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ORGANIZATIONAL KNOWLEDGE NETWORKS AND LOCAL SEARCH: THE ROLE OF INTRA-ORGANIZATIONAL INVENTOR NETWORKS

SRIKANTH PARUCHURI[1]* and SNEHAL AWATE[2]
[1] *Department of Management & Organization, The Pennsylvania State University, University Park, Pennsylvania, U.S.A.*
[2] *Department of Strategy, Indian School of Business, Gachibowli, Hyderabad, India*

Research summary: *While firms tend to build on their own knowledge, we distinguish between depth and breadth of local search to investigate the drivers of these behaviors. Given that inventors in a firm carry out the knowledge creation activities, we strive to identify inventors responsible for these behaviors by employing the notion of an intra-firm inventor network. A longitudinal examination of 14,575 inventors from four large semiconductor firms using patent data supports our hypotheses that the reach of inventors in the intra-firm network and their span of structural holes have independent and interactive effects on these two types of local search behaviors. These findings have implications for research on exploitation and exploration, organizational knowledge, knowledge networks, and micro-foundations.*

Managerial summary: *Large amounts of knowledge may reside within firm boundaries, and managers are interested in understanding who may leverage this knowledge to generate novel ideas. We focus on collaborations among knowledge workers to address this question. Using the collaborations among all knowledge workers in a firm, we show that those who have higher reach to all others and those who form bridges to connect unconnected groups of workers tend to leverage not only more organizational knowledge, but also knowledge that is more dispersed in the organization. Managers could use these insights to shape the use of organizational knowledge by firm inventors, and also to make decisions about granting or withholding access to internal knowledge platforms for knowledge workers.*

INTRODUCTION

Recognizing the prevalence and significance of local search (March, 1991; Nelson and Winter, 1982), scholars have examined the drivers of or ways to overcome local search (Monteiro, 2015; Rosenkopf and Almeida, 2003; Stuart and Podolny, 1996; Tzabbar, 2009). Some of these explanations reflect the micro-foundations approach (Felin and Foss, 2005) and primarily focus on individual characteristics (Audia and Goncalo, 2007; Rosenkopf and Almeida, 2003; Tzabbar, 2009; Tzabbar and Kehoe, 2014; Tzabbar, Silverman, and Aharonson, 2015). Others have taken a more macro approach and focused on firm-level attributes, such as absorptive capacity (Cohen and Levinthal, 1990), organizational slack (Greve, 2007), organizational structure (Jansen, Van den Bosch, and Volberda, 2006), alliances (Stuart and Podolny, 1996), role of headquarters (Monteiro, 2015), and organizational age and size (Kotha, Zheng, and George, 2011).

In this article, we complement both these streams of earlier research and focus on intra-organizational networks, and in particular, on individuals occupying different positions in the intra-organizational networks. When an organization creates new technological knowledge, it is the inventors in

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*Correspondence to: Srikanth Paruchuri, Smeal College of Business, 404 Business Building, University Park, PA 16802. E-mail: sup28@psu.edu

the organization who create the new knowledge by recombining existing knowledge (Fleming, 2001). So, when organizations build on their own technological knowledge, it is the inventors who build on the organizational knowledge. But, not all inventors are likely to build on organizational knowledge equally. Some inventors may build more on organizational knowledge than others. These variations may stem from differences in awareness of the entire organizational knowledge that exists, owing to inventors' bounded rationality (Cyert and March, 1963), and access to the entire organizational knowledge (Allen and Cohen, 1969). Prior research suggests that these differences among individuals in terms of their awareness and access to organizational knowledge can be explained in terms of their positions in the intra-firm network (Allen and Cohen, 1969; Burt, 1992; Nerkar and Paruchuri, 2005). In essence, we examine the extent to which individuals occupying different structural positions in the intra-organizational network engage in local search behavior.

Employing the notion of intra-organizational inventor network, we specifically examine the relationship between an inventor's reach and span of structural holes in this intra-organizational inventor network with local search behavior. Focusing on organizational boundaries, we distinguish between two dimensions of local search: depth of local search—the amount of organizational knowledge that he or she recombines in his or her innovations—and the breadth of local search—the extent of technological domains and geographic locations from which organizational knowledge is recombined. We also examine the interactive effect of an inventor's reach and span of structural holes. Our findings, using patent data on 14,575 inventors from four large semiconductor firms, largely support this theoretical framework and have implications for research on organizational exploitation and exploration, organizational knowledge, knowledge networks, and micro-foundations of firm R&D.

THEORETICAL BACKGROUND AND DEVELOPMENT

Dimensions of organizational local search

Prior research has theorized and broadly documented that firms build on their own knowledge (March, 1991; Nelson and Winter, 1982; Teece, 1988). Specifically, March (1991) posited that organizational knowledge is easily accessible and already familiar compared to external knowledge bases. Exploiting this familiar and accessible knowledge not only is less costly, but also provides more certainty on the outcomes than exploring knowledge from outside the firm's boundaries. We follow this stream of research to focus exclusively on local search within organizational boundaries—use of organizational knowledge for recombination activities (Katila and Ahuja, 2002; Rosenkopf and Nerkar, 2001).

Building on and extending this research, we distinguish between two dimensions of local search: depth and breadth of local search. *Depth of local search* refers to the amount of organizational knowledge that is used in one's innovation activities. So, we consider inventors using more organizational knowledge in their innovation activities to perform deeper local search than inventors using less organizational knowledge. This is the same notion of "search depth" developed by Katila and Ahuja (2002). *Breadth of local search* refers to the extent of different domains from which organizational knowledge is drawn. For example, technological breadth (geographical breadth) of local search refers to the extent of technological classes (geographical locations) from which organizational knowledge is drawn. So, we consider inventors who source organizational knowledge from more technological domains as performing broader technological local search than inventors who source organizational knowledge from few technological domains. Note that this notion of breadth of local search is quite distinct from "search scope" developed by Katila and Ahuja (2002). While both notions refer to breadth of search, Katila and Ahuja's notion is unbounded about which knowledge is searched, whereas our notion is bounded by search in organizational knowledge.

Intra-organizational networks and local search behavior

Having clarified our notion of local search, we now theoretically elaborate the role of intra-organizational networks in shaping local search behavior. We focus on the network positions of inventors responsible for such organizational local search behavior. That is, while a firm is said to build on its own knowledge, it is the firm's inventors who actually carry out the knowledge creation activities (Allen and Cohen, 1969). Furthermore, not all of the firm's inventors may build equally on the firm's knowledge. We examine how inventors occupying different positions in the intra-firm inventor network use organizational knowledge in their innovation activities.

An intra-firm inventor network can be conceptualized by considering all of the inventors in a firm as nodes and the collaborations between them as ties. Earlier research has shown that the intra-firm inventor network plays an important role in shaping several outcomes of consequence (Allen and Cohen, 1969; Carnabuci and Operti, 2013; Paruchuri, 2010; Reagans and Zuckerman, 2001; Tushman, 1977).

We posit that the intra-firm inventor network is also important in shaping the use of organizational knowledge in innovation activities. The use of organizational knowledge requires that the firm's inventors be aware of organizational knowledge. However, because of bounded rationality, inventors may not be aware of the entire organizational knowledge. While each inventor may have some organizational knowledge, the network that connects these inventors comprises the totality of the organizational knowledge (Hargadon and Sutton, 1997; Kogut and Zander, 1992). In other words, organizational knowledge is distributed in the intra-firm network, and inventors rely on this network to learn and share knowledge (Hansen, 1999; Hargadon and Sutton, 1997; Reagans and Zuckerman, 2001).

