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Does co-location accelerate knowledge outflows from FDI? The role of MNC subsidiaries' technology sourcing strategies

Alessandra Perri
Universidad Carlos III

aperri@emp.uc3m.es

Raffaele Oriani
LUISS Guido Carli
Department of Business and Management
roriani@luiss.it

Francesco Rullani
LUISS Guido Carli
Department of Business and Management
frullani@luiss.it

Abstract

Despite the strategic importance of the knowledge outflows from FDI for local firms? competitiveness, no study has focused on the speed at which this phenomenon takes place. However, this issue is crucial since the speed at which firms absorb external knowledge influences the time they need to carry out subsequent innovations, their ability to adapt to external changes and enter new markets, thus ultimately affecting their chances to achieve a competitive advantage. This paper tries to fill this gap, by investigating the temporal patterns of knowledge outflows between foreign subsidiaries and firms located in host-regions. Combining International Business literature with insights on Innovation Strategy, we

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DOES CO-LOCATION ACCELERATE KNOWLEDGE OUTFLOWS FROM FDI? THE ROLE OF MNC SUBSIDIARIES' TECHNOLOGY SOURCING STRATEGIES

ABSTRACT

Despite the strategic importance of the knowledge outflows from FDI for local firms' competitiveness, no study has focused on the speed at which this phenomenon takes place. However, this issue is crucial since the speed at which firms absorb external knowledge influences the time they need to carry out subsequent innovations, their ability to adapt to external changes and enter new markets, thus ultimately affecting their chances to achieve a competitive advantage. This paper tries to fill this gap, by investigating the temporal patterns of knowledge outflows between foreign subsidiaries and firms located in host-regions. Combining International Business literature with insights on Innovation Strategy, we provide evidence on the timing of this phenomenon, and discuss the role played by multinational firms' technology sourcing strategies.

INTRODUCTION

Traditional literature on knowledge outflows from FDI suggests that when multinational corporations (hereafter, MNCs) establish their foreign subsidiaries abroad, proximity allows local firms to absorb MNCs' technology and skills (Shaver &Flyer, 2000; Haskel et al., 2007).

Due to this strategic role for domestic firms' competitiveness, much literature has been devoted to ascertain whether or not knowledge outflows from FDI actually occur, to quantify their magnitude, as well as to identify the drivers of this phenomenon (Rodriguez-Clare, 1996; Feinberg & Majumdar, 2001; Almeida, 2006; Singh, 2007). Empirical research on these issues has been mainly settled in less developed countries, where FDI is usually seen as a channel that helps host-regions to "catch up" more advanced territories. However, to draw implications on how knowledge outflows from foreign subsidiaries can improve local firms' technological capabilities in more dynamic and developed settings, it is relevant to evaluate *not only the event* of the knowledge outflow, *but also the time* involved in the knowledge outflows to local firms, relative to other firms.

Rapid knowledge outflows from FDI may allow local firms to build "second-mover" advantages (Lieberman & Montgomery, 1988), since the faster a "follower" can learn and use a new technology, the more distance it can create between itself and later adopters (Kessler & Chakrabarti, 1996). In addition, the opportunity to gain access to the latest technology has been found to positively impact firms' new knowledge creation (Nerkar, 2003), as well as to accelerate their innovative processes (Fabrizio, 2007), both factors that are crucial to obtain a competitive advantage (Eisenhardt & Martin, 2000; Nonaka et al., 2000).

Subsidiaries of foreign MNCs embody a unique and attractive knowledge base on which local firms can build upon, especially if the latters are wholly domestic and, hence, do not have the chance to overcome the limitations of local search as multi-location firms do. As a consequence, the speed at which local firms are able to capture the knowledge flows originating from foreign subsidiaries is a relevant dimension along which to evaluate the benefits – for firms in a given location - arising from the presence of multinational corporations.

Especially in high-tech industries, where imitation, constant new discoveries and obsolescence reduce the length of technology-based advantages (Markman et al., 2005), the rate at which new knowledge diffuses to the agents of a given context, allowing them to build on its innovative content, might be more important than the mere expectation that such dissemination will happen, sooner or later.

In sum, within advanced regional contexts, in order for local firms to benefit from MNCs' technology, subsidiaries' knowledge not only has to flow over the local knowledge network, but it has to do it faster than it does elsewhere. To shed more light on this issue, in this paper, we track the temporal patterns of foreign subsidiaries' knowledge diffusion within and outside their host-location, and answer to the following research questions: (1) *Does a subsidiary's knowledge diffuse faster within its host-location than elsewhere?* and (2) *What drives the speed of a subsidiary's knowledge diffusion within its host-location?*

In answering these questions, we combine International Business and Innovation literatures, and suggest that the speed of local diffusion of a subsidiary's knowledge is influenced by its technology sourcing strategies. Technology sourcing can be defined as firms' approach to the creation of new knowledge, both in terms of the exploitation of internal R&D and the acquisition of external technology (Nicholls-Nixon & Woo, 2003).

