Organizing for Knowledge Generation:

Internal Knowledge Networks and the Contingent Effect of External Knowledge Sourcing

When faced with a new technological paradigm, incumbent firms opt for internal development and/or external sourcing to obtain the necessary new knowledge. We explain how the effectiveness of external knowledge sourcing depends on the properties of internal knowledge production. In particular, we apply a social network lens to delineate interpersonal, intra-firm knowledge networks to capture the emergence of two important firm-level properties: the incumbent's internal potential for knowledge recombination and the level of knowledge coordination costs. We rely on firm-level network microstructures to track the emergence of these properties across 106 pharmaceutical companies over a 25-year period. We find that a firm's success in developing knowledge in a new technological paradigm using external knowledge sourcing is contingent upon the microstructure of its internal knowledge network.

Working Paper, October 31, 2014.

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Competence-destroying technological change poses significant challenges for an industry's incumbent firms (Tushman and Anderson, 1986). To build knowledge within a new technological paradigm, incumbents invest in internal knowledge development (Tripsas, 1997), human capital (Zucker and Darby, 1997), strategic alliances (Rothaermel, 2001), acquisitions of new entrants (Higgins and Rodriguez, 2006), or in combinations of those strategies (Rothaermel and Hess, 2007). There is a significant degree of consensus in the strategy literature that successful renewal depends on incumbents developing skills in both internal knowledge development and external knowledge sourcing (Helfat *et al.,* 2007).

Clearly, both internal development and external sourcing have received considerable attention in the literature as more or less isolated strategic choices. We have a somewhat limited understanding, however, about the conditions that favor one sourcing mode over the other. Capron and Mitchell (2009) echo this statement when arguing that a firm's selection capability, defined as the ability to choose among modes of knowledge sourcing, is an underemphasized form of capability. Further, Nickerson and Zenger (2004: 1) suggest that the key question is not "how to organize to exploit already developed knowledge or capability, but rather how to organize to efficiently generate knowledge and capability."

We contribute to this line of burgeoning research by applying social network concepts to address the question of how to organize and choose among knowledge sourcing efforts to efficiently generate new knowledge. We predict the effectiveness of knowledge sourcing strategies for incumbent firms trying to develop new knowledge within an emerging

technological paradigm. We track their internal and external sourcing activities in a fine-grained manner as they co-evolve over time. As the incumbent firms generate new knowledge, we use collaborative network analysis to capture important properties of their internal knowledge production process. In particular, we look deep inside the firm to track the inter-personal networks of knowledge workers to assess not only the value created by knowledge generation but also its production costs. To track external sourcing, we examine the incumbents' activity with knowledge-related alliances and acquisitions.

Our core argument is that the effectiveness of a firm's external knowledge sourcing strategies to build new knowledge is contingent upon the properties of that firm's internal knowledge production. We focus on two such properties: the firm's potential for subsequent internal knowledge recombination and the knowledge coordination costs associated with its existing knowledge production system. We explain why external sourcing is bound to be less effective for new knowledge generation for firms which either already possess strong potential for further knowledge recombination internally or already incur high coordination costs in their existing knowledge production process.

To proxy for these firm-level properties, we look at the micro-structures of their knowledge networks and we rely on the concept of emergence (Kozlowski et al., 2013). We explain how the structure and evolution of interpersonal knowledge networks inside incumbent firms result in the emergence of firm-level knowledge properties such as recombinative potential and coordination costs. In essence, we describe how firm-level network properties emerge from internal individual-level network structures and interactions (Moliterno and Mahony, 2011). In short, we argue that differences across firms in these knowledge network properties underlie the

contingent effect of their external knowledge sourcing choices on their knowledge performance within a new technological paradigm.

To be sure, the question of complementarity between internal and external knowledge sourcing has received some attention in the literature (Parmigiani, 2007; Parmigiani and Mitchell, 2009). Research has documented that the degree of complementarity depends on the firms' absorptive capacity (Cohen and Levinthal, 1990), intellectual property considerations and the type of research and development conducted (Cassiman and Veugelers, 2006), interactions across levels of analysis (Rothaermel and Hess, 2007), capability differences across vertical value chain segments (Jacobides, 2008), and the type of experience in different learning stages (Hoang and Rothaermel, 2010). The idea that it is differences in internal knowledge bases essentially drive boundary choices has also been highlighted before (Jacobides and Hitt, 2005; Jacobides and Winter, 2005; Kogut and Zander, 1992).