Building on this stream of research, we examine how inventors in different structural positions in this network use organizational knowledge in their innovation activities. We posit that the structural positions of inventors in an intra-firm inventor network are associated with differential access to and perceptions of the knowledge distributed in the network, and also provide different motivations for using that knowledge. In particular, we argue that the inventors' reach and span of their structural holes in the intra-firm network—two of the commonly studied positions in the literature—are related to the local search behavior in terms of both depth and breadth of local search. Network reach refers to the short-path lengths to other actors in a network (Schilling and Phelps, 2007), and span of structural holes refers to the number of unconnected groups bridged by the focal inventor (Burt, 1992).

In brief, our thesis is that network positions independently and interactively influence both dimensions of local search. First, compared with a low reach inventor, an inventor with a high network reach has the shortest path lengths to others in the network, which provides the inventor with higher awareness and greater access to the organizational knowledge distributed in the intra-organizational network. Second, compared to inventors who span fewer structural holes, inventors spanning many structural holes have awareness of and access to the organizational knowledge distributed in diverse pockets of the intra-organizational network. This awareness and access will positively influence both depth and breadth of local search. Finally, we argue that these two network measures interact to drive the local search behavior of inventors.

Network reach of inventors

Network reach refers to the short-path lengths to other actors in a network (Schilling and Phelps, 2007). An actor is said to have higher reach in a network if that actor can reach others in the network in the shortest path (Schilling and Phelps, 2007). An actor's reach is the sum of the reciprocal distances that are reachable from that actor to every other actor in a network (Watts, 1999). Prior research found that network reach influences knowledge flows, such that, for example, firms that have higher reach in a network were more productive in the subsequent year (Schilling and Phelps, 2007; Zheng and Zhao, 2013).

We argue that increasing network reach of inventors in the intra-firm network increases both their depth and breadth of local search, as their understanding of the organizational knowledge is enhanced and their motivation to use it in their innovation activities increases. There are several reasons supporting this argument. First, ties are used to share organizational knowledge among inventors. Those inventors who have higher reach can access all other inventors in the shortest paths than inventors who have lower reach (Watts, 1999). Such access available to an inventor with higher reach can provide the inventor with a broader and quicker access to knowledge distributed in the whole network. In essence, inventors with higher reach in the intra-firm inventor network will have better perceptions and understanding of organizational knowledge than inventors with smaller reach. Moreover, these inventors will also have redundant channels for accessing the knowledge distributed in the network, thus opening wider conduits for knowledge flow. This also results in less distortion

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in accessing knowledge. Given that inventors need to know about, understand, and access knowledge to be able to use it in their knowledge creation activities, inventors with higher reach are in a better position to perform local search than inventors with lower reach. Because inventors with higher reach are familiar with and have better access to not only more organizational knowledge, but also organizational knowledge that is distributed in the intra-organizational network in different domains (e.g., technological classes and geographic locations), the depth and breadth of their local search will be higher than that of inventors with lower reach.

Second, inventors are motivated by the impact they make on future technological developments (Nerkar and Paruchuri, 2005). Inventors are likely to extend efforts to increase their own impact by making their own knowledge accessible to others. Compared to inventors with lower reach, inventors with higher reach in the intra-firm network are better able to communicate their own knowledge to others in the firm because of their shortest paths to others (Schilling and Phelps, 2007). Moreover, they can communicate it to others with less distortion. Consequently, inventors with high network reach have higher internal citations than inventors with low reach (Schilling and Phelps, 2007). Such recognition of high reach inventors in the organization may cause them to identify more with organizational knowledge. And, such higher identification leads them to champion organizational knowledge more, which reflects in their local search behavior. Because inventors with higher reach can identify not only more strongly with more organizational knowledge, but also with organizational knowledge in more domains (e.g., technological and geographic domains) than inventors with lower reach, the depth and breadth of their local search will also be higher.

Additionally, others in the organization can relate to innovations that are built on organizational knowledge better because of their familiarity with it (Cohen and Levinthal, 1990). Inventors can make their innovations more familiar to others in the firm if they build on organizational knowledge than building on external knowledge (March, 1991). This aspect implies that the impact of high reach inventors' knowledge in the organizational realm could be substantially higher if they build their innovations by recombining organizational knowledge—more as well as from different domains—than if they build innovations by recombining less organizational knowledge or knowledge in only few domains. In contrast, even if inventors with small reach can generate innovations familiar to others, by recombining organizational knowledge, they may not be able to communicate their innovations widely in the organization, as they either lack ties to or have long paths to most others (Schilling and Phelps, 2007). Thus, inventors with low reach do not have as much motivation as high reach inventors to use organizational knowledge to increase their own impact.

In summary, increasing reach of an inventor in the intra-organizational inventor network is associated with richer access, better perceptions and understanding of organizational knowledge, and a stronger motivation to use it in their innovation activities. Both these aspects—ability and motivation—together increase the inventor's local search behavior, both in terms of depth and breadth of local search. Thus, we hypothesize that:

> *Hypothesis 1: An increase in the reach of inventors in an intra-firm inventor network will be positively related to (a) the depth and (b) the breadth of local search.*

Span of structural holes of inventors

Burt (1992) has brought together the information benefits underlying weak ties, network control benefits of betweenness centrality, and the power benefits of favorable exchange positions to develop the concept of structural holes. If an actor is the only bridge or connection between two groups of unconnected actors, the actor is defined as spanning a structural hole. Given that the focal actor is the only connection between the two unconnected groups, the ties of the focal actor provide benefits that are additive rather than overlapping (Burt, 1997). For example, Hargadon and Sutton (1997) found that IDEO, a design firm, was more innovative because it spanned different, unrelated industries.

First, as inventors span more structural holes, they have access to organizational knowledge distributed more widely in the intra-firm network. Given that inventors spanning many structural holes form bridges that connect unconnected groups, these inventors are better able to locate and access knowledge in different, unconnected parts of the network (Burt, 1992, 1997). This ability provides them with a perspective on the unique

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opportunities for recombining knowledge from different parts of the network (Fleming, Mingo, and Chen, 2007; Hargadon and Sutton, 1997). For example, Fleming *et al.* (2007) showed that inventors' spanning of structural holes was positively related to their ability to generate innovations that bring together novel combinations of knowledge from hitherto uncombined domains. Such perspective of inventors spanning more structural holes on unique recombinations increases the extent of their organizational local search.

Second, we argue that inventors spanning many structural holes are more motivated than inventors spanning few structural holes to use organizational knowledge for two reasons: identification and enhancement of their brokering benefits. To elaborate, inventors spanning more structural holes have higher recognition from the organization, in terms of internal citations from firm inventors, than inventors spanning few structural holes (Nerkar and Paruchuri, 2005). Such higher recognition causes more identification with organizational knowledge, and this higher identification leads them to use more of organizational knowledge in their activities.

Additionally, inventors spanning many structural holes tend to receive higher benefits from recombining organizational knowledge than inventors spanning few structural holes. That is, while inventors spanning structural holes have higher impact on organizational activities, others will be able to use these inventors' innovations even more if they are already familiar with that knowledge, which can be achieved by recombining organizational knowledge (Cohen and Levinthal, 1990). Thus, if inventors spanning structural holes generate innovations by recombining organizational knowledge, they may more easily disseminate and relate their innovations to others through their wider reach in the intra-organizational inventor network because of the familiarity of others with the recombined organizational knowledge (Fleming *et al.*, 2007). In contrast, inventors spanning few structural holes may not be able to disseminate their innovations widely even if they generate those innovations by recombining organizational knowledge as they do not span or span few structural holes (Burt, 2004). Consequently, the benefits of, and hence, motivation for using organizational knowledge in their innovation activities are considerably lower for inventors spanning few structural holes than for inventors spanning many structural holes.