Plenty of research has demonstrated that firms' technology sourcing behaviour affects the characteristics of the newly created knowledge (Laursen & Salter, 2006; Rosenkopf & Nerkar, 2001; Almeida & Phene, 2004; Phene & Almeida, 2008). In turns, the characteristics of knowledge, and the way different technology sources are combined to produce it, impacts the ease with which it can spread and be absorbed by other agents (Kogut & Zander 1993; Zhao, 2006).

Using data on a sample of 1530 patents filed by U.S. subsidiaries of foreign MNCs operating in the semiconductor industry, we provide preliminary descriptive evidence on the advantages of being co-located with MNCs' subsidiaries, in terms of the speed with which co-located firms can absorb knowledge outflows spilling from the foreign firms' boundaries. In addition, we show that the breadth of a subsidiary's technology sourcing strategy slows down the speed of the process of local diffusion of its knowledge, suggesting that subsidiaries that integrate several knowledge sources to create new technology are also more able to keep their knowledge secret for a longer time.

This paper has four main contributions. First, it elaborates on the role of the speed of knowledge outflows from FDI, as a relevant attribute that needs to be considered in order to comprehensively assess the impact of the spillover phenomenon on local firms' competitiveness. Literature has already recognized the strategic importance – for firms' competitiveness - of both the FDI knowledge spillover effect (Haskel et al., 2007; Singh, 2007) and the pace of innovative processes (Markman et al., 2005); yet - to the best of our knowledge - no study has combined these insights and investigated how knowledge flows from foreign subsidiaries to local firms manifest in time. Second, it empirically investigates the temporal patterns of knowledge spillovers from foreign subsidiaries to local firms in a context where the technology cycle time is short (i.e., the semiconductor industry), and the speed of knowledge diffusion can be a crucial determinant of local firms' competitive advantage. Third, it investigates the drivers of such speed by linking traditional International Business literature with perspectives on Innovation Strategy, and finds that the breadth of a subsidiary's technology sourcing increases the time it takes to local firms to absorb pieces of the subsidiary's knowledge. Fourth, it offers new insights on the mechanisms that foreign firms can use to protect their knowledge from external appropriation in their host-regions.

The reminder of this paper is organized as follows. First, we review literature on FDI spillovers and underline the relevance of the temporal dimension of the innovation process. Second, we develop a theoretical framework in which we use the Innovation literature to explain the time patterns of local spillovers. Finally, we elucidate the empirical strategy and discuss the preliminary results and the future developments of the analysis.

THEORETICAL BACKGROUND

Innovation has been described as the ability to create new recombination of existing knowledge (Schumpeter, 1942). However, relying just on the knowledge residing within a firm's organizational boundaries may not always be sufficient to activate successful innovative processes. An increasing number of studies has indeed demonstrated the importance of external knowledge sourcing as a determinant of innovation (Von Hippel, 1988; Szulanski, 1996; Laursen & Salter, 2006). Yet, literature has suggested that a firm's search for external knowledge inputs tents to be "*technologically and geographically bounded*" (Rosenkopf & Almeida, 2003: 751).

In order to innovate, firms placed in a given region can leverage on the set of knowledge sources available in the surrounding local environment (Almeida, 1996). However, to be successful and outperform rivals, firms must do more than simply absorbing knowledge from outside; most importantly, they must do it *quickly*. The speed of this process can determine a firm's capacity to adapt to external changes, foresee and react to competitors, and enter new markets (Salomon & Martin, 2008). In fact, the ability to accelerate the innovation process is crucial to obtain a competitive advantage (Eisenhardt & Martin, 2000).

Subsidiaries of foreign multinational corporations (hereafter, MNCs) represent a critical source of knowledge for co-located firms, since they embody the MNC's superior technology and may be themselves very active in terms of knowledge creation (Almeida & Phene, 2004). In fact, foreign direct investment (hereafter, FDI) is considered a catalyst for local firms' technological upgrading (Singh, 2007; Haskel et al., 2007), and its role as an enabler of technology transfer to host countries has been central in both International Economics and International Business literatures.

In the perspective of local firms, the opportunity to gain access to subsidiaries' knowledge is crucial. By internalizing the MNCs' knowledge, local firms have the chance to acquire "*modern technology as well as management, distribution and marketing skills*" (Singh, 2007; p.765) that allow them to improve their performance. Although scholars from various disciplines have extensively analysed the intensity of the knowledge flows from MNCs to local firms (Almeida, 1996; Branstetter, 2006; Singh, 2007), as well as their antecedents (Wang & Blomstrom, 1992; Perez, 1997; Driffield & Love, 2007) and the channels through which they take place (Fosfuri et al., 2001; Song et al., 2003; Cassiman & Veugelers, 2002), research has failed to consider the *time patterns* of this process, thus neglecting the role that *a fast access* to external knowledge inputs can play for the success of local firms' innovation productivity. However, this issue is relevant because the speed at which external knowledge is acquired determines the rate at which subsequent innovations - that build upon the external knowledge absorbed - can be carried out, thus allowing the firm to leapfrog competitors and to gain a strategic advantage (Lieberman & Montgomery, 1988).