The novel contribution in our study, however, results from the application of social network concepts to develop a fine-grained picture of the state of a firm's internal knowledge production process, and to capture the potential for knowledge recombination and accompanying coordination costs. Moreover, this fresh approach enables us to document the role of the firm's internal knowledge network as an important but overlooked contingency factor when evaluating the effectiveness of external knowledge sourcing choices. As a result, we also offer a significant contribution to the growing literature on knowledge networks and their importance for firm performance (Phelps, Heidl, and Wadhwa, 2012).

Empirically, we examine the phenomenon using large but detailed longitudinal panel datasets of both firms and individual inventors within these firms. When estimating the contingent effects of external knowledge sourcing choices, we dynamically update the firms'

internal knowledge networks to address the co-evolution of internal knowledge and knowledge sourcing choices. We test the theoretical framework in the global pharmaceutical industry, where we track the innovative activities of 106 incumbent firms in their effort to adapt to the new biotechnology paradigm over 25-year period (1974-1998). We rely on the firms' patenting portfolios of over 267,000 individual inventors to build internal networks for biotech knowledge generation. We apply network theory to extract information from intra-firm networks about the individual inventors' network positions, the overall network structure, and subsequently the firms' knowledge properties of knowledge recombinative potential and coordination costs in its knowledge production process.

To foreshadow our conclusions, we submit that selecting an efficient way to develop new knowledge is a highly consequential strategic choice driving firm-level heterogeneity. Although external sourcing using alliances and acquisitions has well-documented independent benefits for new knowledge generation, we argue herein that external sourcing is not as effective, in some cases even harmful, when combined with a certain state of internal knowledge production. We conclude by discussing theoretical implications of this work on boundary choices, knowledge generation, and knowledge networks. We also highlight managerial implications concerning the contingent effects of external knowledge sourcing on new knowledge development.

THEORY AND HYPOTHESES

One of the most enduring themes in strategy research is the mandate for incumbent firms to undertake knowledge sourcing strategies in the face of environmental changes (Agarwal and Helfat, 2009). An ability to execute both internal and external knowledge sourcing modes effectively is necessary especially in many science-based business environments (Pisano, 2010). Internal development of knowledge is important because firms need a certain level of internal

understanding to evaluate external knowledge opportunities (Cohen and Levinthal, 1990) and to better coordinate the generation of new knowledge (Grant, 1996). External knowledge sourcing is also important to prevent obsolescence and encourage acquisition of new knowledge that is largely dissimilar to the firm's existing knowledge base, and thus to foster innovation (Rosenkopf and Nerkar, 2001).

One question that has received significant attention is how firms choose their knowledge boundaries for new knowledge development. Scholars have examined the relative explanatory power of transaction cost and knowledge-based theories in predicting make-or-buy decisions (Poppo and Zenger, 1998). We know that firms may favor external sourcing because of a preference for outsiders' knowledge (Menon and Pfeffer, 2003), internal social comparison costs (Nickerson and Zenger, 2004), or availability of knowledge suppliers and an intense competitive environment (White, 2000). Firms may also choose external sourcing because of dyadic considerations such as knowledge fit (Baum, Cowan, and Jonard, 2010), status similarity (Chung, Singh, and Lee, 2010), or mutual trust through fairness with potential partners (Ariño and Ring, 2010). Further, firms may rely on external sourcing because of their prominent position in interfirm networks (Gulati, 1999; Yang, Lin, and Lin, 2010). Alternatively, more firm-specific explanations such as the depth of the firm's internal knowledge base have also been documented as drivers of the internal vs. external sourcing choice (Zhang and Baden-Fuller, 2010). Finally, there is also research that attempts to explain the preference for certain external sourcing modes over others (e.g., alliances vs. acquisitions, see Hagedoorn and Duysters, 2002; Vanhaverbeke, Duysters, and Noorderhaven, 2002).