To summarize, an increase in the span of inventors' structural holes provides the inventor with unique perspectives on recombining knowledge distributed in unconnected parts of the network. It also motivates them to use this distributed organizational knowledge in their innovation activities. Both of these aspects—ability and motivation—increases the inventor's local search behavior. Such higher local search behavior of inventors who span more structural holes takes both forms identified earlier: depth and breadth of organizational knowledge local search, as inventors spanning more structural holes get access to more organizational knowledge as well as knowledge distributed in more domains (e.g., technologies and geographies) than inventors spanning few structural holes. Therefore, we posit that:

> *Hypothesis 2: An increase in the degree to which inventors span the structural holes in an intra-firm inventor network will be positively related to (a) the depth and (b) the breadth of local search.*

The interaction between network reach and the span of structural holes

We further argue that the span of structural holes not only independently influences local search, but also negatively moderates the relationship between an inventor's reach and his or her extent of local search. That is, the positive effect of higher network reach on organizational local search will be higher for inventors spanning few structural holes than for inventors spanning many structural holes in the intra-organization inventor network. To elaborate, an increase in an inventor's reach is not only associated with a broader and quicker access to the knowledge that is widely distributed in the intra-organizational network, but also with a less distorted understanding of that knowledge (Schilling and Phelps, 2007; Watts, 1999). These benefits of network reach are more helpful for inventors spanning few structural holes in identifying and utilizing organizational knowledge compared to inventors spanning more structural holes. The reason is that, when inventors span many structural holes, they already have access to knowledge distributed widely in the network and increase in their network reach is only generating a redundant benefit (Burt, 1992, 1997). But, inventors who span only few structural holes do not have wider

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access to the organizational knowledge because they do not span bridges, and such inventors will find the broader and quicker access associated with higher network reach more useful in identifying organizational knowledge required for their innovation activities. Further, the less distorted access associated with higher network reach also helps inventors spanning few structural holes to gain more unique perspectives on recombining and sourcing organizational knowledge than inventors spanning more structural holes, as inventors spanning more structural holes already have such insights due to their bridging position (Fleming *et al.*, 2007).

Second, we argued earlier that the motivation of inventors to use organizational knowledge increases with an increase in their network reach because inventors with higher reach have higher identification with organizational knowledge and also get more impact from using organizational knowledge in their innovation activities than inventors with lower reach. Developing on this point, we argue that such an association of network reach with motivation will be weaker for inventors spanning many structural holes than inventors spanning fewer structural holes. To elaborate on identification mechanism, the increase in identification with increasing network reach will be higher for inventors who span few structural holes than for inventors who span many structural holes, as they are already highly identified with the organizational knowledge. Inventors who span few structural holes do not get much recognition, in terms of internal citations, from others in the organization, and an increase in their network reach will then considerably increase such recognition. In contrast, inventors who span many structural holes already have high impact and an increase in their network reach still leads them to the same inventors, which will limit the amount of additional recognition that they receive. Thus, the additional identification with increasing network reach tends to be limited for inventors spanning many structural holes.

Moreover, the knowledge created by inventors spanning many structural holes becomes cognitively accessible and easily comprehensible to scientists in more diverse groups because such inventors interact with diverse, unconnected groups of inventors in the intra-organizational inventor network (Burt, 2004; Fleming *et al.*, 2007). An increase in the network reach of such inventors allows them to communicate this knowledge to the same organizational scientists. In contrast, knowledge created by inventors spanning only a few structural holes is cognitively accessible and easily comprehensible to only limited groups of interconnected scientists because such inventors interact with inventors from limited parts of the network (Fleming *et al.*, 2007). However, an increase in the network reach of such inventors allows them to communicate this knowledge in a rich fashion to a broader group of scientists in the organization, as they can now reach most other inventors of the firm in the least possible steps. Thus, the effect of network reach on the impact from using organizational knowledge is much higher for inventors spanning few structural holes than inventors spanning many structural holes. Given that inventors typically want to have influence, we can infer that the increase in the motivation to use organizational knowledge with network reach is much higher for inventors who span few structural holes than for inventors spanning many structural holes.

Last, increase in network reach implies access to more information. This information access could turn into information overload for inventors who span many structural holes, as they access not only more information, but also information from diverse unconnected groups in the network. However, this increased access to information with increasing network reach is more beneficial for inventors spanning few structural holes, as these inventors were focused in their own group and access to more information could be productively utilized by them.

In summary, the effects of network reach on organizational local search through better access and higher motivation are more pronounced for inventors spanning few structural holes than those who span many structural holes. Such local search behavior reflects in all three forms identified earlier: the amount of organizational knowledge, the breadth of organizational technological domains, and the breadth of organizational geographic locations from which firm knowledge is drawn. Consequently, we hypothesize the following:

> *Hypothesis 3a: The positive relationships between inventors' reach in the intra-firm inventor network and the depth of local search is negatively moderated by the span of their structural holes in the network.*

> *Hypothesis 3b: The positive relationship between inventors' reach in the intra-firm inventor network and the breadth of local search is negatively*

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moderated by the span of their structural holes in the network.

RESEARCH METHODS

Research site and data sources

To test these hypotheses, we needed a context where R&D is an important strategic factor and where the use of existing knowledge in creating new knowledge can be tracked. The semiconductor industry is one context that fits both these criteria. R&D is a very important strategic factor for semiconductor firms, which spend huge amounts on such endeavors to develop the intellectual property that forms the basis for their future profits (Macher and Mowery, 2004). Additionally, the pace of technological developments underlying semiconductor industry seems to follow Moore's law. Moreover, the knowledge idiosyncrasy in this industry is also driven, among other aspects, by the significant dependency of these firms on foundries used for manufacturing (Macher and Mowery, 2004). These aspects of the industry make semiconductor firms an appropriate setting to study local search behavior.

Furthermore, because intellectual property is the basis for the profits of companies in this industry, semiconductor firms tend to protect their intellectual property through patents, meaning that they tend to patent almost all patentable innovations (Levin *et al.*, 1987). Each patent is an identifiable and discrete piece of innovation that includes novelty. In addition, data about these patents is publicly available. Thus, these patents form a good indicator of knowledge developed within semiconductor firms (Carnabuci and Operti, 2013). Moreover, these patents also consist of a section called "prior art," which lists all of the relevant prior knowledge on which this innovation is built. If innovations are considered knowledge recombinations (Fleming, 2001; Nerkar, Paruchuri, and Khaire, 2007; Schumpeter, 1934), "prior art" identifies all the prior knowledge that was recombined to generate the innovation. Consequently, research has considered these "prior art" citations as indicators of knowledge flows (Almeida and Kogut, 1999; Jaffe, Trajtenberg, and Fogarty, 2000; Rosenkopf and Almeida, 2003; Rosenkopf and Nerkar, 2001). Recent research has cast doubts on the prior art citations as indicators of knowledge flows, as some of these are incorporated by the patent examiner (e.g., patent examiner working with the U.S. Patent and Trademark Office or USPTO). However, our research question about citations to organizational knowledge is less prone to these issues for two reasons. First, inventors may not ignore relevant citations to organizational knowledge, as it solidifies the firm's intellectual ownership of these innovations. Second, inventors may not add irrelevant citations to organizational knowledge because patent examiners make sure that only relevant patents appear in the prior art section. Both these factors allow us to have confidence in using prior art citations to capture the phenomenon of interest in this article.