THEORY

Geography and The Speed of Knowledge Outflows

Traditionally, there has been a general consensus among academics and policymakers about the role of geography in the process of knowledge diffusion (Jaffe et al., 1993). Research on the speed with which knowledge spreads geographically has mainly be positioned in the related literature as a further proof of the phenomenon of the localization of knowledge diffusion. Jaffe and Trajtenberg (1999) claim that, since knowledge is expected to follow a diffusion process through geographic, institutional and technological spaces, "*researchers that are nearby along each of these dimensions would be particularly likely to benefit disproportionately in the time period immediately after the antecedent innovation occurs*".

In their study of the patterns of citations among patents developed by inventors in the U.S., the U.K., France, Germany and Japan, they find that patents whose inventors are from the same country cite each other systematically more than inventors from other countries, and that these citations come sooner.

The reason for the relationship between time and the "localization effect" of knowledge diffusion lies in the nature of knowledge itself. Recently created knowledge is believed to be highly tacit (Griffith et al., 2006). Such attribute makes face-to-face interactions associated with proximity extremely important for its transfer. Going ahead with its life-cycle, knowledge becomes more explicit and easier to transfer even without the need of intensive personal communication; as a consequence, its dissemination is less bounded to geography. The basic idea underlying this reasoning is that proximity increases the frequency of face-to-face interaction and eases the development of interfirm trust, both factors that are critical for the process of tacit knowledge transfer (Bathelt, Malmberg & Maskell, 2004; Lawson & Lorenz, 1999; Maskell, 2001; Storper & Venables, 2004).

In the context of International Business, several scholars have demonstrated that foreign subsidiaries and local firms come into contact and share resources through several channels (Almeida, 1996; Rodriguez-Clare, 1996; Song et al., 2003; Feinberg & Majumdar, 2001; Chung, Mitchell & Yeung, 2003; Javorcik, 2004; Haskel et. al, 2007; Singh, 2007; Driffield et al., 2010). In fact, when foreign firms establish in a region and conduct research locally, they become part of the local knowledge network (Cohen & Levinthal, 1990), a condition that drives them to interact, thus exchanging information, technology and know-how with the domestic counterparts. Empirical evidence documents that foreign subsidiaries' personnel often develops informal network of scientists abroad, thus facilitating the exchange of knowledge locally. As an example, Saxenian (1994) reports the importance of the informal contacts between local and foreign firms for the knowledge sharing process and the dynamism of high-tech regions.

In addition, the embeddedness literature (Andersson et al. 2002; 2007) highlights that foreign subsidiaries develop strong business and non-business relationships with local counterparts, that often encompass tight interaction, building of trust and interdependence, all channels through which knowledge can be easily transferred from the foreign subsidiaries to the local context.

Building on this evidence, we suggest that the localization of MNCs' subsidiaries in a foreign region creates a wide set of interaction opportunities with local firms, that act as crucial facilitators for the transfer of knowledge, especially in the very first stage of its creation, thus allowing the MNCs' technology to spill over the local knowledge network faster than it does elsewhere.

As a consequence, we expect that:

> *Hypothesis 1. A foreign subsidiary's knowledge diffuses faster within its host-location than elsewhere.*

The Role of Subsidiaries' Technology Sourcing Strategies

The role of firms' knowledge sourcing behaviour as a determinant of technological performance has been long acknowledged in the literature within a wide range of theoretical perspectives (Von Hippel, 1988; Lundvall, 1992; Veugelers, 1997; Chesbrough. 2004; Laursen & Salter, 2006; Vega-Jurado et al., 2009). By acquiring knowledge from external sources and recombine them with internal resources, firms can feed their innovative process and give rise to new ideas, products and processes. Within the IB setting, research on multinational corporations has strongly emphasized the importance of sourcing knowledge from the outside (Frost, 2001; Almeida & Phene, 2004; Cantwell & Mudambi, 2005). Through the establishment of foreign subsidiaries abroad, MNCs pursue the objective to tap into geographically distributed pools of knowledge. In fact, multinational firms are commonly defined as geographically distributed networks of innovation, whose main ability is to assimilate, create and integrate knowledge on a global basis (Bartlett & Ghoshal, 1989; Kogut & Zander, 1993; Frost et al., 2002). A well established stream of literature suggests that technology sourcing in multinational subsidiaries is a peculiar process, since they are simultaneously exposed to two different knowledge environments: (1) the *internal* multinational corporation network, composed of the headquarters and other subsidiaries; (2) the *external* network of host country firms (Almeida & Phene, 2004). The opportunity to absorb knowledge from both these networks is nontrivial for their innovative performance, since the creative use of distant - and, thus, diverse - sets of knowledge inputs leads to distinctiveness and uniqueness. Hence, the *breadth of a subsidiary's technology sourcing* – as resulting from the subsidiary's ability to absorb and creatively combine knowledge from the different knowledge contexts to which it is exposed - is a crucial element of their innovative strategy.