In parallel, several insightful studies have addressed the question of implementation, that is, how can firms effectively use different external sourcing modes to build new knowledge? For

example, prior work has shown how firms can maximize the effectiveness of alliances by altering intra-alliance value appropriation regimes (Adegbesan and Higgins, 2011), alliance scope (Oxley and Sampson, 2004), or alliance learning objectives (Kale, Dyer, and Singh, 2002; Rothaermel and Deeds, 2004). In addition, others have documented how firms can increase the benefits of acquisitions by increasing the size of the acquired knowledge base (Ahuja and Katila, 2001), by acquiring information about the targets' R&D activities prior to the acquisition (Higgins and Rodriguez, 2006), by relying on complementary knowledge (Makri, Hitt, and Lane, 2010), and by altering the level of post-acquisition integration (Puranam, Singh, and Chaudhuri, 2009). We also know how firms can make contracting more effective through repeated exchange and learning (Argyres, Bercovitz, and Mayer, 2007; Mayer and Argyres, 2004). Taken together, novel theoretical work combined with careful empirical analysis has provided an understanding of the factors that drive knowledge boundary choices and of the levers that can increase the effectiveness of various knowledge sourcing initiatives.

There is, however, mounting evidence that firms increasingly rely on a combination of internal and external sourcing (Capron and Mitchell, 2009; Parmigiani, 2007; Parmigiani and Mitchell 2009). We do have some evidence about factors that affect the degree of complementarity: the basicness of R&D and intellectual property considerations (Cassiman and Veugelers, 2006), careful orchestration of innovation strategies across levels of analysis (Rothaermel and Hess, 2007), and across structural and functional domains (Lavie and Rosenkopf, 2006). Therefore, beyond understanding how firms choose their knowledge boundaries and examining ways to increase the effectiveness of independent sourcing strategies, we need to better understand the conditions that make external sourcing effective when combined with the firm's existing stock of internal knowledge. This is where we aim to provide

a theoretical and empirical contribution. In particular, we rely on an atomistic knowledge-based conceptualization of the firm and its knowledge-sourcing choices.[1]

We observe that firms find themselves endowed with an internal capacity for knowledge generation as a consequence of past internal knowledge development and external knowledge sourcing choices. We argue herein that the state of a firm's internal knowledge production process determines the effectiveness of external knowledge sourcing. Importantly, by choosing this atomistic perspective, we do not reject the importance of dyadic or network views. Instead, we believe that the atomistic view, which is the traditional lens in strategic management and focuses on the firm itself rather than its position in a larger network or its dyadic relationships, is in line with our emphasis on the selection question between external and internal knowledge sourcing strategies. We argue that when a firm's knowledge production process is characterized by certain knowledge network properties then external knowledge sourcing may be more or less appropriate for new knowledge generation.

Essentially, we address the question of organizational design for knowledge building (Madhok, 2002). In this line of thought, differences in knowledge bases determine firm boundaries (Kogut and Zander, 1992). Here, we focus on a similar interaction between internal knowledge and knowledge sourcing choices when firms determine their knowledge scope. We dynamically track a firm's internal knowledge base as it evolves over time, and argue that the effectiveness of external knowledge sourcing is contingent on properties of a firm's knowledge base; more specifically, the firm's potential for subsequent internal knowledge recombination and the associated coordination costs. We suggest that when a firm's internal knowledge network

[1] In an atomistic perspective, the firm alone (as an atom) decides whether or not to engage in external knowledge sourcing based on its internal knowledge capabilities. The "atomistic view" (the firm alone) is juxtaposed to a "dyadic view" (the firm in partnership/alliance with another firm) and the "network view" (the firm as an actor or node embedded in a network).

exhibits properties of either high potential for knowledge recombination or high knowledge coordination costs then external knowledge sourcing is less effective.

Our logic for this baseline argument is the following: one of the main benefits of external knowledge sourcing is the fact that it provides a firm with access to new knowledge. If the firm already has the capacity to internally recombine existing knowledge then that positive knowledge effect of external sourcing should be diminished to some extent at the margin. In other words, under these conditions, external sourcing becomes a substitute of internal knowledge sourcing. Similarly, one of the main costs of external sourcing is the cost of coordination – firms have to identify partners, work with them, commit resources, actively try to transfer knowledge, monitor progress, make adjustments, and so on. If they already face high coordination costs internally in their internal knowledge production process, then the coordination burden of external sourcing will be amplified and as a result. Again, any positive knowledge effect of external sourcing should be diminished at the margin. In other words external sourcing becomes a substitute of an internal knowledge production that exhibits high existing coordination costs.