While our hypotheses can be tested using cross-sectional data structure, we employed a longitudinal data structure for robust testing. In particular, we selected the study period from 1985 to 2010. We examined the extent of organizational knowledge used by inventors who differed in their network reach and span of structural holes in the intra-firm inventor network. To do so, we constructed unique intra-firm networks for each firm. We also had to construct this network for each year of observation. To make this task manageable, we used four large semiconductor firms, which were in the top 25 assignees with the USPTO (Alcacer, Gittelman, and Sampat, 2009), as our research contexts—a convenience selection of research contexts. In particular, we collected information about patents from 1975 to 2010 using patent data available on Harvard Dataverse (Lai *et al.*, 2011) that belonged to the following four assignees, their subsidiaries, and their U.S. and non-U.S. acquisitions: Advanced Micro Devices (AMD) Inc., Micron Technology Inc., Koninklijke Philips N.V., and Texas Instruments (TI) Inc. Since each firm is an empirical context, this selection of four contexts to study our research question is superior to typical social network studies that investigate only one context. We identified the subsidiaries of these firms using 10-K filings and annual reports. Further, we gathered their acquisitions in the sample period using Thomson Reuters's SDC Platinum database. Given that we are interested in inventors' use of organizational knowledge, we did not consider the acquired unit's knowledge prior to acquisition as a part of organizational knowledge. However, as a robustness check, we also used dataset where this target knowledge prior to acquisition was also included in construction of variables.

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There is also diversity in these four research contexts selected. While Philips was a major semiconductor firm, it had demerged the semiconductor business and sold it off to a consortium of private equity investors in 2005–2006. Micron was and continues to be in semiconductor memory devices (dynamic random access memory, flash memory, and solid-state drives), even though it briefly forayed into sensor business. AMD was and continues to be in computer processors and related technologies (microprocessors, motherboard chipsets, embedded processors, graphics processors, etc.). Last, TI is a semiconductor design and manufacturing firm, producing a wide range of semiconductor products, including consumer electronics and computers, sensors and controls, digital signal processors, and so on. While TI also made several acquisitions and divestitures, TI focused even more on semiconductors, in contrast to Philips, which divested its semiconductor business. Given these differences, we also performed analysis on each research context in robustness tests.

All the inventors who patented with these four firms during our observation period formed our sample. In total, we had 14,575 unique inventors from these four firms in our analyses. We observed each inventor from 1985, if their first patent was prior to 1985, or the time they first patented with the firm. The observation of each inventor ended in 2010. We converted each inventor's observation into multiple annual spells.

Sample, dependent variables, and analytical techniques

Even though information is available from 1975, we chose 1985 as our starting date because the identification of organizational knowledge requires that each organization has prior knowledge that its inventors can use. Starting too early would create a bias, as none of the prior citations on these patents would have been considered organizational knowledge due to lack of information about their assignees. Leaving a sufficient window of time before we began would reduce this bias. We ended our observation in 2010. For each year, organizational knowledge is said to consist of all the patents assigned to the firm or its subsidiaries from 1975 up to the last year.

There are two dependent variables in our study representing two dimensions of organizational local search: depth and breadth of local search. These dependent variables are based on the prior art citations of inventors' patents, excluding citations to inventors' own knowledge. For each year in which an inventor applied for patents, we examined the prior art section of those patents. As mentioned earlier, such prior art citations are considered knowledge that is recombined to generate the innovation and also capture knowledge flows (Almeida and Kogut, 1999; Jaffe, Trajtenberg, and Henderson, 1993; Rosenkopf and Almeida, 2003).

The first dependent variable is the depth of local search, that is, the extent of organizational knowledge sourced by an inventor. We measured this as both an absolute count as well as the ratio of the total knowledge sourced. For each inventor-year when an inventor has patent application(s), we counted the prior art citations in those patents to the organizational knowledge, which is indicated by the assignees on these cited patents. The ratio form of this dependent variable is computed as the ratio of the amount of prior art citations to organizational knowledge made by an inventor in a given year, divided by total number of prior art citations made by that inventor in that year.

The second dependent variable is the breadth of local search, that is, the extent of domains from which organizational knowledge is sourced. We also measured this in both the count and the ratio forms. Moreover, prior research has examined two distinct domains: technological classes and geographic areas. So, we measured breadth along these two dimensions. The technological breadth of local search is computed as the number of unique technology classifications of an inventor's citations to organizational knowledge in a year. And, the ratio form of this dependent variable is computed as this count divided by the total number of technology classes cited by an inventor in that year.

We computed the geographic breadth of local search as the total number of unique locations on the inventor's prior art citations to the organization's patents in a year. The ratio version is measured as this count divided by the total number of unique locations on the inventor's prior art citations. These were the locations of the inventors and not the assignee as assignee locations often refer to the headquarters location. Our measure, thus, captured where the knowledge resided more accurately. Further, using the locations' latitude-longitude information, we combined nearby locations that were within 30 miles of each other.

Given that the first form of dependent variables are in counts that have values of zero or above, we could fit the Poisson family distributions. Ordinary linear squares regressions are not a good fit because this count measure violates the homoskedastic, normally distributed error structure. Moreover, given the over-dispersion that is present in the data (the standard deviation is not equal to the mean) (Cameron and Trivedi, 1998; Hausman, Hall, and Griliches, 1984), we used the negative binomial models. For the ratio dependent variables, we applied fractional regression method to analyze these dependent variables (Papke and Wooldridge, 1996).

We also made four other adjustments. First, given that inventors can patent in multiple years, they may have multiple observations. Not taking this possibility into consideration would mean an incorrect estimation of the standard errors. Consequently, we estimated robust standard errors based on inventors (Liang and Zeger, 1986). Second, a firm may have multiple inventors, implying some commonality among the inventors of a firm. In addition, we wanted to test the local search behavior of the inventors within each firm. To do so, we included firm fixed-effects by including indicator variables for each firm in the regression. Third, we included year fixed-effects to capture any period specific patterns.

Finally, the amount of organizational knowledge used has a valid value only when the inventor patents in a given year. If the inventor did not patent in a given year, the value of this measure for that inventor in that year would be undefined. Moreover, such patenting may not necessarily be random and may be systematically related to the extent of organizational knowledge used. For example, an inventor may not generate innovation for a long time if that inventor is familiarizing himself or herself with external knowledge. To address this issue, we employed the control function approach proposed by Blundell and Powell (2004), and Villas-Boas and Winer (1999). We prefer this approach as opposed to instrumental approach because the instrumental approach was found to be ineffective for nonlinear estimators (Davidson and MacKinnon, 1993). In particular, we included a correction factor to account for the effects of the time since the inventor last patented on his or her current productivity. The current productivity of an inventor is regressed against the time since prior patenting, as an exogenous instrument. And, control variables included all of the firm-level control variables described below as well as fixed-effects for each firm. We also included individual-level controls of tenure, prior external sourcing, prior productivity, and average number of collaborators. The negative binomial regression for this analysis included robust clustering on inventors. The residual from this regression, the correction factor, was entered as an additional explanatory variable in the main regression analyses. We analyzed the results both with and without this correction factor.

Variables of theoretical interest

Construction of intra-firm inventor network

Our theoretical predictors are inventors' network reach and span of structural holes in the intra-firm inventor network. To measure these predictors, we first constructed the intra-firm inventor network by examining the successful collaborations among the inventors in a firm. We considered the inventors as nodes in the intra-firm network and the successful collaborations, namely, copatenting, as ties that connect these nodes. In other words, there is a tie between two nodes (inventors) when those two inventors have successfully collaborated (copatented). Collaboration between inventors is a strong tie that facilitates the transfer of tacit knowledge because it involves extensive communications and requires the inventors to share their expertise with one another (Allen and Cohen, 1969; Hansen, 1999; White, 1961). Furthermore, multiple ties among the inventors are an indication of the strength of the tie. Given that collaboration ties once established have no expiration date, one issue to consider is the duration of the validity of a tie. We considered two alternatives. First, it is possible that a tie exists for a short period after the collaboration and withers after that. For example, two inventors may collaborate successfully for three years. During that period, they have a tie with one another. However, after that period, the tie ends. The second alternative is that these ties last forever. We selected the first option because there is knowledge decay over time, and without further collaboration, the tacit understanding between the two inventors may be exhausted. We also selected this option because it accords with similar approaches used in earlier research (c.f. Cattani and Ferriani, 2008; Nerkar and Paruchuri, 2005). Consequently, we created a network of all of the collaborations among inventors of each firm in a three-year period, and used

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it to determine the extent of the network reach and span of structural holes of each inventor in the firm. For example, we calculated an inventor's position in the intra-firm network in 1988 from the network of all of the successful collaborations among inventors in years 1985–1987. We created an intra-firm network for each firm for each year in our observation period, from 1988 till 2010, using a moving window of three years.