Innovation literature has suggested that technology sourcing strategies affect the structure of the newly created knowledge, in ways that may influence the ease with which it diffuses to other agents. In fact, the way resources are put together to create new knowledge influences the process of knowledge transfer. Rajan and Zingales (2001) demonstrate that when innovators rely on internal routines and firm-specific knowledge, external agents may find it difficult to absorb the resulting information, due to their limited understanding of the general structure of technology. Teece (1986) has suggested that the use of specialized and co-specialized complementary assets, unavailable to agents others than the innovating firm, is crucial to hamper competitors' expropriation of the proprietary technology. In the specific context of multinational corporations, Zhao (2006) has showed that MNCs' subsidiaries that conduct R&D in countries with weak IPR regimes use strong internal linkages among firm-specific technologies that are dispersed among the other ties of the MNC's internationalised network, thus creating both organizational and geographical barriers to the dissemination of their knowledge within the host-location.

We define the "breadth" of a subsidiary's technology sourcing strategy as the extent to which a subsidiary (i) recognizes and absorbs knowledge from the set of external sources it has access to and (ii) combines it with its own knowledge as well as with knowledge acquired from other MNC's internal sources. Such integration of heterogeneous and geographically differentiated knowledge inputs is likely to increase the complexity and tacitness of knowledge (Westney & Sakakibara, 1986; Zhao, 2006). Local firms that want to absorb the subsidiary's knowledge are exposed to the challenge of accessing the complementary technology that has been used by the foreign unit to develop its knowledge. However, gaining access to such technology is highly difficult since its *locus* is either within other MNCs' ties or in geographically distant knowledge contexts. The more a subsidiary increases the breadth of its technology sourcing, the more complex its knowledge architecture will be, the greater the effort local firms need to dedicate to understand it.

Based on this reasoning, we suggest that a "broad" technology sourcing strategy will increase the time it takes to local firms to absorb the subsidiary knowledge, thus exerting a negative moderating effect on the speed of the process of local knowledge outflows. Hence:

Hypothesis 2. The breadth of a subsidiary's technology sourcing reduces the speed at which its knowledge diffuses over the host-location.

METHODS

Data and Sample

The objective of this analysis is to examine (1) the time patterns of subsidiaries' knowledge diffusion within their host-region, and (2) the effect of subsidiaries' technology sourcing on this process. To this aim, the empirical strategy we pursue is to compare the speed of the subsidiaries' knowledge diffusion process across situations of co-location and non co-location, and to subsequently analyse the role of the breadth of subsidiaries' technology sourcing.

We test our hypotheses on a sample of patents developed by US-based subsidiaries of European and Asiatic firms from the semiconductor industry. The semiconductor industry seems to be the most appropriate empirical setting of this research. In fact, the U.S. semiconductor industry has historically been the target of a large number of inward FDI (Almeida, 1996). Therefore, how to profit from knowledge inflows coming from foreign subsidiaries is a fundamental issues for local agents affiliated to this industry. In addition, the semiconductor sector is characterized by a short technology cycle time (Stuart and Podolny, 1996; Almeida and Phene, 2004), which makes the speed of knowledge transfer a crucial aspect for firms' technological performance. Finally, the extensive use of patents that characterizes this industry allows for an appropriate tracking knowledge flows phenomena.

To create our sample, we followed the procedure used by Almeida and Phene (2004) and Phene and Almeida (2008). We considered the largest semiconductor companies by sales leaders, in year 2005, and select the first 10 European and Asiatic MNCs. This list of firms was compiled using information from Gartner Dataquest and Osiris. For this set of MNCs, we indentified every U.S. subsidiary engaged in innovation between 1983 and 2001, and the set of semiconductor patents these subsidiaries developed in the US host-region. In order to identify a subsidiary's semiconductor patents, we have used Derwent's technological classification. Hence, we retained only patents belonging to the first four Derwent patent classes included in the section "Semiconductors and Electronic Circuitry": U11 (semiconductor materials and processes), U12 (discrete devices), U13 (integrated circuits) and U14 (memories, film and hybrid circuits). Our final sample is composed of 1.530 patents, which were filed over an 18-years period.

For each of the resulting 1530 patents, we traced the patterns of forward citations, to infer the existence of a knowledge flow between the organizations to which the patents were assigned, and analysed the filing date and the first inventor's address in order to build measures on the speed of knowledge transfer and on co-location. Therefore, our level of analysis is the citing patent – cited patent pair. The original size of our sample of citing patent – cited patent pairs is 12.315, but since we excluded self-citations from any unit of the MNC, the final size is 10.317 observations.

The advantages of using patent citation data to analyze the knowledge outflows phenomenon stem from the rich information content provided by patent documents, which includes the geographic location of both the inventor and the "owner" of the innovation, as well as its time and technology. Thanks to this information, patents allow to identify the locus of the innovative activity, the organization to which the patent is assigned, and – most importantly - the temporal characteristics of the invention. In addition, what is pivotal for knowledge spillover studies is that patent documents report a list of citations to other patents which serves the function to indentify the

[1] This means that, in order to be part of our sample, a U.S. subsidiary had to have registered for at least one semiconductor patent during the whole period. Moreover, we checked for the existence of the subsidiary since its establishment until the end of our period of observation. Note that, even if the period of observation of patents stops in 2000, we gathered citation level data up to 2006.

technological antecedents to the particular innovation (Almeida, 1996), and whose inclusion is mandatory in the U.S. patent system.