Two insightful studies are closely related to our work in that the authors explicitly examine the effectiveness of external knowledge sourcing under various organizational conditions. Nickerson and Zenger (2004) argue that is the problem type (e.g., its level of decomposability) that dictates the efficiency of alternative knowledge sourcing strategies. Capron and Mitchell (2009) show that the effectiveness of external renewal modes in building new resources depends on the size of the capability gap between current and needed resources and on the level of internal constraints that arise for the internal social context. Building upon this prior work, we highlight the importance of two additional internal firm-level properties: the firm's potential for future knowledge recombination in the new knowledge area and the

coordination costs associated with its internal knowledge generation process. Importantly, our specific theoretical contribution is the application of social network thinking to a firm's internal knowledge network in order to capture recombinative potential and coordination costs and in turn, show how these two properties drive the effectiveness of external knowledge sourcing.

Central to our argument is a move from examining a firm's internal inter-personal knowledge networks, which emerge as the firm builds knowledge in the new paradigm, to inferring the state of the firm's internal knowledge properties. In what follows, we detail our logic to justify this link. One of the more common strategies of incumbent firms faced with a technological discontinuity is to heavily invest in internal knowledge development to generate new knowledge (Argyres and Liebeskind, 2002). There is also evidence that knowledge generation has increasingly become a communal team-based endeavor (Wuchty, Jones, and Uzzi, 2007). Incumbents design structures internally to stimulate knowledge recombination and reconfiguration (Henderson and Clark, 1990; Henderson and Cockburn, 1994). As incumbents make an effort to adapt using internal and external sourcing investments, individuals deep within firms collaborate to develop new knowledge. At the firm level, this activity of interpersonal collaboration results in extensive knowledge networks with the objective of new knowledge generation. The nodes of these networks are individuals participating in knowledge production. Ties between individuals reflect direct collaboration with the objective of knowledge co-creation.

To capture the knowledge base properties of interest, we examine the structure of these knowledge networks. We know that structure is important for the network's overall knowledge performance. A relaxed structure facilitates improvisation (Brown and Eisenhardt, 1997), a cohesive structure affects individuals' capacity to transfer knowledge (Reagans, Zuckerman, and McEvily, 2004), network heterogeneity drives learning (Reagans and Zuckerman, 2001), and

network range supports knowledge transfer (Reagans and McEvily, 2003). A network which is nearly decomposable, i.e., it is characterized by cohesive clusters linked with cross-cluster ties, is the most effective for generation of useful new knowledge (Yayavaram and Ahuja, 2008). Finally, efficiently structured networks perform better in the short run while effectively structured networks are more appropriate for long-run performance (Lazer and Friedman, 2007).

We build on this line of work and directly examine structural attributes of the incumbent firm's knowledge network. We conceptualize the process of new knowledge production as a structural knowledge-based process of recombination of existing knowledge stocks (Fleming, 2001). We focus on attributes that can be linked with the firm's potential for future knowledge recombination. In particular, we focus on two dimensions: the degree of the network's clustering and its average path length. A highly clustered network indicates a structure that is abundant with cohesive micro-clusters of knowledge production which have been shown to facilitate future knowledge recombination. In other words, if an incumbent firm has internally a knowledge network that exhibits high clustering, it means that the firm has relatively large groups of individuals working together in tight-knit clusters to generate relevant new knowledge. When that happens, we know from prior work that the likelihood of further knowledge recombination increases (Reagans et al., 2004). In addition, average path length captures the average distance between any two actors in the network. Longer paths indicate a network that is largely heterogeneous, has extensive range, and relies on significant breadth of knowledge stocks. In other words, if an incumbent firm has an internal knowledge network with high average path length, it means that the firm's individuals are working in many, diverse, and relatively unrelated knowledge areas. Again, we know from prior work that when this happens, the likelihood for promising further knowledge recombination increases.

From these knowledge network attributes, we infer the firm-level property of potential for future knowledge recombination. To accomplish this, we rely on the theoretical concept of multilevel emergence. Kozlowski and Klein (2000) define multilevel emergence as a bottom-up process whereby individual behavior and dynamic interactions result in a higher-level property for the group. In our case, the firm level property of knowledge recombinative potential emerges bottom-up from the structure of independent micro-level knowledge behavior and interactions. We examine an incumbent firm's internal knowledge network as it evolves, changes, and dynamically reconfigures itself following new knowledge production. These attributes make it a fertile ground for the emergence of a higher-level property (Kozlowski et al., 2013). Similarly, the emergence of the firm-level property of potential for future knowledge recombination from the individual-level interactions can be seen as emergence from lower-level network interactions (Moliterno and Mahony, 2011; Ployhart and Moliterno, 2011). The firm-level property emerges from the clustering or path length structure of the underlying knowledge network. Taken together, we argue that if a firm has an internal knowledge network with high clustering and average path length then that firm has significant potential for internal future knowledge recombination. This in turn should make external sourcing strategies less effective for new knowledge at the margin because the firm is able to effectively generate new knowledge internally.