Inventor's network reach

We used UCINET VI (Borgatti, Everett, and Freeman, 2002) to compute an inventor's reach in the intra-firm inventor network. An inventor i's reach is the sum of reciprocal geodesic distances to every inventor in the network (Schilling and Phelps, 2007):

$$\sum_{j} 1/d_{ij},$$

where d_{ij} is the geodesic distance between inventors i and j, and $i \neq j$.

Thus, inventors connected to other inventors through smaller path lengths have higher reach in the intra-firm inventor network. We computed this variable yearly for all the inventors using the annual intra-firm inventor networks.

Inventors' span of structural holes

We used UCINET VI to calculate the span of the structural holes of each inventor in each of the annual intra-firm networks created for each firm in our sample (Borgatti *et al.*, 2002). More specifically, given that we are concerned with information flows in the network, we used Burt's (1992) efficiency measure, which calculates the ratio of nonredundant contacts to total contacts:

$$\left[\sum_{j}\left(1-\sum_{q} p_{iq} m_{jq}\right)\right]/C_j,$$

where p_{iq} is the proportion of inventor *i*'s ties invested in connection with contact *q*, m_{jq} is the marginal strength of the relationship between contact *j* and contact *q*, and C_j is the total number of contacts for inventor *i*. This formula yields a value with ranges from 0 to 1, with higher values representing the spanning of a larger number of structural holes.

Control variables

While we are theoretically focused on the role of the inventors' network reach and their span of structural holes, there may be other factors that influence the extent to which inventors use organizational knowledge. Therefore, we controlled for several firm-level and inventor-level factors in the analyses, whose description is presented in Table 1.

RESULTS

Table 2 presents the descriptive statistics and simple bivariate correlations. The results of the negative binomial regression analysis for different dimensions of local search are presented in Table 3, and the results of fractional regression analysis are presented in Appendix S1, Supporting Information. Models 1–3 of Table 3 present the results for the local search depth, Models 4–6 present the results for technological breadth of local search, and Models 7–9 present the results for geographical breadth of local search.

We first focus on results for the local search depth in Models 1–3 of Table 3. Model 1 of Table 3 presents the results of the negative binomial regression with only the control variables. To test Hypotheses 1a and 2a, we included the network reach and span of structural holes of inventors in Model 2. Hypothesis 1a predicts a positive relationship between an inventor's network reach and his or her local search depth. The coefficient of network reach in Model 2 is positive and significant, thereby supporting Hypothesis 1a. An increase in one standard deviation of network reach increased the depth of local search in the count form by five percent. Hypothesis 2a predicts a positive relationship between an inventor's span of structural holes and the depth of his or her organizational knowledge local search. The coefficient for this term is positive and significant, thereby supporting Hypothesis 2a. An increase in one standard deviation of span of structural holes increased the depth of local search in the count form by five percent.

In Model 3, we introduced the interaction term. The coefficient of the interaction is negative and significant in Model 3. This result plotted in Figure 1 in Appendix S2, Supporting Information shows that the positive effect of network reach on the depth of inventors' local search is more pronounced for inventors spanning few structural holes than for inventors spanning more structural holes. To

Table 1. Measurement of control variables

Variable name	Operationalization
Firm-level variables	
Firm self-cites	Aggregate internal sourcing by all inventors in the firm
Firm knowledge breadth	Number of three-digit USPTO classes in which a firm has patented cumulatively up to the last year
Firm geographic breadth	Number of distinct locations that appear in cumulative firm knowledge up to last year in terms of the firm's inventors' locations; we combined nearby locations that were within 30 miles of each other
Firm R&D expenses	R&D expenses as a percentage of sales
Firm patents lagged	Number of successful patent applications of the firm in the prior year
Firm patents cumulative	Count of all patents that are assigned to the focal firm up to last year
Firm size	Total number of employees of the firm in the previous year
R&D alliances	R&D alliances a firm had formed in the last five years
Mktg. alliances	Marketing alliances a firm had formed in the last five years
Inventor level variables	
Inventor left censor	Coded as one for inventors active prior to 1988, and zero otherwise
Prior external sourcing	Cumulative "prior art" citations of external knowledge in the patents applied for up to last year
Prior productivity	Total number of patents generated by the inventor up to last year
Current productivity	Number of patents applied for by the inventor in the current year
Inventor citations received	Cumulative number of citations received by an inventor up to last year
Claims	Average number of claims per patent on all the patents of the inventor in the current year
Current external sourcing	Count of an inventor's all prior art citations to patents that did not belong to the firm
Inventor expertise breadth	Number of technological classes in which he or she patented up to the past year
Tenure	Difference in years between the current year and the first year of the inventor's patenting with the firm
Inventor in headquarters	Coded as one if the inventor's location is within the 30-mile radius of the headquarters location, and zero otherwise
Number of prior collaborators	Average number copatentees of each inventor until the current year
Breadth of collaborators' expertise	Number of unique USPTO technology classes in which the focal inventor's collaborators had patented

make sure that these effects are significant (Hoetker, 2007; King, Tomz, and Wittenberg, 2000; Zelner, 2009), we also examined the marginal effect of network reach conditional on the spanning of structural holes and the associated 95 percent confidence intervals, shown in Figure 2 in Appendix S2, Supporting Information. The interaction is said to be significant at a particular value of a moderator if the confidence interval of the marginal effect of the other variable does not include zero. This analysis showed that the marginal effect of network reach is different from zero for the values of the spanning of structural holes up to 0.8, but not after 0.8.That is, the interaction effect is significant in the span of structural holes range of 0.00–0.80, but not for span of structural holes greater than 0.80. Given that this value range is close to two standard deviations above the mean of the span of structural holes, our interaction effect holds for the vast majority of inventors in our sample. However, this interaction effect was not significant in the fraction regression analysis presented in Appendix S1, Supporting Information. Thus, we posit that Hypothesis 3a is partially supported.

