International knowledge sourcing by foreign MNE subunit's innovation: competence creating vs competence exploiting

Sarah Edris
Rutgers Business School
Department of Management and Global Business
sarah.edris@rutgers.edu

John Cantwell
Rutgers Business School
Department of Management and Global Business
cantwell@business.rutgers.edu

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ABSTRACT

This paper examines the patterns of international knowledge sourcing in competence-creating (CC) vs competence-exploiting (CE) types of innovative activity by foreign-located MNE subunits in the pharmaceutical industry. We use backward patent citations to establish the structure of the knowledge sources on which foreign-located subunits rely in developing new inventions for their CC and CE innovations. For the period 1976-2014 we examine the effects on international knowledge search for foreign subunits of their capacity to draw upon intra- and inter-organizational ties for different technical purposes in a relational system. We find that interfirm and university based linkages increase international sourcing for exploitative efforts, but that foreign subunits rely on diverse sources in their local environment for creative efforts. To further understand the knowledge landscape, we support our statistical analysis through an examination of the evolution of the knowledge network for the purpose of CC and CE knowledge sourcing, and compare their network structures. We discuss the organizational affiliations and differentiated networks within which foreign subunits source knowledge to develop innovative activity. Our findings extend international business studies by shedding light on how firms benefit from where and for what technical purpose they source their knowledge. Our findings have important policy and managerial implications.

Key words: MNE, knowledge networks, international sourcing, innovation

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INTRODUCTION

The more open international environment has been a stimulus to expanding the range of geographic and organizational knowledge sourcing activities of foreign subunits. The context for which MNEs have taken part has become more open and networked in recent years, allowing a greater access to international markets, and an increase in intrafirm and inter-organizational knowledge exchange. The international business literature has highlighted the importance of inter- and intra-organizational networks in influencing technological development. Recent studies in particular have explored the relationship between the use of internal and external knowledge sources in innovation, and the evolving structure of knowledge development within and across national boundaries (Cantwell et al. 2019). In this paper, we use backward patent citations to establish the structure of knowledge accumulation over time and space, and examine these sources of MNE networks for competence-creating (CC) and competence-exploiting (CE) search efforts. We ask, for which technological purpose do MNEs draw on intra-firm, intra-industry, university, and hospital knowledge, and across which geographic boundary.

We draw on several strands of literature to form the context of our research. First, we build on the technological accumulation approach (Cantwell, 1989), in which technological knowledge is understood as being cumulatively developed through international MNE networks, and new technologies rely on novel combinations of prior knowledge (Arthur, 2009). This knowledge is either derived locally or globally, depending on the conditions under which MNEs source technological knowledge (Frost 2001), and their organizational ties. We then discuss the implications for the nature of CE and CC technological development efforts in MNE foreign subunits. The increasing business networks, and the changes in the composition of the organizations involved, are particularly due to a change in subunit roles (Cantwell and Piscitello, 2000). As a result of this changed organizational responsibility, MNE subunits are not only engaging in creating new fields of capabilities, they're also relying on international connections and networks for both CE efforts, reflecting the emergence of knowledge-seeking (Doz et al., 2001; Thursby & Thursby, 2006) as opposed to traditionally local market-seeking or resource-seeking strategies. With these considerations in mind, we adopt an international business interpretation of social network analysis (SNA), as featured in Cantwell et al. 2019, to further examine the structural changes of networked relationships for the purpose of knowledge building, and make suggestions as to how the nature of CC and CE activities affect international sourcing. We ask: under what conditions, and for which technical purpose, do MNEs source knowledge internationally, and through which type of organizational tie is that knowledge sourced?

We test hypotheses by examining organizational ties and structure of MNE networks in the pharmaceutical industry between 1976 and 2014. We detect links between organizations by considering their aggregated cites to other organizations. We provide a descriptive investigation of the changing structure of CC and CE networks over time, and compare the change in composition of sources. Here, we claim that subunits have come to rely more on international interfirm, university and hospital knowledge sources for exploitative efforts, but continue to rely on local linkages for explorative activities. This is due in part to the internationalization of professional and epistemic communities (Thomson, 1993), the increase in ties between international scientific networks and technological practice (Mazzoleni and Nelson, 2007), and the increase in scope of knowledge dissemination within and between organizations (Dunning, 1995).

The main theme in the conventional literature has been the relevance of local knowledge search for CC activity. However, less attention has been given to how international knowledge sourcing has been affected by the activity of foreign located subunits in a relational system. This paper examines the patterns of international knowledge sourcing in CC vs CE types of innovative activity, and shows the relative significance of the diverse knowledge sourcing of CC, and the more international, application focus of CE. We therefore examine the effect of organizational sources of knowledge that foreign subunits in our sample have relied in developing CE and CC technologies on sourcing knowledge beyond a locally bounded context.

We use a unique and novel dataset of organizational knowledge ties created by patents granted by the US Patent and Trademark Office (USTPO) to examine the relationship between the largest corporate groups active in the pharmaceutical industry and various organizations in developing CC and CE technologies. We also compliment the empirical analysis by applying techniques from network analysis. This allows us to go beyond traditional indicators to understand the landscape of knowledge building using patent citations, which, by allowing us to construct nodes (organizations) from the patents and the links between them using citations, reveals the social structure of the network. The timespan for network analysis covered the period 1976 to 2014 to represent a historical outlook of knowledge building across technological fields, space and time.

Compared to recent studies adopting patent-based network approaches, which focus on actor linkages, agency, and the channels of knowledge transmission, thereby enhancing our knowledge on the role of individual inventor networks on innovation, we examine the sources or antecedents of knowledge over time in terms of nodes described by a combination of the technological field, location of invention, the organization and industry of origin, and in particular, the ties entailed in the structure of knowledge accumulation. Thus, we pay attention to the evolving structures of geographic, organizational, and cross-technological field knowledge development over time to address the remaining gap in our understanding of the performance of MNEs as a whole as opposed to the performance of a focal actor within the MNE.

The paper is structured as follows. First, we review the literature and hypothesize the effects on sourcing knowledge internationally, depending on the search effort undertaken by the foreign subunit. Next, we describe the empirical research methodology and the data employed; and examine the evolution of our networks across technological fields, space and time. We then specify our models and report the results. Finally, we discuss our findings, the implications for future research, and draw some conclusions.