Hypothesis 1: External knowledge sourcing and internal knowledge sourcing in networks with high recombinative potential are substitutes, such that the interaction between external knowledge sourcing and an internal knowledge networks is negative, and thus decreases a firm's knowledge generation at the margin.[2]

[2] We can restate hypothesis 1 in a more formal way: If we define *internal knowledge sourcing in networks with high recombinative potential* as $KnowNet_{HighRecomb}$ and *external knowledge sourcing as* $KnowSource_{Ext}$, and *a firm's knowledge generation* as π , it follows that

$$\pi\left(KnowNet_{HighRecomb}, KnowSource_{Ext}\right) - \pi\left(KnowNet_{HighRecomb,} \overline{KnowSoure_{Ext}}\right)$$

Although the structure of a knowledge network has been used to predict its knowledge generation performance (Brown and Eisenhardt, 1997; Reagans and Zuckerman, 2001), it has not been relied upon to capture the level of internal coordination costs. In fact, scholars argue that the importance of coordination costs associated with internal knowledge production has generally been neglected by the theories of boundary choice (Langlois and Foss, 1999). Yet, Argyres and Silverman (2004) find that a firm with a centralized R&D structure generates more impactful innovations through a reduction in internal coordination costs. In addition, Rawley (2010) documents how increases in internal coordination costs constrain economies of scope. We build on these insights and argue that if an incumbent firm generates knowledge in a new area and the firm already faces high internal knowledge production and coordination costs then external knowledge sourcing strategies are less effective for new knowledge generation because they would simply add to the existing coordination burden. It is costly to recognize, evaluate, and appraise external knowledge (Levinthal and March, 1993). These costs increase if a firm's absorptive capacity is effectuated through an internal knowledge network burdened with high coordination costs.

To capture coordination costs of a firm's internal knowledge network, we rely on two structural attributes of the network: the average number of collaborative ties that knowledge

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$< \pi\left(KnowNet_{HighRecomb}, \overline{KnowSource_{Ext}}\right) - \pi\left(\overline{KnowNet_{HighRecomb,}}\ \overline{KnowSoure_{Ext}}\right)$,

where *prime* indicates that a firm does not engage in external knowledge sourcing or does not possess an internal firm knowledge network that has high recombinative potential. The formula states that, new knowledge generation by a firm that does possess an internal knowledge network with high recombinative potential *and* engages in external knowledge sourcing simultaneously is lower than for a firm that does only rely on its internal knowledge network with high recombinative potential and does not engage in external knowledge sourcing, holding all else constant (Milgrom and Roberts, 1995).

producers have and the average number of collaborative ties required for a new knowledge stock. More ties on average for every knowledge-generating individual suggest a significant coordination burden for the organization. Developing and maintaining collaborative ties requires time and attention at the individual level, resources that are removed from the individual's pursuit of knowledge development per se. The average number of ties per new knowledge stock, similarly, suggests elevated coordination costs as every new knowledge stock requires a higher, on average, level of interpersonal collaboration. As a result, these structural network attributes suggest an internal knowledge network with significant coordination costs arising from the knowledge production process. Following a similar multilevel emergence logic (Kozlowski et al., 2013), the firm-level property of a high coordination burden in the firm's knowledge production system emerges directly from the individual-level interactions that suggest elevated coordination costs per individual and per new knowledge stock. At the same time, one of the main costs of external knowledge sourcing is the cost of coordination – firms have to identify partners, work with them, commit resources, monitor collaboration, transfer knowledge, make adjustments, etc. Merely evaluating external knowledge is costly because it requires a commensurate level of absorptive capacity (Lane and Lubatkin, 1998; Levinthal and March, 1993). Taken together, we argue that if a firm has an internal knowledge network characterized by high coordination costs then external sourcing becomes less effective for new knowledge at the margin because external sourcing adds significantly to the coordination burden, potentially negating any benefit to external sourcing.

Hypothesis 2: External knowledge sourcing and internal knowledge sourcing in networks with high coordination costs are substitutes, such that the interaction between external knowledge

sourcing and an internal knowledge networks is negative, and thus decreases a firm's knowledge generation at the margin.[3]

In summary, we highlight both the value creation potential of internal knowledge networks in the form of recombination potential and the associated coordination costs. How many benefits a firm captures from external knowledge sourcing depends partly on its internal knowledge network attributes. We, therefore, explicitly examine the influence of a firm's network structure on knowledge creation, an unexplored topic in prior research (Phelps et al., 2012). We summarize our conceptual model in Figure 1.