We now turn to focus on the results of the analyses for the technological breadth of organizational technological domains from which firm knowledge is sourced, which are presented in Models 4–6 of Table 3. While Model 4 includes only control variables, Model 5 includes the main theorized variables along with control variables. Hypothesis 1b could not be rejected, as the coefficients of network reach in these models are positive and significant. An increase in one standard deviation of network reach increased the technological breadth of local search in the count form by five percent. Similarly, Hypothesis 2b could not be rejected, as the coefficient of span of structural holes in

Table 2. Descriptive statistics and simple bivariate correlations

Variable	Mean	SD	Min.	Max.	1	2	3	4	5	6	7	8	9	10
1. DV1: depth of local search	5.55	28.90	0.00	1,364										
2. DV2: technology breadth of local search	1.78	3.04	0.00	46.00	0.66									
3. DV3: geographic breadth of local search	1.48	2.29	0.00	27.00	0.54	0.77								
4. Firm self-cites	7.25	1.39	1.39	10.29	0.23	0.37	0.32							
5. Firm knowledge breadth	182.63	55.22	0.00	243.00	0.03	0.05	0.10	0.45						
6. Firm geographic breadth	141.76	82.88	0.00	35.00	−0.10	−0.17	−0.09	−0.01	0.70					
7. Firm R&D expenses	0.10	0.21	0.01	0.81	0.30	0.44	0.36	0.64	0.08	−0.30				
8. Firm patents lagged	557.41	406.04	0.00	1,901	0.14	0.22	0.19	0.65	0.46	0.23	0.39			
9. Firm patents cumulative	8.04	1.02	0.00	9.34	0.05	0.09	0.15	0.45	0.86	0.61	0.16	0.42		
10. Firm size	77.22	74.07	2.23	305.00	−0.12	−0.22	−0.21	−0.32	−0.16	0.28	−0.35	−0.10	−0.33	
11. R&D alliances	3.75	4.87	0.00	25.00	−0.09	−0.12	−0.10	−0.10	−0.04	−0.12	−0.32	−0.10	−0.19	0.28
12. Mktg. alliances	2.13	3.63	0.00	20.00	−0.07	−0.09	−0.08	−0.17	−0.06	−0.21	−0.25	−0.16	−0.18	0.12
13. Inventor left censor	0.01	0.09	0.00	1.00	−0.01	0.01	0.00	−0.06	−0.11	−0.10	−0.04	−0.08	−0.14	−0.02
14. Prior external sourcing	0.64	4.12	0.00	192.33	0.40	0.31	0.28	0.12	0.06	−0.05	0.27	0.06	0.09	−0.10
15. Prior productivity	4.54	14.52	0.00	389.00	0.40	0.36	0.33	0.13	0.10	−0.04	0.26	0.07	0.14	−0.14
16. Current productivity	1.90	2.76	1.00	101.00	0.68	0.52	0.45	0.17	−0.03	−0.12	0.17	0.08	−0.02	−0.10
17. Inventor citations received	0.30	1.88	0.00	55.16	0.29	0.27	0.23	0.08	0.07	−0.02	0.19	0.02	0.10	−0.10
18. Claims	17.24	11.80	1.00	182.00	0.13	0.21	0.18	0.23	−0.06	−0.20	0.34	0.11	0.00	−0.18
19. Current external sourcing	0.25	1.02	0.00	47.65	0.71	0.48	0.42	0.18	0.01	−0.09	0.26	0.09	0.03	−0.12
20. # of prior collaborators	0.38	0.81	0.00	21.00	0.19	0.26	0.25	0.02	−0.02	−0.13	0.03	−0.01	−0.05	−0.12
21. Breadth clbrts. expertise	1.60	2.55	0.00	47.00	0.37	0.42	0.33	0.17	−0.04	−0.14	0.14	0.08	−0.03	−0.11
22. Tenure	2.51	3.69	0.00	26.00	0.13	0.22	0.23	0.11	0.19	0.02	0.16	0.06	0.24	−0.24
23. Inventor expertise breadth	2.15	3.38	0.00	37.00	0.27	0.37	0.30	0.15	0.12	−0.06	0.21	0.07	−0.07	0.39
24. Inventor in headquarters	0.26	0.44	0.00	1.00	0.15	0.26	0.17	0.24	−0.12	−0.34	0.42	0.35	0.22	0.24
25. Network reach	22.99	49.28	0.00	291.3	0.26	0.36	0.33	0.36	0.20	−0.08	0.39	0.35	0.22	−0.24
26. Span of structural holes	0.27	0.37	0.00	1.00	0.14	0.23	0.22	0.17	0.06	−0.11	0.19	0.14	0.07	−0.16

Variables	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
12. Mktg. alliances	0.83														
13. Inventor left censor	−0.06	−0.03													
14. Prior external sourcing	−0.08	−0.06	−0.01												
15. Prior productivity	−0.08	−0.05	−0.01	0.83											
16. Current productivity	−0.06	−0.04	0.01	0.26	0.35										
17. Inventor citations received	−0.08	−0.05	−0.01	0.74	0.85	0.22									
18. Claims	−0.13	−0.09	−0.02	0.07	0.07	0.09	0.05								
19. Current external sourcing	−0.09	−0.08	−0.01	0.41	0.36	0.65	0.25	0.11							
20. # of prior collaborators	0.04	0.06	0.18	0.29	0.54	0.30	0.44	0.04	0.16						
21. Breadth clbrts. expertise	−0.02	−0.01	0.03	0.16	0.27	0.53	0.21	0.10	0.34	0.48					
22. Tenure	−0.06	0.00	0.00	0.26	0.49	0.14	0.40	0.02	0.11	0.45	0.27				
23. Inventor expertise breadth	−0.19	−0.11	0.01	0.10	0.15	0.13	0.12	0.16	0.11	0.10	0.15	0.69			
24. Inventor in headquarters	−0.13	−0.08	−0.03	0.23	0.37	0.27	0.21	0.12	0.22	0.31	0.29	0.17	0.20		
25. Network reach	−0.13	−0.08	−0.03	0.23	0.37	0.27	0.21	0.12	0.22	0.31	0.29	0.37	0.48	0.27	
26. Span of structural holes	0.00	0.02	0.07	0.15	0.29	0.20	0.14	0.05	0.11	0.31	0.23	0.41	0.52	0.17	0.56

All correlations above |0.02| are significant at the $p < 0.05$ level.

these models are also positive and significant. An increase in one standard deviation of span of structural holes increased the breadth of local search in organizational technological domains in the count form by three percent.

Model 6 additionally includes the interaction term between network reach and span of structural holes, which is used to test Hypothesis 3b. The interaction term is negative and significant, and the interaction graph presented in Figure 3 of Appendix S2, Supporting Information shows that the interaction is in the hypothesized direction. The analysis of marginal effect of network reach on technological breadth of local search conditional

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Table 3. Negative binomial analysis of local search