THEORETICAL BACKGROUND AND HYPOTHESES

The original received internalization explanation of the existence of the MNE is based on the supposition that the MNE is merely a vehicle for technology transfer; technology is first developed in the parent company, then disseminated to subsidiaries as a central resource (Buckley & Casson, 1976); its knowledge may then spill over to the local environment in the place where it is sited. The early question in the IB field was therefore 'under what conditions does the firm transfer technology internally within the MNE or externally to other firms (e.g. through licensing)?' (see e.g. Buckley & Casson, 1976, for an analysis that was grounded within transaction cost economics). When technology transfer occurs within the MNE, according to the conventional account this is because the primary concern of the firm is fear of knowledge leakage. In this view, technology is typically treated as a form of public good, as being analogous to information that is fully tradable, and can be transmitted at low marginal cost. However, tacit capability is also a part of technology, and this private good element is not easily traded or exchanged. Thus, an alternative line of work can be traced back to another question, 'under what conditions do MNEs source technology internationally through a network of geographically dispersed affiliates?' (e.g. Dunning 1998; Cantwell 1989). This supposes instead that the MNE is primarily a vehicle for innovation or technology creation, of which technology transfer becomes then part of a wider story. This research stream derived from innovation studies led to a greater interest in the competence-based or capabilities-based approach to the firm in the analysis of the MNE (Cantwell & Piscitello 2000; Teece 2014), and in the role of inter-company networks through which MNEs may be able to capture returns on their innovation (Mowery, Oxley, & Silverman, 1996).

The theory of technological accumulation views MNEs as agents of cumulative technology creation (Cantwell, 1989, 1991). Technological knowledge tends to be built cumulatively over time (Nelson and Winter, 1982; Rosenberg, 1982), and so creating new knowledge entails drawing on a variety of different sources. MNEs are distinguished by deployment of international networks for innovation, since these networks reinforce the local specialization of spatially dispersed but connected learning processes. Indeed, because technology is actually difficult to transfer across different contexts (Teece, 1997), recent work has not only investigated how technological change is localized into its geographic context, but the conditions under which sub-units of firms continue to innovate in their own local subsidiary environment (Rugman & Verbeke, 2001). These studies find that they may do so to tap into the local innovation system and discover new ways of innovating in that environment, in what has been termed competence-creating types of activity (Cantwell & Mudambi, 2005), and in such cases they become more locally embedded in the local innovation system. It therefore follows that especially once it has a subsidiary network in which at least some subsidiaries are locally competence-creating, the MNE is not just an agent of technology transfer but more generally a vehicle for international innovation or distributed knowledge creation through a geographically dispersed yet connected network.

Recent literature has shown that typically only some selected subsidiaries are highly innovative contributors and central to their knowledge networks of relationships within the corporate group (Birkinshaw & Hood, 1998; Chini, 2004), which reinforces the significance of the conceptual distinction between competence-creating (CC) and competence-exploiting (CE) types of subsidiary or subsidiary activities (Cantwell & Mudambi, 2005). Some of this work has related the typology of subsidiary technological development to the overall mandates of subsidiaries using survey evidence, although it seems reasonable to suppose that there may be elements of both CC and CE types of technological efforts in any given foreign-owned subsidiary, i.e. CC subsidiaries are likely to perform at least some CE efforts, and vice versa (Cantwell & Piscitello 2014; Zander, 1999). To be sure, CE activity is akin to public good element of technology, which is then more readily available, is more common with other subunits of the corporate group, and can be more easily shared and circulated across different parts of the enterprise. CC activity is more akin to novelty of private element of technology that depends on the distinctiveness of a subunit's network, or what's different about the subunit as opposed to what's shared within the subunit as a group.

Historically, technological knowledge related to the MNC's core field of specialization was primarily created in the parent company, upon which subunits and external partners relied. In this traditional model, new competency creation typically occurred in selected subunits; however, there has been an increased interaction between local creativity (e.g. adapting to local conditions or establishing relationships with other firms or scientific institutes) and knowledge availability within the parent, such that the role of both, knowledge that is internal and external to the MNE is critical in the creation of new competencies within the subunit. This ability to source knowledge from a variety of organizations has also affected the extent to which foreign subunits have begun to source knowledge internationally, and differed in doing so for CC and CE types of activity.

We therefore follow the stream of literature which investigates subsidiary evolution in terms of the course of the distribution of CC and CE forms of activities. In particular, we are concerned with how and why the knowledge base of the corporate group comes to draw upon the generation of knowledge in specific geographical contexts and through the distinctiveness of the local innovation systems of these spatially dispersed settings in which an MNE has subsidiaries (Almeida & Phene, 2004; Frost, 2001). When MNEs disperse knowledge development, they may be attempting to access geographically dispersed and hence diverse knowledge bases, which each reflect the innovative traditions of a given location (Kogut & Zander, 1993; Almeida, 1996; Frost 2001). Subsidiary innovation is therefore driven by both the differentiation of innovation across places and across firms (Almeida, 1996; Frost 2001), especially when the subsidiary becomes embedded in its local network, which may be constrained by the prior composition of domestic firm networks in the local environment (Cantwell & Mudambi, 2011). However, what can be seen to be missing from the literature is the simultaneous combination of the effects of the geography of knowledge sourcing and the organizational distribution of innovation across actors, particularly in terms of the conditions for continued and sustained international innovative efforts of existing subsidiaries.

To be sure, the ease with which technology is transferred within the MNEs network may be attributed to the establishment of a common social community with shared values across its differentiated subunits (Kogut and Zander 1993; Nohria and Ghoshal 1997), and the networked pattern of inter-unit knowledge exchange (Chini 2004; Monteiro, Arvidsson and Birkinshaw 2008), where the more central subunits in the internal MNE network tend to engage in greater knowledge-based interactions with both their parent firm, and their own local environment. In addition, the greater ease of people in the macroeconomic environment, as well as the internationalization of professional and scientific communities (Held el al., 1999; Morgan, 2001; Karlsson et al., 2010), has contributed to the international diffusion of knowledge. This openness has been held together by more reciprocal knowledge exchanges within and across organizations, increasing the scope for discovering new knowledge combinations (Cantwell & Piscitello, 2014). Indeed, since each organization possesses a limited amount of knowledge, building on the knowledge of a variety of organizations and across geographical space is the key to novelty in further knowledge development. Innovative efforts are therefore a function of combining internal and external knowledge sources (Veugelers and Cassiman, 1999; Cantwell et al. 2019), and geographically distant sources. One key external network through which subunits may access relevant knowledge is firms in other industries. The opportunities for finding important sources of complementary knowledge through inter-industry have also increased the extent of international dispersion of CC activity, but little is known on the geographic sourcing of CE activity.