As literature has widely documented, there are certainly several potential shortcomings to using patent citation data to investigate knowledge flows. First of all, patents and patent citations represent by definition the codified part of technology, and do not allow to capture the transfer of tacit knowledge, thus encompassing a potential systematic under-estimation of the knowlede flows phenomenon. However, this problem is partially mitigated by the fact that codified knowledge and tacit knowledge have been found to be correlated and complementary (Mowery, Oxley, & Silverman, 1996). An additional issue deals with the examiner-added citations, which might create noise in the quantification of knowledge flows, since not all the citations contained in the patent document are spontaneously indicated by the inventor. Notwithstanding this limitation, empirical spillover analysis has long recognized the effectiveness of the citation measure (Jaffe et al., 1998; Fogarty et al., 2000; Alcacer & Gittelman, 2006; Branstetter, 2006), and lets us be confident about its general significance.

To avoid bias due to abnormal patterns of citations along time, we consider only forward citations occurring in the first ten years after the filing date of the focal subsidiary patents. In fact, since the typical life-cycle of a semiconductor product is 5 years (Stuart & Podolny, 1996), allowing for a 10-years observation window seems a fair choice. In addition, our focus of the speed of knowledge transfer seems to be consistent with the establishment of a limited observation period. Since semiconductor companies generally use the U.S. patent system to record their innovations (Almeida & Phene, 2004), to the aim of this study, we consider only patents filed under this system.

In order to test our main effect, we identify co-location between the subsidiary patent and the citing patent as the situation in which these patents belong to the same US

"Metropolitan Statistical Area[2]", and create a dummy variable that allows us to compare the speed of knowledge outflows across situations in which patents are and are not co-located. Subsequently, we observed how the main relationship changes along different levels of breadth of technology sourcing, to identify the effects described in our second hypothesis.

Measures

Dependent Variable: Speed of Subsidiaries' Knowledge Transfer. To measure the speed of subsidiaries' knowledge diffusion, we use the (log of) number of months (plus 1) between the subsidiaries patent application date and the application date of the patents that cite it as prior art. This measure provides an indication of the pace with which subsidiaries' knowledge was utilized in subsequent innovation. Trajtenberg et al. (1997) suggest that the average forward lag between an innovation and its antecedents is a measure of the "*remoteness in time*" of a patent. The shorter this time, the younger is the knowledge source upon which the patent builds, and the higher the speed of its diffusion.

Independent Variable: Co-Location. In order to test our main effect (hypothesis 1), we need to identify situations of co-location between the subsidiary's patents and the citing patents. Therefore, we use a dummy variable that takes the value of 1 if the subsidiary patent and the citing patent belong to the same US Metropolitan Statistical Area, and 0 otherwise. Following recent trends in management and IB literature (Tallman & Phene,

[2] According to the U.S. Census Bureau, a Metropolitan Statistical Area is "*a geographic entity, defined by the Federal OMB for use by Federal statistical agencies, based on the concept of a core area with a large population nucleus, plus adjacent communities having a high degree of economic and social integration with that core*".

2007; Zhao & Islam, 2007), we chose to identify co-location using the "Metropolitan Statistical Area[3]", instead of the "State". This choice is justified by the observation that many of the relevant U.S. semiconductor technology clusters cross several states (e.g., New York - New Jersey – Connecticut), and that - similarly - some states host more than one cluster (e.g., California).

Moderating Variable: Breadth of Technology Sourcing. To capture the breadth of technology sourcing of the subsidiary, we started from Phene and Almeida's (2008) proxy for subsidiaries' combinative capability, an index that measures "*the breadth of knowledge (in terms of its sources) that the subsidiary has used in past innovations*" (Phene & Almeida, 2008, p.909). This measure was developed to capture "*the extent of integration of knowledge from different sources by the subsidiary*" (Phene & Almeida, 2008, p. 908-909). We adopted the measure at the technology-level, and classified the proportion of patents cited by the subsidiary's patent in six possible categories of knowledge sources, that reflect the knowledge contexts to which a subsidiary has the opportunity to access to: the subsidiary itself, the headquarter, other subsidiary in the MNC, other organizations in the host country, other organizations in the home-country, other organizations in all other countries (Phene & Almeida, 2008). The geographical diversity of the subsidiary's knowledge was then captured by the following formula:

$$DIV = 1 - \Sigma_j X p^2_j$$

[3] According to the U.S. Census Bureau, a Metropolitan Statistical Area is "*a geographic entity, defined by the Federal OMB for use by Federal statistical agencies, based on the concept of a core area with a large population nucleus, plus adjacent communities having a high degree of economic and social integration with that core*".

where DIV is the geographical diversity of a subsidiary's knowledge, and pj is the proportion of cites made by the subsidiary's patent to each category j. This measure captures the value of a subsidiary's knowledge, as stemming from its ability to combine the knowledge absorbed from several and geographically distributed knowledge sources with its own knowledge (Kogut & Zander, 1993; Phene & Almeida, 2008). This variable ranges between 0, when the subsidiary has used just one knowledge source to develop its innovation, and 0.83, when knowledge has been homogeneously sourced from the six knowledge source categories.