Dimension of local search	Depth			Technological breadth			Geographical breadth		
Model #	1	2	3	4	5	6	7	8	9
Correction factor	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Firm level controls									
Firm local search	0.255**	0.250**	0.252**	0.196**	0.195**	0.196**	0.214**	0.210**	0.211**
	(0.025)	(0.025)	(0.025)	(0.022)	(0.022)	(0.022)	(0.021)	(0.021)	(0.021)
Firm technology breadth	0.006**	0.007**	0.007**	0.001	0.001	0.001	0.002	0.002	0.002
	(0.003)	(0.003)	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Firm geographical breadth	−0.012**	−0.013**	−0.013**	−0.007**	−0.008**	−0.008**	−0.009**	−0.009**	−0.009**
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Firm R&D expense	−3.024**	−3.444**	−3.363**	−2.879**	−3.090**	−3.044**	−2.643**	−2.896**	−2.828**
	(0.485)	(0.497)	(0.496)	(0.316)	(0.322)	(0.322)	(0.303)	(0.312)	(0.311)
Firm patents (last year)	−0.000**	−0.000**	−0.000**	−0.000**	−0.000**	−0.000**	−0.000**	−0.000**	−0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Firm patents (cumulative)	1.391**	1.375**	1.366**	1.161**	1.153**	1.147**	1.191**	1.181**	1.172**
	(0.097)	(0.096)	(0.096)	(0.071)	(0.071)	(0.071)	(0.070)	(0.070)	(0.070)
Firm size	−0.009**	−0.009**	−0.009**	−0.004**	−0.004**	−0.004**	−0.008**	−0.008**	−0.008**
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
R&D alliances	0.013	0.016*	0.016*	0.018**	0.020**	0.019**	0.019**	0.021**	0.020**
	(0.009)	(0.009)	(0.009)	(0.007)	(0.007)	(0.007)	(0.006)	(0.006)	(0.006)
Marketing alliances	−0.013	−0.015	−0.015	−0.039**	−0.040**	−0.040**	−0.033**	−0.033**	−0.033**
	(0.010)	(0.010)	(0.010)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
Inventor level controls									
Left censored inventors	0.425**	0.396**	0.372**	0.293**	0.272**	0.256*	0.311**	0.273**	0.253**
	(0.152)	(0.153)	(0.152)	(0.133)	(0.134)	(0.134)	(0.126)	(0.127)	(0.127)
Prior external sourcing	−0.014**	−0.013**	−0.016**	0.007*	0.008*	0.006	0.005	0.006	0.003
	(0.006)	(0.005)	(0.005)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Prior productivity	−0.001	−0.002	−0.001	−0.007**	−0.008**	−0.007**	−0.001	−0.002	−0.001
	(0.002)	(0.002)	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Current productivity	0.220**	0.214**	0.215**	0.086**	0.083**	0.085**	0.099**	0.095**	0.097**
	(0.012)	(0.012)	(0.012)	(0.008)	(0.008)	(0.008)	(0.009)	(0.009)	(0.009)
Cumulative cites received	0.013	0.031	0.029	−0.001	0.007	0.006	−0.026**	−0.017	−0.017*
	(0.018)	(0.019)	(0.019)	(0.011)	(0.012)	(0.011)	(0.010)	(0.010)	(0.010)
Number of claims	0.012**	0.012**	0.012**	0.007**	0.007**	0.007**	0.007**	0.007**	0.007**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Current external sourcing	0.404**	0.402**	0.402**	0.113**	0.113**	0.112**	0.118**	0.119**	0.119**
	(0.060)	(0.059)	(0.059)	(0.029)	(0.029)	(0.029)	(0.030)	(0.030)	(0.030)
No. of prior collaborators	0.107**	0.101**	0.097**	0.043**	0.041**	0.038**	0.103**	0.099**	0.096**
	(0.026)	(0.026)	(0.025)	(0.018)	(0.017)	(0.017)	(0.019)	(0.018)	(0.018)
Breadth of collaborators' expertise	0.002	0.001	0.001	0.031**	0.030**	0.030**	0.015**	0.014**	0.014**
	(0.006)	(0.006)	(0.006)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Tenure	0.045**	0.042**	0.042**	0.021**	0.019**	0.018**	0.032**	0.030**	0.029**
	(0.005)	(0.005)	(0.005)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Inventor expertise breadth	−0.000	−0.012*	−0.014**	0.045**	0.039**	0.037**	0.007	−0.001	−0.003
	(0.006)	(0.007)	(0.007)	(0.005)	(0.005)	(0.005)	(0.004)	(0.004)	(0.004)
Inventor in headquarters	0.066*	0.047	0.057	0.086**	0.075**	0.082**	−0.032	−0.044*	−0.037
	(0.039)	(0.039)	(0.039)	(0.026)	(0.026)	(0.026)	(0.024)	(0.024)	(0.024)
Theorized variables									
Network reach		0.001**	0.005**		0.001**	0.003**		0.001**	0.004**
		(0.000)	(0.001)		(0.000)	(0.001)		(0.000)	(0.001)
Span of structural holes		0.144**	0.192**		0.090**	0.128**		0.145**	0.188**
		(0.042)	(0.043)		(0.028)	(0.029)		(0.028)	(0.029)
Network reach*			−0.005**			−0.004**			−0.004**
Span of structural holes			(0.001)			(0.001)			(0.001)
_cons	−10.038**	−9.932**	−9.881**	−8.077**	−8.021**	−7.993**	−8.459**	−8.384**	−8.332**
	(0.585)	(0.580)	(0.579)	(0.419)	(0.418)	(0.418)	(0.423)	(0.421)	(0.421)
Log likelihood	−54818	−54777	−54761	−47990	−47974	−47961	−45510	−45481	−45464
Change in log likelihood (w.r.t base model)		41	57		16	29		29	46

(1) $*p < 0.1$; $**p < 0.05$; (2) $N = 29{,}961$; (3) each model includes firm and year fixed effects; (4) robust standard errors based on inventors are presented in parentheses.

on the span of structural holes and the associated 95 percent confidence interval in Figure 4 of Appendix S2, Supporting Information shows that the interaction is significant in the range of structural holes below 0.75. The interaction is not significant if span of structural holes is above 0.75, which is a small fraction (~3%) of overall sample of inventors. This result suggests that no additional marginal benefits accrue due to network reach when the span of structural holes is really high—a result consistent with our logic. Thus, this result provides support for Hypothesis 3b.

Last, we turn to the results of the analyses of the geographic breadth of local search, which are presented in Models 7–9 of Table 3. While Model 7 includes only control variables, Model 8 include the main theorized variables along with control variables. Hypothesis 1b could also not be rejected for the geographical breadth of local search, as the coefficients of network reach in these models are positive and significant. An increase in one standard deviation of network reach increased geographic breadth of local search in the count form by five percent. Similarly, Hypothesis 2b also could not be rejected for the geographic breadth of local search, as the coefficients of span of structural holes in these models are also positive and significant. An increase in one standard deviation of span of structural holes increased the geographical breadth of local search in the count form by five percent.

Model 9 additionally includes the interaction term between network reach and span of structural holes, which is used to test Hypothesis 3b. The interaction term is negative and significant, and the interaction graph presented in Figure 5 of Appendix S2, Supporting Information shows that the interaction is in the hypothesized direction. The plots of marginal effect of network reach on the extent of organizational geographic locations conditional on the span of structural holes and the associated 95 percent confidence interval, presented in Figure 6 of Appendix S2, Supporting Information shows that the interaction is significant in the range of structural holes from 0.00 to 0.76, but not above 0.76. This is very consistent with our theorized logic, and thus, this result provides support for Hypothesis 3b.

Robustness tests

First, analysis with the correction factor excluded from the specifications yielded results identical to the ones presented here. Second, dropping variables with high correlations from the specification also yielded results similar to the ones presented here. Third, we also applied quasi-maximum likelihood Poisson specification (Grogger and Carson, 1991; Wooldridge, 1997) for the count models, and the results were consistent with the ones presented in the article. Fourth, while the main analysis did not include the knowledge acquired through M&A as the focal firm's knowledge base, recomputing all our measures by including the target's knowledge prior to acquisition in the firm's knowledge base also yielded results similar to the ones presented in the article. Fifth, eliminating outliers of network reach resulted in identical results, except the interaction effect for the depth of local search, which was not significant. Last, analyzing each firm context separately yielded similar results for all firms except Philips. We found that neither the main hypothesized effects nor the interaction effect in the Philips sample were significant. One reason for these inconsistent results of Philips may have to do with its complete disbanding and discarding of its semiconductor operations to NXP semiconductors.

DISCUSSION

Creating new knowledge by building on existing organizational knowledge is shown to be prevalent in organizations (March, 1991; Nelson and Winter, 1982). While the organizations are said to perform local search, it is the individual inventors who carry out these activities. Hence, understanding which inventors contribute to such behavior is quite important. We focused on examining network positions of inventors in an intra-organizational network. We do so by building on the established research exploring the importance of intra-organizational networks for knowledge creation activities (Allen, 1977; Allen and Cohen, 1969; Carnabuci and Operti, 2013; Reagans and Zuckerman, 2001). Thus, we specifically addressed the question: To what extent do inventors in different positions in the intra-firm network perform local search in their innovation activities?

An empirical examination, from 1985 to 2010, of 14,575 inventors belonging to four large semiconductor firms broadly supported our theoretical framework. In particular, we found that inventors with high network reach and inventors who span more structural holes were likely to perform more local search than inventors with low network reach and inventors who span few structural holes, respectively. Moreover, there was a negative interaction between network reach and span of structural holes on inventor local search behavior. These results held true for both dimensions of local search: depth and (technological and geographical) breadth of local search.