An influential part of the innovation studies and strategy literature highlights the positive effect of external knowledge search, as can be demonstrated by the growth of collaborative research and various types of licensing and know-how agreements, as well of course informal linkages in seeking and absorbing that know-how (Laursen and Salter, 2014; Chesbrough, 2006; Cohen and Levinthal 1989). In this way, the ability to become a knowledge source for other parts of the corporate group depends on the degree to which a subsidiary can acquire from its local environment knowledge relevant to the existing core knowledge base of the MNEs. This is particularly important in the pharmaceutical industry, which relies heavily on inter-organizational networks in absorbing complementary areas of knowledge, and generating innovation (Edris, 2019). These knowledge-based networks increase the awareness of each firm about the knowledge repositories available from external sources, and how they may potentially fit with the firm's own efforts, especially when sub-units within the firm are geographically dispersed and so search can reach into a greater diversity of sources.

However, little is known about the role of intra- and inter-organizational knowledge linkages in a relational system, and how these roles function internationally, and for which technical purpose. While the strategy literature seems to suggest that most of the benefits of inter- and intra- organizational networks are features of some network configuration or structure, the geographic characteristics of these networks has generally been overlooked in this literature. Prior empirical work has also focused primarily on a focal inventor as an actor within the firm, and the immediate inventor network of that actor, rather than the overall network structure of the MNE. Gutler et al. (2012) in particular have tested the benefits that accrue to the overall organization as opposed to the actor, yet the local vs global distinction featured in their work is driven by the network, and not the geographical contexts of which the MNEs are a part.

There is a stream of research in economic geography and international business which offers some guidance about the organizational innovative outcomes of local vs global connectivity. On the one hand is the embeddedness perspective (Almeida & Phene, 2004), which argues that sub-units are embedded in the environment they are situated in, and so source knowledge from their local, inter-organizational networks (Cantwell & Iammarino, 2000). There is also an established literature which suggests that university-industry linkages in particular tend to be geographically localized (D'Este, Guy, & Iammarino, 2013; D'Este & Iammarino, 2010; Jaffe, Trajtenberg, & Henderson, 1993), although little is known about connections to hospitals and health care facilities, and to which extent locally embedded, competence creating sub-units then share the knowledge they discover from such facilities with other organizations located in the same geographic environment. We expect that MNEs are likely to draw on relatively distant knowledge locally from both, intra- and inter-organizational networks in their explorative search efforts, but are likely to draw on specialized knowledge wherever it is in the world.

The IB and strategy literature highlights the crucial role of international networks in providing MNEs with access to innovative activities organized across borders (Cano-Kollmann et al, 2016;). MNEs therefore need to connect to international networks, to access and combine technological knowledge developed globally (Turkina and Assche, 2018). Intra-organizational linkages between the parent firm and its foreign-located subunits are therefore associated with global search efforts (Berry, 2014; Cantwell & Piscitello, 2014, 2015; Monteiro, 2015), though little is known about the structure of these international intra-MNE networks. Moreover, while local organizational networks help the MNE in its explorative search efforts, international connectivity can do so to a greater extent in further exploiting their capabilities (Scalera et al, 2018), because the probability of acquiring the right specialized knowledge is greater, particularly when searching for excellence in core scientific fields, or the best university science-based knowledge. However, the literature on university-industry linkages seems to lack insight about the type of knowledge being sourced internationally, and for the purposes of different kinds of knowledge building efforts – explorative or exploitative. Even less is known about the connections to clinical or medical practices. We expect that foreign subunits are likely to draw on intra-MNE knowledge for subsequent innovations, as confirmed in prior IB literature. We hypothesize that ties with biotech and pharmaceutical firms, universities and hospitals are related to international sourcing for CE activity, and more distant, inter-industry ties are related to local sourcing for CC activity. Thus:

Hypothesis 1: An increase in linkages with biotech and pharmaceutical firms will lead to an increase in international sourcing for CE activity.
Hypothesis 2: An increase in inter-industry linkages will lead to a decrease in international sourcing for CC activity.
Hypothesis 3: An increase in university linkages will lead to an increase in international sourcing for CE activity.
Hypothesis 4: An increase in hospital linkages will lead to an increase in international sourcing for CE activity.

METHOD

Organization of data

We identified 45 major corporate groups engaged in US patenting in the pharmaceutical field listed in Table 1a and examined the geographical distribution of their technological activity (Cantwell, 1995). These firms are either pharmaceutical/biotech firms with at least 250 patents over the period or firms in related industries with a substantial interest in pharma, i.e. at least 40% of their patents in the pharmaceutical field. For example, we include Bayer, which has a major pharmaceutical business; Monsanto, a firm that successfully shifted toward a biotech model for R&D; and Novartis, which quickly sold off its' chemical businesses following its creation through the merger of Ciba-Geigy and Sandoz to focus on pharmaceuticals. We do not include firms such as Du Pont, a firm that responded to the chemical crisis by diversifying into pharmaceuticals. Even though it had strong marketing capabilities, it failed to build ties with scientific institutes, which is critical to success in developing pharmaceutical technologies in the current era. Du Pont eventually sold its' drug division to Bristol-Meyers Squibb, a large pharmaceutical company in our sample.

The share of total world patents in the pharmaceutical field for which these 45 corporate groups are responsible is around 35%. To identify the subsidiaries of these firms, an historical examination of the ownership structure of each pharmaceutical corporate group was conducted through an extensive search into their history using the D&B Who Owns Whom directories. We then consolidated patenting assignees associated with each of these corporate groups, and identified the organizational affiliation of assignees that are cited parts of the knowledge network (knowledge sources) of the citing groups. The cited organizations include other corporate groups, as well as smaller firms, universities, research institutes, hospitals or health care providers, and government institutes.