Insert Figure 1 about here

METHODS

We test the contingency model developed in the global pharmaceutical industry. The industry experienced a competence-destroying technological discontinuity with the emergence of biotechnology (Pisano, 1996; Tushman & Anderson, 1986). Large incumbent pharmaceutical firms faced tremendous pressures to adapt to the new technological paradigm because their

[3] We can restate hypothesis 2 in a more formal way: If we define *external knowledge sourcing* as $KnowSource_{Ext}$ and *internal firm knowledge networks that are characterized by high coordination costs* as $KnowNet_{HighCoordCosts}$, it follows that

$$\pi\left(KnowSource_{Ext,}\, KnowNet_{HighCoordCosts}\right) - \pi\left(KnowSource_{Ext,}\, \overline{KnowNet_{HighCoordCosts}}\right)$$

$$< \pi\left(KnowSource_{Ext,}\, \overline{KnowNet_{HighCoordCosts}}\right) - \pi\left(\overline{KnowSource_{Ext,}}\, \overline{KnowNet_{HighCoordCosts}}\right),$$

where *prime* indicates that a firm does not does not engage in external knowledge sourcing or does not possess an internal firm knowledge network that has high coordination costs. The formula states that new knowledge generation of a firm that possesses an internal knowledge network with high coordination costs *and* engages in external knowledge sourcing simultaneously is lower than for a firm that relies only on external knowledge sourcing, holding all else constant (Milgrom and Roberts, 1995).

upstream research knowledge was inconsistent with the new technology. The need for large pharma companies to build a new knowledge base was exacerbated by the fact that they failed to innovate through developing new blockbuster drugs, while the R&D expenditures were rising and average sales per drug were falling at the same time (Higgins and Rodriguez, 2006). The pressures to build new knowledge in biotech as a potential avenue for future innovation are illustrated by the following trends: between 1990 and 2000, R&D expenditures grew from $6.8 billion in 1990 to $21.3 billion (17% of revenues); new drug development costs increased from $231 million to $802 million; and average sales per patented drug fell from $457 million to $337.[4]

To develop new knowledge within the new biotechnology paradigm, incumbent pharma companies invested in internal and external technology sourcing (Pisano, 1996). Internally, pharmaceutical companies invested in building up their research capability and human capital. Externally, the incumbent firms invested in exploration alliances to build new knowledge bases, in exploitation alliances to leverage their existing complementary assets, and in acquisitions of smaller biotechnology firms to capture both tacit and explicit knowledge (Rothaermel and Deeds, 2004; Pisano, 2006).

We submit that this industry is a viable setting to test our contingency hypotheses about the interactions between external and internal knowledge sourcing. Following investment in internal development and external knowledge sourcing, pharmaceutical incumbents firms were able to slowly build new biotech-related knowledge internally and thus adapt to the technological discontinuity. We track this process to capture the development of internal new knowledge in

[4] All in constant, inflation-adjusted 1999 U.S. dollars.

the emerging paradigm from the beginning of the biotech revolution, and examine the effectiveness of various external knowledge sourcing strategies.

Our sample consists of 106 incumbent pharmaceutical firms worldwide, representing more than 80% of global sales in this industry. The year 1974 approximates the beginning of industry research in biotechnology, one year after the invention of a technique to recombine DNA developed by Cohen and Boyer in 1973. To assess how successful incumbent pharmaceutical firms have been in adapting to biotechnology and to avoid a sample selection bias, we tracked all firms in existence in 1974 forward in time. We collected annual data for the knowledge sourcing strategies of those firms over a 25-year period, beginning in 1974 until the end of 1998.

We characterize firms in the sample as incumbents because they were active in the pharmaceutical industry focusing on human therapeutics prior to the emergence of biotechnology. Horizontal mergers are fairly common in this industry; when a merger occurred we combined the data of the merging firms into one entity, and continued tracking it forward. Not only did we track the sample forward in time, we also constructed a detailed "family tree" to trace all firms in existence at the end of the study period back in time to their "ancestors," all the way back to the beginning of the study. This "family tree" allowed us to identify horizontal mergers with great accuracy. To explicitly control for a horizontal merger event, we created an indicator variable to capture this event.

