results may be shared by other MNCs emerging in small home markets, but this remains an empirically open question. On the balancing side, the sample firms are corporations with long and extensive exposure to international markets and international business so trends and patterns have been able to evolve themselves. Second, the data do not account for the reverse diffusion of technological capabilities emerging after 1990, but the length of the measured time period should have allowed for fundamental tendencies to surface and be detected. There is little evidence that the fundamental drivers of reverse diffusion within the MNC should have changed significantly during the last fifteen years. If anything, the pace may be assumed to have quickened even more, and this would be in line with the already observed trends in the current paper.

SUMMARY

The objective of this paper was to empirically investigate longitudinal patterns in diffusion of technological capabilities from foreign subsidiaries to headquarters, more specific to examine pace of reverse diffusion and how it has changed over time. In doing so, this paper adds to the current literature explaining knowledge and technology diffusion in the MNC, making a contribution by the highlighting of the pace of diffusion of technological capabilities from foreign subsidiaries to headquarters. At the general level the results suggests that the pace of reverse diffusion has increased over the window of observation, in other words, the later into the time period a new technological capability emerged the faster it is diffused to headquarters. Pace of reverse diffusion has not previously received direct empirical attention, and the empirical finding in this paper lend support for previous studies arguing that diffusion of capabilities within the modern MNC takes place more rapidly, something that previously mostly been implicitly assumed.

Moreover, this paper raises important questions that future research in this area should consider addressing. First, more research is needed on diffusion patterns of technological capabilities by advanced foreign subsidiaries and the effect of different control and incentives mechanisms on the diffusion pace and effectiveness. It would also be interesting to look at the more specific role of headquarters regarding reverse diffusion and the underlying mechanisms driving reverse diffusion in the MNC. Second, this is one of few attempts examining the difference in the diffusion pace of greenfield and acquired foreign subsidiaries and in order to confirm the results additional studies drawing upon a broader sample are needed. Moreover, future studies should control for national origin and more specific subsidiary characteristics and attributes, such as how long the acquired subsidiaries have been a part of the MNC, and to what extent the capability is closely connected to the core technology of the MNC, which would allow for a better understanding of how the choice of entry-mode influences diffusion of technological capabilities by advanced foreign subsidiaries within MNCs.

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APPENDIX A

The sample of consolidated Swedish multinational firms

Firm[a]	Principal field of industrial activity
AGA (1904)	Industrial gases
Alfa Laval (1878)	Separators, agricultural equipment
ASEA (1883)[c]	Power generation and distribution equipment
Astra (1913)	Pharmaceuticals
Atlas Copco (1873)	Pneumatic and hydraulic equipment
Electrolux (1910)	White goods, home appliances
Ericsson (1876)	Telecommunication equipment
ESAB (1904)	Welding equipment
Fagersta (1873)	Metals, rock drills
MoDo (1873)	Pulp and paper
Perstorp (1880)	Chemicals, conglomerate
Pharmacia (1911)	Pharmaceuticals
PLM (1919)	Packaging material
Saab-Scania (1891)	Automotive products, aircraft
Sandvik (1862)	Specialty steel and metals, hard materials
SCA (1925)	Pulp and paper
SKF (1905)	Ball- and roller bearings
Stora (1888)	Pulp and paper
Tetra Pak (1946)	Liquid packaging machinery
Trelleborg (1905)	Rubber products, conglomerate
Volvo (1915)	Automotive products, food

[a] Years within parentheses indicate the year of establishment.

[c] ASEA merged with Swiss Brown Boveri et Cie. in 1987 and observations are truncated in 1988.

Appendix B

Sample of consolidated sample firm

Sandvik:

Sandvik Aktiebolag
Sandviken Jernverk AB
AB Sandvik Coromant
AB Sandvik Hard Materials
AB Sandvik Rock Tools
Alston Tool + Gauge Company Ltd.
Diagrit Grinding Company limited
Disston Inc.
Edsbyns Industri AB
Eurotungstene
Fagersta Secoroc
Garnett-Bywater Limited
Greenleaf Corporation
Hack Saws Limited
IMK Industriservice AB
Madison Industries Inc.
Oberg C.O. + Co. AB
Osprey Metals Limited
Safety S.A.
Sandco Limited
Sandvik Coastal Inc.
Sandvik Conveyor GmbH
Sandvik Conveyor Inc.
Sandvik GmbH
Sandvik Hard Materials Ltd.
Sandvik Inc.
Sandvik Kosta GmbH
Sandvik Rock Tools Inc.
Sandvik Special Metal Corporation
Sandvik Steel of Colorado Inc. Mesne
Sandvik Tobler S.A.
Santrade Ltd.
Seco Tools AB
Spooner Edmeston Engineering Ltd.
Tobler S.A. Mecanique de P. F.-S.
Tobler S.A.
Uddeholm Strip Steel Aktiebolag

APPENDIX C

Methodological notes

Patents as a proof of advanced technological capabilities: Using the existence of U.S. patents as proof of a subsidiary's capacity to contribute significantly to the technological and strategic development of the multinational group runs the risk of including subsidiaries in the sample which only display serendipitous technological discoveries. While it has not been possible to estimate the relative proportion of these subsidiaries in the current sample, only a very small number of the identified subsidiaries were responsible for only one patent over the entire period.