Insert table 1a here

We extracted from USPTO websites all patents granted from 1976-2016 belonging to the 45 groups identified, and all the earlier patents that were cited by these. The citing patents of the major groups included all the patents from their worldwide research facilities, not only their patents invented in the pharmaceutical field. The record for each patent included the ultimate ownership (the affiliation of the assignee) and the location of invention, as well as the year in which the patent was granted and the technological field of activity (derived from the patent class and sub-class). We also recorded the sector of activity of each organization; the home or headquarter country of each firm; and coded the locations from which US patents in the pharmaceutical fields originate. We then examined all pairs of citing and cited patents identified, which account for over 70% of both, the number of cited patents (regardless of how many times each patent was cited) and citations (individual citing-cited pairs).

The analysis was conducted on the foreign subunits of these corporate groups – defined as firm-location combinations, meaning the entire operations of a given MNE in a particular host country; we disaggregated the citing subunit's activity to distinguish between CE and CC components, following Cantwell and Piscitello (2014). CC activity represents exploratory search efforts into new scientific and technological areas, whereas CE activity represents an extension of search efforts undertaken by the parent firm in the home country. To classify patents in this way, we first constructed a measure of parent firm specialization, i.e. a Revealed Technological Advantage (RTA) index equal to, or greater than 1 in a field. An RTA index allows us to control for inter-field and inter-firm differences in the propensity to patent (Cantwell 1989). Specifically, RTA is defined as follows: $RTA = (P_{ij} / \sum_i P_{wj}) / (\sum_j P_{ij} / \sum_{ij} P_{wj})$, where P_{ij} is the number of patents in technological field j (1,…,6) by a parent firm i, and P_{wj} is the number of all patents in the same sector by all firms. The 6 technological fields broadly organize 56 technological fields in common groupings of types of technology, which themselves collect related classes and subclasses of the USPTO classification system. These are chemical, electrical, mechanical, transport, ICT, and other technologies. We then constructed a measure of a foreign subunit's specialization, i.e. an RTA equal to, or greater than 1 in a field.

We classified patents as CC search efforts if the citing patent is in the same field and in which the citing foreign subunit has an RTA equal to, or greater than 1, but the parent firm has an RTA less than 1 in that field; all other patents were classified as CE, which include those that are merely imitating the parent firm, or subunits that aren't bringing in new areas of specialization into the group knowledge. We therefore proxy the foreign subunit's innovative activity by the number of patents granted in the US to the MNE for research carried out in another country than the MNE's home country. In other words, we exclude parent firms from this study, which, by definition, are the benchmark for which subunits are defined. For example, we exclude all Pfizer's subunits located in the US, Glaxo's subunits located in the UK, etc. Empirically, this is an improvement on Frost (2001), since the data constructed was able to delineate what is CE activity for the subunits, which is more readily available to flow around the enterprise.

Table 1b includes descriptive statistics about the foreign subunits in our sample. As can be seen in that table, the MNE's innovative activity is increasingly conducted abroad, i.e. the total number of patents in foreign subunits rose from 7,510 in period 1 to 15,656 in period 8. We identified and observed 297 foreign subunits developing CC technologies and 579 foreign subunits developing CE technologies, and ran separate regressions for these from 1976 to 2014 (broken into 5-year intervals) because the USPTO has not updated its classification system from which we are able to group the 56 technological fields, and use the 6 aggregate level classification in constructing our RTAs and determining the CC and CE patents for our analysis. Otherwise we would have run the analysis to 2016.

Insert table 1b here

For both, CC and CE citing patents, we grouped citations according to whether the implied knowledge sourced from cited to citing patent was from other subunits within the MNE, firms in the same or other industries, universities, hospitals, research or government institutes, and whether it was local (within the same country of invention) or international. While some other recent studies have used patent data to examine individual inventor or co-inventor knowledge networks, we trace knowledge sources or antecedents over time within or between nodes represented by organizational sub-units that conduct research leading to patentable inventions. The sub-unit is defined as a major citing corporate group in a specific location - the combination of all citing patents with assignees associated with that firm and inventors resident. We measure the intensity of citations (backward citations) within or between firms active in the pharmaceutical industry, and with other organizations, whether firms in other industries or universities, research institutes or hospitals, paying attention to the changing geography knowledge sourcing for CC and CE activities. Thus, our nodes are organizations in a geographical location in both CC and CE networks.

Patent citation analysis

We adopt a perspective of networks within and between firms, and other organizations, which share information, recombine ideas, and generate outcomes that result in innovation using patents granted in the US. The key feature of these patents is that each patent record includes its citations. Prior work has found that these citations provide a suitable proxy for organizational networks, since they indicate an organizational, geographic, and technical link for the purpose of knowledge building (Frost, 2001; Almeida 1996; Jaffe et al. 1993). Our essential analytical scheme is grounded upon a conceptualization of technological knowledge accumulation over time, as an evolutionary process. Each dyad or connection between an earlier cited patent A and a subsequent citing patent B represents a recognition of knowledge relevancy, or a step in a knowledge building process. In Jaffe *et al.*'s (1993) words, 'a citation of Patent X by Patent Y means that X represents a piece of previously existing knowledge upon which Y builds.' Frost (2001) in particular has argued, if local innovative activity of subunits is exploitative, subsidiaries are more likely to cite the parent company, with the added qualification that the technology of the parent is adapted to the local environment; whereas competence creating subunits are more likely to cite local actors (Frost 2001; Kogut & Zander, 1993;, Almeida, 1996) and leverage potential benefits of local differentiation compared to what would have been received from the parent firm. In this paper, we focus specifically on the conditions under which subunits in a given location cite prior patents originating in their local environment or internationally, and for which technical purpose.

We therefore follow prior research in examining the patent citation network as a proxy for MNE knowledge, which allows us to collect and compare network data from multiple organizations. In this, we also follow previous studies which have empirically examined organizational-level outcomes using patents (Gutler et al. 2012), though in our work, we focus specifically on patent citation ties between organizations as a whole, e.g. major corporate groups and firms within the same industry, in other industries, with hospitals, research institutes, and universities, and national laboratories or government institutes, as opposed to focal actors within organizations, which aren't necessarily accessing the different innovative traditions of geographically dispersed knowledge bases that international subsidiaries have access to. Citation data are therefore distinct from inventor networks in allowing us to examine the organizational and geographic characteristics of knowledge networks.