Taken together, the pharmaceutical industry provides an almost ideal setting for our study because it is as close as strategy researchers can recreate a laboratory experiment. Because the dating of the biotech revolution (post 1973) for the pharma companies is well established, we are able track a sample of firms forward that were all founded prior to the new technology paradigm.

In particular, traditional pharma firms were created during a time when chemistry was the foundational science (Galambos and Sturchio, 1998). All pharma firms born within the "old" chemical-based screening paradigm in the sample experienced the same exogenous treatment effect ("emergence of biotech"). This type of "natural experiment" allows us to can assess how effective incumbent pharma firms were in adapting to the new knowledge paradigm. We explain the observed heterogeneity by differences in a firm's internal knowledge network structures combined with its external knowledge sourcing strategies.

We constructed the key dependent and independent variables using patents granted to the firms by the USPTO. Albeit not without problems, patent counts have been used extensively to measure a firm's new knowledge creation activities and innovative performance (e.g., Ahuja, 2000; Henderson & Cockburn, 1994; Stuart, 2000; Rothaermel and Hess, 2007). Moreover, as demonstrated in the Cohen, Nelson, and Walsh (2000) survey of close to 1,500 manufacturing firms in the U.S. with in-house R&D activity, patenting in the pharma industry is one of the most important strategic activities, and is mainly done to protect intellectual property. Across 34 different industries surveyed, Cohen, et al. (2000) find that patenting in the pharma industry ranks second only to the medical device industry in assessing patents as an effective mechanism to protect intellectual property. This implies that patents are used to protect new knowledge generation, the dependent variable of this study. In addition, Hagedoorn and Cloodt (2003) studied different measures of performance of 1,200 large firms in high-tech industries (aerospace and defense, computers and office machinery, electronics and communications, and pharmaceuticals) and found that in the pharma industry the bi-variate correlation between patents and patent citations = 0.78; patents and R&D expenditures = 0.70; and patents and new products = 0.59. This indicates that the overlap in explaining variance across different knowledge-related

measures is quite high. Hagedoorn and Cloodt (2003: 1375) conclude: "the results of the analysis … indicate that the overlap between each of these four indicators is that great … that in high-tech sectors any of these four indicators [patents, patent citations, R&D expenditures, and new products] could be taken as a measure of innovative performance in the broad sense."

Although there are some alternatives such as projects in pipeline, new products, or even publications by scientists, we submit that tracking individual-level patenting activity is the most appropriate available source of information for our purpose. Projects or products are much removed in time from the date of actual knowledge production; and publications may be more or less unrelated to applicable product-related firm-level knowledge efforts. Although many of these measures are highly correlated as shown by Hagedoorn and Cloodt (2003), patent counts provide the most appropriate theoretical and empirical fit with our study. The date of patent applications is close in time to the date of knowledge creation. Moreover, patents are strategically important in the pharma industry, providing a strong incentive for companies to patent knowledge that is novel, useful, and non-obvious.[5]

Taken together, patents by incumbent pharma firms in the new field of biotechnology, therefore, seem to be an appropriate measure to capture new knowledge generation. We used the NBER patent data file (Hall, Jaffe, and Trajtenberg, 2001) to create a patent portfolio for each one of our firms from 1974 to 1998. We tracked all different names under which firms patent and collected patent data for their subsidiaries to make sure that we capture each firm's full patenting activity.

Dependent Variable

[5] Statutory definition of a patentable invention by USPTO.

To proxy the successful development of knowledge in the emerging biotech paradigm by pharmaceutical incumbents, we relied on the annual count of biotech patents assigned to the firms in our sample. Patents are an important input into the knowledge conversion process from invention to innovation (Griliches, 1990). We enhanced the accuracy of the patent count metric by focusing only on biotech patents as dependent variable (while controlling for the firm's entire patent output). This enabled us to obtain a theoretically more proximate metric of a firm's knowledge development in the new paradigm because incumbent pharmaceutical firms did not possess any knowledge base in biotech prior to its emergence. As explained, the biotech revolution was a discontinuity for existing pharmaceutical companies. This makes the research design akin to a natural laboratory because all incumbent firms were exposed to the same treatment effect (emergence of biotech) but significant heterogeneity emerged in firms' capability to develop knowledge and adapt to the new technology.