Control Variables. To control for the fact that patents belonging to the same technological class may cite each other earlier, we add a measure of technological proximity ("*tech_proximity*"). This measure is built as a dummy variable which takes the value of 1 if the citing patent belongs to one of the semiconductor classes we used to select our focal subsidiaries' patents (that is, Derwent's U11, U12, U13 and U14 technological classes), and 0 otherwise.

Subsidiaries that have been located in a given region for a long time might be more integrated in the local knowledge network, thus allowing for a faster diffusion of their knowledge. To control for this potential effect, we included in our analysis a variable, subsidiary age ("*sub_age*"), measured as the number of year in which the subsidiary has been located in the US host-region.

Since patents belonging to different technological classes can follow different patterns of diffusion, we controlled for this effect by including *technology class dummies*. Moreover, we cleaned the analysis for any effects due to time, by including a *year dummy* representing the application year of the focal patents. In addition, since patents that have a high innovative content can be expected to diffuse more rapidly, we include a measure of the patent's "quality" ("*tech_value*"), measured as the number of total forward citations that the patent receives within the 10 years window of observation.

The stage of technological development of a given region in a technology can affect the extent to which an innovation in this field can spread and be used in such a location. To account for this effect, we added a measure ("*Region_Tech_Dev*") defined as the total number of semiconductor patents that are registered in the region in the application year of the focal patent.

Finally, we included in our analysis a measure of technological complexity of the subsidiaries' semiconductor patents, to account for the fact that more complex technologies are more difficult to be understood outside the firm's boundaries, and therefore its diffusion process can be slower. To build this measure, we analyses all the backward citation the subsidiary patents referred to previously invented patents, and classified the latters according to their main technology class. We then measured our variable ("*tech_complexity*") through the following formula:

$$\text{Tech\_complexity} = 1 - \Sigma_j \text{ X } p^2_j$$

where pj is the proportion of cites made by the subsidiary's patent to each technology class j.

RESULTS

Table 1 reports the descriptive statistics for our measures. On average, the lag of the forward citation lag of our patents is equal to about 4. This corresponds to a value of the number of months it takes to subsequent inventors (both co-located and non co-located) to use subsidiaries' knowledge of 64.09 months, that is more than 5 years. The mean value of the index that measures the use of different categories of knowledge sources is 0.42, suggesting that on average subsidiaries have their knowledge sources relatively distributed among the possible ones (note that the index varies between 0 when all the knowledge is sourced from a single context and 0.84, when the subsidiary homogenously uses all the available knowledge sources).

Insert Table 1 about here

Table 2 reports the correlation coefficients between the variables considered in our descriptive analysis, showing that the breadth of subsidiaries knowledge sourcing is negatively correlated with the citation lag, that is, with the time it takes to other inventions to build on the subsidiary's knowledge.

Insert Table 2 about here

Table 3 reports the results of the OLS regression models. We first test a baseline model that includes all our control variables. As expected, the results show technological proximity between the cited and the citing patents decreases the citation lag. Innovations in a given technology are more easily used by inventors in the same technological field. In addition, the negative and significant coefficient of the stage of technological development of the region ("*Region_Tech_Dev*") confirms that technologies diffuse faster in location that are more advanced in that area of expertise.

The coefficient of our measure of the subsidiaries patents' technological value is positive and significant, suggesting that patents of higher value take more time to be absorbed. Although this can seem counterintuitive, it may suggests that patents of higher technological value have a more innovative content which takes more time to be codified and used by other inventors.

Insert Table 3 about here

In order to test our first Hypothesis, in Model 2, we included our colocation dummy. The negative (-0.058) and significant ($p<0.01$) coefficient of "Colocation" shows that, on average, citations from patents that are spatially closer (that is, located in the same Metropolitan Statistical Area) occur earlier than citations from patents that are more distant. Note that all self-citations (that, forward citations that come from any other unit of the multinational firm – either the focal subsidiary, the headquarters and other subsidiaries) have been excluded from the analysis to focus only on the different rapidity of transfer to external agents.