Outline description of the networks

The term 'knowledge networks' is used in the literature to denote a set of nodes and their knowledge relationships (Carnabuci & Bruggeman, 2009; Yayavaram & Ahuja, 2008). In a knowledge network, the nodes represent the knowledge generating, transmitting and receiving units; the link between them indicates the knowledge-based relations between these nodes. Our motivation for adopting a networked approach is our interest in studying the wider system among actors or overall structure of the knowledge network compared to the more atomistic or reductionist perspective adopted in the strategy literature. Within this network, the individual actor can combines and re-combines inputs sourced from diverse knowledge sources (Kuhn, 1962; Graham, 2015; Jackson, 2008).

We employ network visualization techniques to provide a first assessment of the evolution of the structure of MNE networks responsible for CC and CE patents over the period 1976 to 2014 (Powell et al., 2005; Rosenkopf & Padula, 2008; Tomasello et al. 2016). Figure 1 illustrates the MNE network of subunits responsible for CE patents. Figure 2 illustrates the network of subunits responsible for CC patents. The organizational links differ in color: intra-MNE in green, intra-industry in blue, inter-industry in black, universities in red, hospitals in pink, research institutes in purple, and government institutes in yellow. We further subdivide these networks into 8 periods to derive network measures for the analysis.

Insert figure 1 here

Insert figure 2 here

We are specifically interested in observing the organizational links MNEs have relied in developing CE vs CC innovations over time; in this way, we not only observe where knowledge is sourced, but for what purpose. Using a social network analysis over time (across periods) as illustrated in Figures 1 and 2, we can observe that the size of the networks increases in terms of nodes (organizations) and intensity of ties (number of citations between organizations); this also means, because new nodes tend to be less connected to central existing nodes, the density of the networks decrease over time (Albert and Barabasi, 2002). In other words, the knowledge network of leading pharmaceutical companies has become far more widespread and interconnected across actors (our network nodes) since the 1970s: the overall network connectivity in terms of the existence of knowledge ties (as measured by the average weighted degree) rose over time, while connectivity in terms of the average intensity of ties (as measured by graph density) fell over time.

We can also observe the difference in the structure of the networks. Indeed, the presence of ties are not stable over time, i.e., just because there is a tie between specific organizations in Period 1, doesn't mean this tie had influenced on the ties with other organizations, e.g. Novartis and Sanofi subunits were identified as one of the most central in Period 1 of the CC networks, but other subunits have become more central in later periods. Another interesting feature of the network is its strength. The strength of the CC networks have been increasing consistently over time, whereas the strength of the CE network decreased in periods 6 and 7, suggesting shifts in firm strategy, but also a change in the composition of network ties over time. The CE networks also take an interesting shape – they were much more centric the first 4 periods, before gravitating towards two opposing poles; in period 8 the network settles towards one of those sides.

Overall, we find an increasing trend in the use of citations along various sources of knowledge. Not only are local and international sources of knowledge being used with increasing frequency, intra-firm and inter-organizational knowledge sourcing show an increasing trend. We also find that there is a bi-directional causality between inter-organizational and intra-firm knowledge ties, as well between local and global ties, suggesting the location of the parent company and MNE network contributes to the development of the MNE innovativeness in a self-reinforcing way. There are also some effects that run in only one direction. Firms that draw on their own intra-firm knowledge networks are more likely to use international inter-organizational networks for their own innovations. In developing CC innovations, foreign subunits have relied primarily on external knowledge sources (hospital knowledge and inter-industry knowledge), whereas in developing CE innovations, foreign subunits have relied on intra-firm and university knowledge. After 1997 especially, we find that knowledge flows between universities and pharmaceutical firms grew more than previously and their share of citations remained stable in later periods; while these university-industry knowledge flows were mainly geographically localized, for CE innovations, we find that subunits have established strong ties with American universities. Finally, we find that knowledge flows between pharmaceutical firms declined, and an increasing reliance on ties with biotech firms.

Statistical analysis

Table 2 summarizes the results of the application of Chow's seminal test (Chow, 1960), which justifies the decision to estimate separate models for the sub-samples, and make comparisons between the estimates of factors that influence the share of international knowledge search. The effects of these factors would have been otherwise ignored if only a pooled sample model were used. All variables appear statistically different between the CC and CE datasets, using this procedure, and so we reject the null hypothesis that the coefficients of the variables are equal for both sub-samples. These findings show a need for certain search strategies to facilitate increased international search efforts.

Insert table 2 here

Based on this finding, the statistical analysis is conducted on a cross-section at the level of CC and CE patents registered to the foreign subunits of our 45 corporate groups between 1976 and 2014 (broken into 5-year intervals), as well as the type of knowledge source these groups have relied in developing these patents, and across which geographic space. The unit of analysis is a subunit-period (297 subunits developing CC technologies; 579 subunits developing CE technologies). There are 648 observations in our CC sample; 1,641 observations in our CE sample.

To test our hypotheses, we developed dependent variables from the two datasets, which are derived from the geographic information contained on citing and cited patents. Thus, the fundamental unit of analysis in the models pertaining to these hypotheses is a foreign subunit-period. We constructed the dependent variables (CC and CE) as an indicator of whether a patent citation was developed by inventors in the local environment, or elsewhere in the world. The dependent variable is therefore the share of international citations for CC and CE patents of the foreign subunits of our corporate groups. We test hypotheses by running separate regressions, one with the dependent variable from the CC sample, and the other, CE. Our hypotheses relate the geographic sources of innovation to characteristics of the organizational link and search effort of the corporate group. Measures to operationalize these were constructed from the citing and cited patent. To test our hypotheses, we calculated the share of CC and CE cites to subunits within the firm, to other firms within the same industry, universities, and hospitals. We also control for the subunits knowledge portfolio and the centrality of the subunits responsible for CC and CE innovations. Table 3 below summarizes the variables used in the analysis.

Insert table 3 here

RESULTS

Table 4 provides descriptive statistics and Tables 5a and 5b provide a correlation matrix of the CC and CE variables.

Insert table 4 here

Insert table 5a here

Insert table 5b here

Results are reported in Table 6, which is divided into two sections by geographic dependent variables of the search effort implied. Numbers in parentheses represent standard errors. Interpretation of the regression coefficient follows a normal pattern: positive, significant values indicate that an increase in that variable increases the share of international citations for CE search efforts in model 1, CC search efforts in model 2, *ceteris paribus*.