Limitations and future research avenues

Before addressing the theoretical implications, we must acknowledge some limitations that could also create avenues for future research. The first limitation arises from the way we capture local search behavior. While patent citations is a standard way of capturing such use of prior knowledge in innovation activities (Almeida and Kogut, 1999; Katila, 2002; Rosenkopf and Almeida, 2003), there is other organizational knowledge—tacit knowledge—that may be used in innovation activities. However, such tacit knowledge flow is not captured in the patent data. Future studies could potentially gain access to a firm's internal records or survey inventors to capture such knowledge flow. The second limitation arises from the use of patent data in capturing collaboration among inventors. While copatenting reflects successful collaborations, there may be other collaborations that have not yet become successful or dissolved without generating any outcomes. Despite being unimportant for some outcomes, such collaborations may play an important role in knowledge transfer within organizations. Here, too, future research could gain access to a firm's internal records to try to discern these kinds of ties. Additionally, patent data also represents successful innovation efforts. Future research could also include even nonsuccessful efforts to examine this phenomenon. The third limitation relates to other potential ties that may exist among inventors. While we focus just on collaboration ties, other ties such as those of friendship or formal hierarchical relationships may exist as well. Such ties could be important for information flows, and future research could explore the significance of such ties for the extent of organizational knowledge use.

Theoretical implications

We are among the first to identify inventors who do more local search than others within the organizational boundaries. These findings have theoretical implications for the literature on organizational exploration/exploitation, organizational knowledge, knowledge networks, and micro-foundations literature. First, while earlier research has highlighted the prevalence of organizational exploitation over exploration (March, 1991; Martin and Mitchell, 1998; Nelson and Winter, 1982), what is missing from this research is an understanding of how different resources within a firm contribute to this process. A firm is comprised of heterogeneous resources, and not all resources are equally likely to make organizations exploit their existing knowledge. Some resources may contribute more to the firm's exploitation behavior than others. Such differential contributions by a firm's resources are implied in the case study of Tripsas and Gavetti (2000), who investigated the role of managerial cognition in shaping the firm's capabilities and search behavior. Our article contributes to this stream of research by focusing on inventors as resources and demonstrating that inventors who have higher reach in the network, and those who span many structural holes in that network, make organizations more prone to exploiting their existing knowledge. This ability to identify the differential contribution of inventors to a firm's exploitative behavior is not only theoretically important, but also practically consequential because of the ability to design intervention actions more effectively.

Our demarcation of local search into two dimensions, depth and breadth of organizational local search, extends our notions of local search and enriches our way of thinking about exploitation. Earlier research has identified such a distinction in generic search behavior—Katila and Ahuja (2002) identified search depth and search scope as two forms of search. While search depth is similar to the depth of local search, search scope was conceptualized as the range of domains from which knowledge was sourced. Thus, search scope describes one form of exploration. In contrast, our notion of breadth of local search is restricted to search within the organizational knowledge, and hence, describes a form of exploitation. While we did not find significant differences in the findings for these two dimensions, future research could compare and contrast these two dimensions on their antecedents and consequences even in other aspects of local search, such as geographic and technological local search.

Our findings also complement and enrich findings by Wang *et al.* (2014). For example, Wang

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et al. found that inventors who span many structural holes in collaboration networks had larger exploration than inventors who spanned few structural holes. This finding, along with our finding that inventors who span many structural holes in the organizational collaboration network also tend to perform higher local search than inventors who span few structural holes, implies that inventors performing more exploration need not necessarily perform less exploitation. These findings then add to the discussion on exploration and exploitation as well. Specifically, while March (1991) has projected exploration and exploitation as a trade-off, recent research has shown that exploration and exploitation could be quite distinct, unrelated scales or are related in a complex way (Gupta, Smith, and Shalley, 2006; He and Wong, 2004; Knott, 2002). For example, Knott (2002) considered exploration and exploitation as complements rather than substitutes, and Gupta *et al.* (2006) considered that same action could be interpreted as both exploration and exploitation. Our finding and Wang *et al.*'s (2014) finding together suggest the same inventors may be driving both exploration and exploitation.

Second, our findings also contribute to understanding the factors that lead to the idiosyncratic nature of organizational knowledge. Specifically, earlier empirical research on path dependence has typically focused on understanding the localization of knowledge flows in a geographic region (Almeida and Kogut, 1999; Saxenian, 1996; Singh, 2005). Nerkar and Paruchuri (2005) expanded this investigation by studying localizations of knowledge within firms. In particular, they showed that inventors who occupy central positions and who spanned structural holes were able to influence others in the firm to use their knowledge in recombination activities. Our study complements these findings by demonstrating that inventors who have higher network reach and who span structural holes are also likely to source more of the organizational knowledge. These two studies, taken in concert, show that inventors with more reach and inventors who span many holes are linchpins for making organizational knowledge more idiosyncratic, as they build on more organizational knowledge and influence others to build more on organizational knowledge.

Third, our article also contributes to research on intra-organizational knowledge networks. While earlier studies in this vein have examined the implications of intra-firm networks for influence, power, and productivity (Allen, 1977; Allen and Cohen, 1969; Brass, 1984; Carnabuci and Operti, 2013; Guler and Nerkar, 2012; Ibarra, 1993; Reagans and Zuckerman, 2001), this research has yet to examine the effect of network characteristics on patterns of knowledge sourcing among inventors. Variations in knowledge sourcing could exist based on different dimensions such as geographical, technological, or firm boundaries. Earlier research has, to date, not studied whether the position of an inventor in the network of inventors has an influence on how the inventor sources knowledge along these different dimensions. While we addressed the question about the sourcing of knowledge within organizational boundaries along these different dimensions, this line of thought raises other important questions that need to be addressed about the effects of network positions on external sourcing along these different dimensions as well.

Last, our research also has implications for research on micro-foundations (Felin and Foss, 2005; Paruchuri & Eisenman, 2012). This research has proposed that organizational actions could be understood by examining the processes that occur at lower level. This burgeoning research on firm innovation activities is focused on the role of inventors in shaping firm activities (Audia and Goncalo, 2007; Grigoriou and Rothaermel, 2014; Kehoe and Tzabbar, 2015; Paruchuri et al., 2007; Paruchuri, 2010, 2016; Tzabbar, 2009). For example, Nerkar and Paruchuri (2005) showed how the individual inventors propel organizations' R&D to evolve in certain directions and found certain inventors to play more influential role than others. Our research complements and extends this research by identifying those inventors who propel organizational local search behavior.

Managerial implications

Our research also has practical implications for managers. Earlier research found that local search may lead to innovations with lower impact. Yet, other research found that local search will enable creation of idiosyncratic organizational knowledge that could become a source of sustained competitive advantage. Irrespective of which camp a manager subscribes to, our research identifies those individuals that drive local search behavior in knowledge creation activities, and thus, provides a lever to them to tune the local search behavior in the desired direction. Additionally, our research also has implications for managers in terms of managing platforms that are developed to share knowledge among employees for internal purposes.[1] The intriguing question for these managers is about allowing access: Who should get access to these platforms? If they provide access to everyone, inventors will search locally and experimentation will suffer. If they restrict access to only a chosen few decision-makers, they favor experimentation but limit exploitation. Our research suggests that managers could use the inventors' network positions in the intra-organizational network as a way to decide. Because these positions are distinct from formal organizational roles, it allows identification of inventors who would enable managers to achieve their desired level of local search.

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[1] We are greatly indebted to anonymous reviewer for identifying this managerial implication.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article:

Appendix S1. Results of fractional regression analysis.

Appendix S2. Graphs of Interaction Effects.

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