In Model 3, we included our measure of the breadth of subsidiaries' technology sourcing, which does not have a direct significant effect on the speed of the local spillover effect. To test our second hypothesis, in Model 4, we interacted the colocation dummy with our measure of the breadth of subsidiaries' technology sourcing, using the mean centering technique. The interaction term turns our to be positive (0.208) and significant ($p<0.05$). This result supports our second hypothesis, according to which a high breadth of a subsidiary's technology sourcing slow down the process of local diffusion of its own knowledge. To better understand our results, in Figure 1, we have depicted the differences in the relationships between the citation lag and our co-location measure in situations where the breadth of the subsidiaries' technology sourcing is high or low. It is shown that the slope of the line for our main relationship decreases for situations of high breadth of technology sourcing. It appears that, in presence of co-location among citing and cited patents, the time it takes to local agents to use the subsidiaries' knowledge is greater, when the latter is built up by using a high breadth of technology sources. This evidence suggests that when subsidiaries combine inputs from several technology sources, it will take more time to local agents to absorb the resulting knowledge, because of an increase in complexity and tacitness. More specifically, these results suggest that – in presence of a low breadth of the subsidiaries' technology sourcing – the relative advantage of being co-located to the foreign firm is higher, as shown (Figure 1) by the greater difference, in terms of citation lag, between the co-located and non co-located agents.

Insert Figure 1 about here

DISCUSSION AND FUTURE RESEARCH

Initial results indicate that foreign subsidiaries' knowledge diffuses faster within the local context than elsewhere, thus suggesting the existence of a time-based advantage for co-located firms. Previous literature in both International Economics and International Business has already provided evidence on the quantitative dimension of the benefits, in terms of knowledge outflows, that domestic firms enjoy due to MNCs' foreign direct investment. In this study, we complement this finding by showing that local agents' gains from foreign subsidiaries' localization are not only based on the *quantity* of technology that can be absorbed, but also on the *speed* of this absorption. Being co-located to foreign subsidiaries offers to local firms the opportunity to come in contact with newly created technologies sooner than more distant agents do. This allows to anticipate competitors in the development of new products and processes that build on the focal inventions, and provides the chance to explore new technological patterns before other firms.

However, our results also show that, when MNCs' subsidiaries develop new knowledge by integrating technological inputs originating from the several knowledge sources to which they are exposed, the speed of the local spillovers diminishes. This finding can be read in the perspective of the knowledge protection strategies of multinational firms. In fact, previous literature shows that foreign firms perceive the high risk of expropriation of their knowledge when operating abroad (Zhao, 2006; De Faria & Sofka, 2010; Mariotti et al., 2010), thus enforcing their protection mechanisms. Consistent with this idea, our results suggest that foreign subsidiaries increase the complexity of their knowledge by combining several, geographically distributed technology inputs in order to counteract the ease of local knowledge dissemination, activated by proximity.

In the perspective of local firms, the hypothesized moderating effect of the breadth of subsidiaries' technology sourcing suggests that the advantage of being co-located is relatively greater in situation of low breadth. In this case, the increase in the speed of knowledge transfer associated with the situation of co-location is much higher, than in the case of high breadth of technology sourcing. This result can be explained considering that, when subsidiaries develop new knowledge by relying on a single technology source, only agents that are spatially close either to the technology source or to the technology recipient (i.e., the subsidiary) find it easier to absorb the newly created knowledge. Conversely, when subsidiaries combine several, geographically differentiated technology sources to create new knowledge, many other agents that are located close to one of the technology sources used by the subsidiaries have a chance to absorb its knowledge.

This paper has several limitations. The first one refers to the use patent citations to infer knowledge flows. When applying for a patent, inventors have to indicate the citations to previous inventions on which a patent builds. This practice is mandatory in the U.S. patent system, though patent examiners can add citations others than those spontaneously selected by the inventor, when they believe there is a clear link between the content of the innovations.

While adding "extraneous" citations, as well as deliberately excluding appropriate citations is not likely, because it would respectively mean to narrow the innovative scope of the patent (Jaffe et al., 1993) and to get exposed to sanctions by the U.S. Patent and Trademark Office (Branstetter, 2006), the citations eventually added by the examiners can represent a relevant problem since, as a matter of fact, examiner-added citations create noise in the quantification of true knowledge outflows. Notwithstanding this limitation, empirical analysis has long recognized the effectiveness of the citation measure to capture knowledge flows (Jaffe et al., 1998; Fogarty et al., 2000; Alcacer & Gittelman, 2003; Branstetter, 2006).

Beyond the examiner-added citations problem, using a citation-measure requires the fixation of an accurate definition of what we mean for the term "knowledge outflows": indeed, it should be taken into account that this measure allows to catch only a specific type of knowledge flows, i.e. those which generates further innovation. Following Branstetter (2006), in this study we consider as knowledge outflows only those processes "*by which one inventor learns from the research outcomes of others' research* *projects and is able to enhance her own research productivity with this knowledge, without fully compensating the other inventors for the value of this learning*".

Unfortunately, the setting of such a strict definition entails a potential systematic under-estimation of this phenomenon. Indeed, when assessing the knowledge contribution that MNCs' subsidiaries can provide to local firms, many other aspects – which cannot be captured by the citation measure – should be accounted for.

First of all, the localization of FDI may induce domestic firms to the imitation or the adoption of existing technologies "imported" in the host country by the MNCs' subsidiaries: although these mechanisms do not generate further innovation, and hence cannot be captured by the citation measure, they do improve the competitiveness of local firms, and should be considered when evaluating the knowledge effects of MNCs' localization.