Insert table 6 here

Overall, the data provide support for our hypotheses, suggesting that international search efforts for CE and CC activity are influenced by the organizational characteristics of the knowledge network. As expected, the negative, significant coefficients on intra-MNE in model 1 indicate that subunit innovations that build directly on prior technologies of other subunits within the corporate group decrease international sourcing for CC activity (*p<.001)*. While we also find a negative, significant impact in model 2, the effect size is smaller (*p<.001)*. This is because CE activity represents the area of commonality across different parts of the enterprise, and so this finding confirms the relevance of CE activity as the organizational knowledge glue that can flow around the network more readily. At the same time, even CE technological efforts need adapting to the local environment.

The positive, significant coefficient on biotech for CE knowledge sourcing suggests that foreign subunit innovation that build directly on prior technologies developed by biotech firms increase international sourcing (*p<.01)*. This is partially due to the more open and collaborative setting that took hold of the industry (thanks primarily to the institutional and organizational support that explained the success of biotech in the US, then elsewhere in the world), in addition to the maturing of biotech, which brought an increasing number of MNEs in the industry (Edris, 2019), and has therefore allowed foreign subunits to draw on a more international network, and exploit their capabilities.

Similarly, the coefficient on university for CE knowledge sourcing is positive and significant ($p<.001$), since the probability of acquiring the right specialized knowledge is greater when searching internationally for exploitative efforts, particularly when searching for knowledge that is external to the firm, such as the best university science-based knowledge, where that knowledge might not necessarily be located where that subunit is situated. To further understand the geographic distribution of the firm-university linkages, we identified where the universities are situated, and found that foreign subunits rely greatly on linkages to US universities – 91% (the top 10 include University of California, University of Texas, MIT, Columbia, Michigan, Stanford, Harvard, Cornell, University of Washington, and University of Florida). The remaining 9% are distributed among universities situated in 23 other countries, suggesting that, for CE technological development, foreign subunits will cite American universities, locally otherwise.

Future research should examine the transmission of knowledge from universities to the industry. Put another way, because no centralized authority commands their development, scientific institutes may be able to generate and transmit their knowledge internationally more quickly through their ability to establish personal ties (Perri et al. 2017). We find no significant impact on hospital-firm, which has to do more with downstream practical applications of knowledge around the core knowledge base of the firm. Though we did find a positive, significant effect at the sub-period level, but this effect went away in the second half of the period. Future research should examine these linkages.

Finally, the negative significant coefficient on interindustry for international knowledge sourcing for CC development suggests that foreign subunit innovation builds on prior knowledge of more diverse actors locally ($p<.01$); these subunits would be more likely to tap into the local innovation system (Cantwell & Mudambi, 2005). In other words, when a firm has a more insider status in its local environment, the less likely it is to source knowledge internationally. In fact, the knowledge portfolio coefficients confirms that an increase in the number of organizational ties in type has a negative, significant effect on international sourcing for both, CE and CC development (*p<.001)*. Moreover, the negative, significant coefficients on subunit centrality indicates a decrease in international sourcing the more central the subunit is to the network (*p<.001)*.

Although the empirical literature has shown that subunit performance involves interunit and local (Phene and Almeida, 2008; Venaik et al., 2005), and international (Cantwell & Piscitello, 2014) knowledge sourcing, we extend prior work by discerning which types of organizational linkages impact international knowledge sourcing, and for which technological efforts, CC vs CE.

DISCUSSION AND CONCLUSION

Where MNEs draw their knowledge from is a central question in international business, particularly in examining the evolution of MNE networks. This study sought to address this question by asking for which technical purpose are MNEs drawing this knowledge, and what are the organizational and geographic characteristics of the network these MNEs have relied. We contribute to the discussion on the MNEs desire to gain knowledge from diverse sources, including other subunits within the corporate group, which may be searching in parallel or in fact competing with other subunits within the firm, other firms within the same or other industries, and universities. Though we weren't able to find support for firm-hospital linkages, we believe this is an opportunity for future research, since little is known about the connections between drug discovery search efforts and downstream knowledge of hospitals. At the same time, our results highlight the role of subunit centrality and the diversity of knowledge sourcing. One key contribution of this study is therefore to ask for which search efforts and though which organizational link do MNEs rely in their knowledge source strategies in an international business context by investigating the evolution of the CE and CC networks and estimating the effects of intra-MNE, intra- and inter-industry, university, and hospital sourcing on the firm's global search efforts.

To be sure, in the conventional literature, the main theme has been the relevance of local knowledge search for CC activity. However, scant attention has been given to how international knowledge sourcing has been affected by the activity of foreign located subunits in a relational system. We examined the international knowledge sourcing of CC and CE types of activity. We first confirmed the Frost 2001 finding, i.e. the conditions under which subunits continue to rely on intrafirm knowledge. We then explored what's outside the parent company and intrafirm relationships, and have been able to show that CC international sourcing depends more on external and knowledge sources, whereas for CE activity, foreign subunits continue to rely on knowledge that is relevant to the industry, from biotech firms and universities. These findings are therefore able to tell us something more about the diverse local knowledge sourcing of CC and the more application focus of CE.

In addition, this paper makes several specific contributions that distinguish it from prior research. Theoretically, we combine international business, innovation, and strategic management strands of literature which dichotomize explorative and exploitative search efforts. Empirically, we link organizational characteristics of knowledge networks to geographic sourcing for knowledge building dating back to the mid-1970s. Key factors that emerged from the analysis include (1) characteristics of the MNEs innovative efforts that suggested a logic of competence-creating or competence-exploiting; (2) the identity of the actors for which the subunits source knowledge, including subunits within the corporate group, other subunits in the pharma and biotech industries, as well as in other industries, universities, and hospitals; and (3) propose an international business interpretation of the network techniques applied at the organizational and geographic level. Indeed, these results suggest that the knowledge sources MNEs rely increase international knowledge search for CE activity is a combination of internal, biotech, and university innovations; and more diverse sources for CC activity. Exploring the dynamics of such linkages holds promise in future research.