Moreover, patent is an indicator of innovative performance, which narrows the focus to technological innovations, articulated knowledge, and the associated capabilities (Phene and Almeida, 2008), leaving out other types of innovations across different stages of the value chain. Patents only capture elements of capabilities that are mainly codified, leaving out an extensive amount of knowledge, especially in the context of strongly networked firms such as MNCs (Mudambi and Navarra, 2004). However, patens can also be perceived as an explicit marker of the existence of a tacit capability underlying the patent, thus in the current paper patents are perceived as explicit knowledge of a process including a technological capability.

Finally, although patents as measure of technology flows is well established in the literature (Jaffe et al., 1993; Almeida, 1996; Almeida and Kogut, 1997; Mudambi and Navarra, 2004) the empirical investigation only provides a picture of the patterns of technological capability diffusion in the MNC; it does not identify specific mechanisms of the diffusion process itself or the nature of the technological capability. Technological capability diffusion is based on the patenting activity of an advanced foreign subsidiary in a technological class that is new to the entire MNC, and the subsequent patenting activity, later in time, in the same technology class by headquarters. According to Wilkins (1974) diffusion may have been brought about in several different and possibly overlapping ways, including the transfer of technology, the international mobility of individuals between subsidiary and headquarters, knowledge exchange as part of inter-subsidiary collaboration or internationally coordinated R&D projects. In some cases, the diffusion of technological capabilities may also be the result of independent work on the same technologies by both a subsidiary and headquarters. This measure is subject to noise, and reverse technological capability diffusion is not completely captured by this variable. However, there is an extensive literature using patent data to measure knowledge and capability flows in the MNC, and it is argued that patent data have the advantage of being objectivity and generally perceived as a good representative of knowledge as a whole (Jaffe, 1986; Archibugi and Pianta, 1992; Almeida and Phene, 2004; Feinberg and Gupta, 2004; Mudambi and Navarra, 2004).

Identification of foreign subsidiaries: The empirical analysis is based on the assumption that over time the sample firms have maintained one subsidiary per country (an assumption supported by the historical accounts and information on the international operations of the sample firms in annual reports), although in some cases individual subsidiaries may have included several legally separate entities. For many of the observations, it is known that the parent firm has been awarded a U.S. patent that had its origin in a foreign country (assumedly because of corporate patenting policies), but the patenting records do not reveal the organizational identity of the unit performing the actual research. In the analyses, it is assumed that the research underlying a patent with for example U.K. inventors was also carried out at the local U.K. subsidiary.

Period of investigation: Although the data cover the period 1893-1990, the majority of entries into new technologies were recorded after 1950. It should be expected that the reliability of data has improved over the measured time period, especially as for most firms the United States may have been perceived as relatively distant in the earlier parts of the 20th century (and hence not prioritized as a country in which patents were sought). Accordingly, this serves as the main reason for dividing up the analysis in two different time periods, 1893-1990 and 1960-1990.

TABLE 1

Pearson Correlation Matrix

	1.	2.	3.	4.	5.	6.
1. Emergence	1.00					
2. Type of subsidiary	0.42**	1.00				
3. Processing industry	0.09	0.19**	1.00			
4. Pharmaceuticals/chemicals	0.01	-0.17**	-0.06	1.00		
5. Automobile industry	0.07	0.05	-0.04	-0.53	1.00	
6. GDP	0.28**	0.03**	0.14	-0.19	-0.18**	1.00

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

TABLE 2

Cox regression: Determinants of pace of reverse diffusion 1983-1990.

Cox regression model				
Covariates				
	Estimate	s.e.	P	Hazard ratio
Year of emergence	0.028	0.008	0.001	1.029***
Acquisitions	0.692	0.638	0.278	1.997
GDP	0.480	0.439	0.274	1.617
Industry		YES		
Culture clusters		YES		
Model fit statistics				
Chi-square		36.021*** (10)		
Censoring information				
69.8% (173 observations)				

Estimates significant at the 0.05, 0.01 and 0.001 level are indicated with *, ** and *** respectively. All tests are two-tailed.

TABLE 3

Cox regression: Determinants of pace of reverse diffusion 1960-1990.

Cox regression model				
Covariates				
	Estimate	s.e.	P	Hazard ratio
Year of emergence	0.096	0.035	0.006	1.101**
Acquisitions	0.620	0.746	0.406	1.859
GDP	0.749	0.704	0.240	2.115
Industry		YES		
Culture clusters		YES		
Model fit statistics				
Chi-square		19.848** (10)		
Censoring information				
80.9 % (148 observations)				

Estimates significant at the 0.05, 0.01 and 0.001 level are indicated with *, ** and *** respectively. All tests are two-tailed.

FIGURE 1

Kaplan-Meier Survival Functions of reverse diffusion of technological capabilities