In addition, when a MNCs' subsidiary locates in a foreign country, its best organizational practices may spread to domestic competitors: Alfaro and Rodriguez-Clare (2004), for instance, highlight that the idea of a MNC in the maquila sector in Honduras to provide a free breakfast to employers (thus boosting their incentive to work, and productivity) rapidly diffused to other firms, becoming a standard for the industry. These effects do not fall within a citation-based knowledge outflows definition, although they clearly have beneficial effects for indigenous firms.

In sum, citations are just a partial and indirect measure of knowledge outflows, though by now the most extensively used (Jaffe et al, 1993; Almeida, 1996; Frost, 2001; Branstetter, 2006; Zhao & Islam, 2007; Agarwal et al., 2009).

Notwithstanding the limitations of the study, which in addition will require us to improve our empirical tests using a regression analysis that is more appropriate to our time-based dependent variable (Cox-models could be an alternative), we believe that this paper also provides some interesting implications that could be useful to both local firms and MNCs. In the perspective of local firms, it offers a more comprehensive evaluation of the potential advantages of being co-located to highly innovative agents like MNCs' subsidiaries. It shows that, under certain conditions, foreign subsidiaries provide local firms with the opportunity to gain a prompt access to recently created knowledge. In the perspective of MNCs, it gives information about the time in which their investment in innovation will provide them a rent, before local competitors' will be able to imitate them; more specifically, it informs subsidiaries' managers on the opportunities associated with a strategic use of the knowledge sources they are exposed to, not only in terms of knowledge creation, but also in terms of knowledge protection. In fact, traditional IB literature has mainly looked at knowledge-based FDI as a means through which multinational firms could increase the quality of their innovation, by sourcing new and diverse sets of knowledge from different locations. In this paper, we show that having access to such geographically distributed knowledge sources may benefit multinational firms in an additional way, that is, by helping them keeping their knowledge secret for a longer time, thus protecting their foreign subsidiaries' competitive assets from local firms' expropriation.

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Table 1. *Descriptive statistics.*

Variable	*Obs*	*Mean*	*Std. Dev.*	*Min*	*Max*
Citation_lag	10317	3.996	0.6334	0	4.796
Colocation	10317	0.142	0.345	0	1
Breadth	10317	0.418	0.203	0	0.8
Tech_proximity	10317	0.665	0.472	0	1
Sub_age	10317	12.495	5.889	0	25
Region_tech_dev	10317	6540.193	4395.885	148	14007
Tech_complexity	10317	0.332	0.275	0	0.898
Tech_val	10317	26.420	23.529	0	102

Table 2. *Correlation matrix.*

	1.	2.	3.	4.	5.	6.	7.	8.
1.Citation_lag	1.000							
2.Colocation	-0.037	1.000						
3.Breadth	0.006	-0.006	1.000					
4.Tech_proximity	-0.035	-0.004	-0.013	1.000				
5.Sub_age	-0.054	-0.063	0.021	0.046	1.000			
6.Region_tech_dev	-0.110	-0.043	-0.016	0.074	0.544	1.000		
7.Tech_complexity	0.031	-0.041	0.172	-0.326	-0.052	0.012	1.000	
8.Tech_val	0.124	-0.003	0.002	-0.209	0.087	-0.009	0.262	1.000

Table 3. *Forward citation lag: OLS regression analysis.*

Dependent Variable: Forward Citation Lag		*Baseline Model Model 1*		*Co-location Model Model 2*		*Model 3*		*Interaction Model Model 4*	
Independent Variables									
Co-location	*Hp. 1*			-0.058	***			-0.058	***
				(0.017)				(0.017)	
Breadth						-0.009		-0.042	
						(0.032)		(0.034)	
Co-location*Breadth	*Hp. 2*							0.208	**
								(0.081)	
Controls									
Tech_Proximity		-0.039	***	-0.039	***	-0.039	***	-0.038	***
		(0.013)		(0.013)		(0.013)		(0.013)	
Sub_Age		0.001		0.001		0.001		0.001	
		(0.001)		(0.001)		(0.001)		(0.001)	
Region_Tech_Dev		-0.000	***	-0.000	***	-0.000	***	-0.000	***
		(0.000)		(0.000)		(0.000)		(0.000)	
Tech_Complexity		0.017		0.013		0.018		0.016	
		(0.024)		(0.024)		(0.025)		(0.025)	
Tech_Value		0.087	***	0.088	***	0.088	***	0.087	***
		(0.008)		(0.008)		(0.008)		(0.008)	
Const		3.764	***	3.378	***	3.760	***	3.771	***
		(0.098)		(0.098)		(0.099)		(0.099)	
F Statistic		19.56	***	19.18	***	18.84	***	18.08	***
R squared		0.041		0.042		0.041		0.043	
N		10.317		10.317		10.316		10.316	

1) Robust standard errors in parentheses.
2) ** p<0.05, *** p<0.01.
3) All models include year dummies and technology class dummies.

Figure 1. *Moderating effect of the breadth of technology sourcing*.