Because of the richness of the data used to conduct the analysis, we were able to detect the links between organizations by aggregating their patent citations to other organizations. The empirical analysis here spanned organizational and geographic levels, not merely the focal actor within a specific firm. The first step is to show the evolution of the CC and CE networks and provide a descriptive investigation of the changing structure of networks over time. We observe that the networks change in the composition for each type of search effort. We then examined the sources of knowledge over time and the ties entailed in the structure of the MNEs knowledge network. Thus, we pay attention to the evolving structures of geographic, organizational, and cross-technological field knowledge development over time to address the remaining gap in our understanding of the performance of MNEs as a whole as opposed to the performance of a focal actor within the MNE, i.e. co-inventor networks link inventors on the basis of their co-involvement in research projects, which entails their active cooperation.

However, the study is not without its limitations. Given the positive significant effect of university linkages on international sourcing for CE types of activity, future research should examine the scientific specialization of the universities where a link is established to better understand which scientific disciplines are relevant for CE types of activities, and how they impact international sourcing. We expect that only some kinds of university science is accessed internationally, while others are accessed locally. While universities may be responsible for the country for which they are situated, contributing to national science and technological availability, the nature of science has itself become more global, e.g. Harvard is not just a national institution, because the nature of science itself has changed, which explains how technology access could be anywhere in the world. This would of course have important implications for science and public policy.

The results of this study also have potentially important implications for issues and debates in international business, innovation, and economic geography. Our results not only show which sources sub-units draw their knowledge, but how these are associated with searching for knowledge internationally. In other words, the extent to which foreign subunits search for CC and CE innovative activities internationally is driven by their engagement in both intra-corporate and ties to various types of organizations (Venaik et al., 2005; Meyer et al., 2011), and that subunits developing CC technologies benefit from both external embeddedness in their local environment, which allow these subunits to access wider internationally dispersed knowledge networks (of other MNE competitors, those within and outside of the pharmaceutical industry; scientific knowledge; hospital knowledge; customers, etc.), and internal embeddedness within their MNE group (Chung and Alcacer, 2002; Cantwell & Piscitello, 2014). In this way, foreign subunits have increasingly relied on international connections external to the MNE for competence-exploiting activities. Results also have important policy implications, given that global knowledge-seeking strategies are affected by recent political trends. Given the openness and cross-border integration of business networks of the current era, firms have increasingly relied on international organizational sources of knowledge, and so the availability of wider knowledge sources have become steadily more important (Cantwell & Piscitello, 2014); however, we confirmed which type of organizational, and for which technical purpose.

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Table 1a.
Listing of MNEs in the sample

Company	Nationality
Abbott	US
Abbvie	US
Amgen	US
Biogen	US
Bristol Myers-Squibb	US
Celgene	US
Eli Lilly	US
Gilead	US
Immunomedics	US
Incyte	US
Ionis	US
Johnson & Johnson	US
Merck & Co.	US
Monsanto	US
Pfizer	US
Promega	US
Regeneron	US
Rigel	US
Vertex	US
Sterling Drug	US
Valeant	CA
AstraZeneca	GB
GlaxoSmithKline	GB
Reckitt	GB
Allergan	IE
Perrigo	IE
Sanofi	FR
Novartis	CH
Roche	CH
Syngenta	CH
Bayer	DE
Boehringer	DE
EMerck	DE
Gruenenthal	DE
Novo Nordisk	DK
Novozymes	DK
Akzo	NL
Astellas	JP
Eisai	JP
Ono	JP
Otsuka	JP
Sankyo	JP
Shionogi	JP
Takeda	JP
Teva	IL

Table 1b. Sample of foreign subunits

Period	*Total Patents*	*Share of CC Patents*	*Total Subunits*	*Total MNE*	*Subunit/ MNE*	*Subunits with CC Patents/ MNE*	*Patents/ Subunit*	*Host Countries*
1976 to 1980	7,510	.10	178	26	6.85	2.85	42.19	39
1981 to 1985	5,723	.10	153	28	5.46	1.96	37.41	31
1986 to 1990	7,676	.14	194	30	6.47	2.63	39.57	36
1991 to 1995	9,863	.13	272	33	8.24	3.12	36.26	36
1996 to 2000	14,117	.09	370	44	8.41	2.57	38.15	48
2001 to 2005	9,975	.23	355	38	9.34	3.39	28.10	48
2006 to 2010	9,678	.29	346	39	8.87	3.15	27.97	45
2011 to 2014	15,656	.20	453	43	10.53	2.70	34.56	46

Table 2. Chow test outcome

Variable	Chow test
Intra-MNE	19.88***
Pharma firms	10.29***
Biotech firms	6.08***
Interindustry	5.46***
Universities	8.05***
Hospitals	4.56***
Knowledge portfolio	3.91***
Subunit centrality	3.75***

****Significant at the 1% level*

Table 3. Names and definitions of variables

Variable	**Operational definition**
Dependent variable	
International sourcing	Foreign subunit's share of international cites
Independent variables	
Intra-MNE	Foreign subunit's share of cites to other subunits within the MNE
Biotech	Foreign subunit's share of cites to biotech firms
Pharma	Foreign subunit's share of cites to pharma firms
Inter-Industry	Foreign subunit's share of cites to firms in other industries
University	Foreign subunit's share of cites to universities
Hospital	Foreign subunit's share of cites to hospitals
Knowledge portfolio	Number of foreign subunit's organizational ties (1,…,10)
Subunit centrality	Eigenvector scores

Table 4. Descriptive statistics

Variable	Observations	Mean	Std. Dev.	Min	Max
International CE	1,641	0.820	0.253	0	1
Intra-MNE	1,641	0.273	0.276	0	1
Pharma firms	1,641	0.531	0.331	0	1
Biotech firms	1,641	0.037	0.118	0	1
Inter-industry	1,641	0.132	0.212	0	1
Universities	1,641	0.067	0.131	0	1
Hospitals	1,641	0.006	0.036	0	1
Knowledge portfolio	1,641	5.121	2.663	1	10
Subunit centrality	1,974	.009	0.072	0	1
International CC	648	0.776	0.299	0	1
Intra-MNE	648	0.219	0.279	0	1
Pharma firms	648	0.380	0.345	0	1
Biotech firms	648	0.014	0.061	0	1
Inter-industry	648	0.290	0.312	0	1
Universities	648	0.055	0.145	0	1
Hospitals	648	0.004	0.033	0	.667
Knowledge portfolio	648	4.340	2.590	1	10
Subunit centrality	922	0.012	.093	0	1

Table 5a. Cross correlation matrix of variables from the CE sample

	Intern	*IntraMNE*	*Pharma*	*Biotech*	*InterInd*	*Uni*	*Hosp*	*K. Port*	*Cent*
Intern	1.000								
IntraMNE	-0.134	1.000							
Pharma	-0.059	0.361	1.000						
Biotech	0.037	0.052	-0.183	1.000					
InterInd	0.023	-0.246	-0.464	-0.117	1.000				
Uni	0.085	-0.203	-0.262	0.070	-0.082	1.000			
Hosp	0.022	-0.075	-0.082	0.007	-0.024	0.040	1.000		
K. Port	-0.276	-0.051	-0.044	0.061	0.029	0.085	0.062	1.000	
Cent	-0.207	0.032	0.001	-0.019	0.026	-0.020	-0.005	0.218	1.000

Table 5b. Cross correlation matrix of variables from the CC variables

	Intern	*IntraMNE*	*Pharma*	*Biotech*	*InterInd*	*Uni*	*Hosp*	*K. Port*	*Cent*
Intern	1.000								
IntraMNE	-0.245	1.000							
Pharma	-0.076	0.490	1.000						
Biotech	0.016	-0.025	0.016	1.000					
InterInd	0.012	-0.402	-0.530	-0.104	1.000				
Uni	0.011	-0.154	-0.181	0.009	-0.098	1.000			
Hosp	0.013	-0.004	0.001	-0.002	-0.052	-0.007	1.000		
K. Port	-0.224	0.017	0.157	0.157	-0.127	0.026	0.065	1.000	
Cent	-0.147	0.060	0.055	0.028	-0.032	-0.007	-0.004	0.203	1.000

Table 6. Results of cross sectional regressions on international knowledge sourcing, 1976-2014

Variable	*DV: International sourcing*	
	CE	***CC***
	(1)	*(2)*
Intra-MNE	-0.118***	-0.334***
	(0.023)	(0.047)
Pharma firms	0.017	0.041
	(0.023)	(0.042)
Biotech firms	0.125**	0.117
	(0.052)	(0.186)
Inter-industry	0.032	-0.114**
	(0.033)	(0.044)
Universities	0.158***	-0.072
	(0.048)	(0.080)
Hospitals	0.187	0.178
	(0.164)	(0.322)
Knowledge portfolio	-0.025***	-0.026***
	(0.002)	(0.004)
Subunit centrality	–0.457***	–0.241**
	(0.076)	(0.102)
Constant	0.955***	0.986***
	(0.021)	(0.035)
R^2	0.129	0.136
Adj R^2	0.124	0.125
Prob > F	0.000	0.000
N	1,641	648

*Note: *p<0.10; **p<0.01; ***p<.001*
Standard errors in parentheses

Figure 1: Evolution of the structure of subunit knowledge sourcing for CE activity

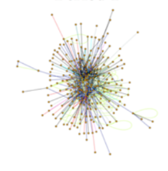
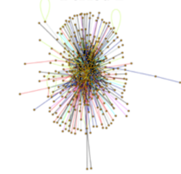
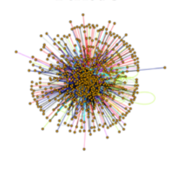
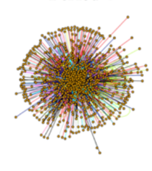
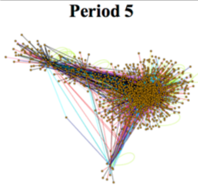
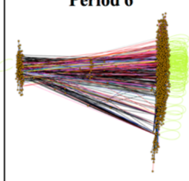
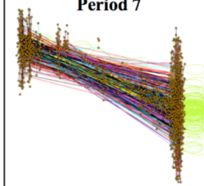
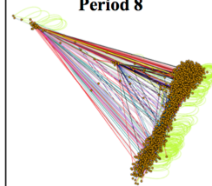
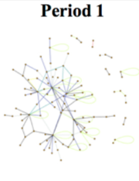
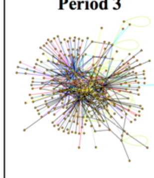
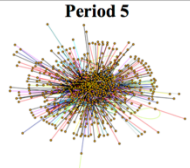
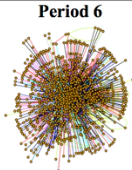
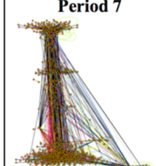
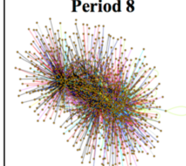
Period 1	Period 2	Period 3	Period 4
			
Degree: 6.149 Strength: 25.851 Diameter: 18 Edge density: 0.012	Degree: 8.069 Strength: 40.473 Diameter: 22 Edge density: 0.011	Degree: 9.412 Strength: 55.990 Diameter: 38 Edge density: 0.008	Degree: 10.499 Strength: 73.385 Diameter: 28 Edge density: 0.006
Period 5	**Period 6**	**Period 7**	**Period 8**
			
Degree: 14.289 Strength: 101.281 Diameter: 29 Edge density: 0.006	Degree: 10.678 Strength: 63.535 Diameter: 68 Edge density: 0.004	Degree: 11.446 Strength: 90.071 Diameter: 99 Edge density: 0.004	Degree: 11.652 Strength: 164.600 Diameter: 426 Edge density: 0.003

Figure 2: Evolution of the structure of subunit knowledge sourcing for CC activity

Period 1	Period 2	Period 3	Period 4
			
Degree: 2.569 Strength: 5.647 Diameter: 7 Edge density: 0.013	Degree: 3.251 Strength: 9.521 Diameter: 19 Edge density: 0.010	Degree: 4.695 Strength: 16.135 Diameter: 19 Edge density: 0.008	Degree: 5.172 Strength: 17.847 Diameter: 112 Edge density: 0.006
Period 5	**Period 6**	**Period 7**	**Period 8**
			
Degree: 6.182 Strength: 22.297 Diameter: 71 Edge density: 0.006	Degree: 5.800 Strength: 34.123 Diameter: 101 Edge density: 0.003	Degree: 5.936 Strength: 59.440 Diameter: 181 Edge density: 0.003	Degree: 6.173 Strength: 72.867 Diameter: 100 Edge density: 0.003