To define which of the patents in an incumbent's patent portfolio are biotech patents, we relied on the definition of a biotech patent provided by the Patent Technology Monitoring Division (PTMD) of the USPTO. The PTMD provides a list of technology classes and sub-classes that capture new knowledge stocks with a strong biotech component. To confirm the validity of this approach, we examined the patent portfolios of dedicated biotechnology firms and the technology classes to which their patents are assigned and we found that our approach of categorizing biotech patents was robust. Finally, to ensure that our measure is as close as possible to the actual date of knowledge generation, we constructed our measure of annual biotech patent counts based on the application date of the patent instead of the grant date.

Intrafirm Knowledge Networks

To capture the state of internal knowledge of incumbent firms in the new biotechnology paradigm over time, we developed intrafirm co-inventing networks for each incumbent firm from 1974 to 1998 based on their biotech patents. Hence, we were able to proxy the level of internal collaboration and knowledge development in biotechnology by looking at the emerging intrafirm co-inventing networks developing in the context of a new technological paradigm. We identified unique individual inventors on these biotechnology patents using the NBER database inventor file based on a combination of last name, first name, and middle name (Hall, et al. 2001). When there was still a conflict even after using all three names and correcting misspelled last names, we expanded our matching criteria to include city and state of residence for each inventor. The resulting dataset captures every inventor with unique inventor IDs associated with patents from 1974 to 1998, resulting in over 267,000 inventors in our sample. This allowed us to develop fine-grained co-inventing networks over time (using UCINET 6). The nodes of the network are individual inventors, and a tie between inventors represents a co-patenting event.

Park et al. (2006) demonstrated that patented knowledge depreciates fairly quickly over time. Following their empirical estimates, we considered knowledge through a tie that is older than five years as somewhat out-of-date. We therefore we developed networks for every firm using a five-year rolling window and assigned the resulting values to the last year of every time window (1982-86 values to 1986, 1983-87 values to 1987, etc.). We analyzed the networks and tracked several network metrics at the firm-network level (density, total collaborative ties, clustering, average path length, etc.).

Independent Variables

To develop the key independent variables to test the hypotheses developed, we used the results of the network analysis to capture the two main properties of an incumbent firm's state of

internal knowledge sourcing: *recombinatory potential* and *coordination costs*. First, we measured each firm's recombinatory potential using two network metrics: *average path length* and *degree of clustering*. Average path length is the average distance (steps through ties) between any two inventors in the firm's knowledge network. The higher the average length, the broader is the firm's knowledge network base and therefore, the higher is the potential for further knowledge recombination. Clustering is the degree to which the firm's network is organized around multiple local neighborhoods of dense interpersonal collaboration, where arguably knowledge recombination is more likely to occur because those clusters are more likely to be characterized by increased motivation to share knowledge, transfer knowledge transfer, and knowledge of who knows what.

Second, we measured coordination costs using two different metrics: *average ties per biotech patent* and *average ties per inventor*. Our objective was to capture the coordination burden of the firm as it develops new biotech knowledge internally. *Average ties per biotech patent* is one aspect of the coordination burden as it reflects the average intensity of collaboration used to generate a biotech patent. Using the previously mentioned five-year rolling window procedure, in order to derive a variable for year *t*, we divided the total number of collaborative ties used to develop biotech patents from year *t*-4 to year *t* by the number of biotech patents produced in year *t*. *Average ties per inventor* is a second aspect of the coordination burden as it reflects the average intensity of collaboration per inventor. To construct this variable, we divided the same total number of collaborative ties by the total number of inventors participating in the knowledge production process during the same five-year window (i.e., the size of the network).

Next, we collected detailed information about the external knowledge sourcing strategies that were undertaken by the pharmaceutical incumbents in our sample. We focused on two such external capability sourcing modes: knowledge-oriented alliances with sources of biotech knowledge (i.e., exploration alliances) and biotech-related acquisitions (Hayward, 2002; Rothaermel, 2001). First, we collected data on the alliance history for every firm in our sample from BioScan and ReCap, databases that have been successfully used in prior research on alliances and are considered the most comprehensive sources for alliance activities (Schilling, 2008). We tracked the alliances that incumbent firms in our sample entered with various sources of biotechnology knowledge (universities and other research institutions as well as biotech firms). Following a common procedure in prior research (Koza and Lewin 1998; Lavie and Rosenkopf 2006; Rothaermel and Deeds 2004), we coded grant, research, and R&D alliances as *exploration alliances* because these alliances focus on the enhancement of upstream research and basic science knowledge. To ensure correct coding, we used multiple research assistants who coded independently the alliances in our sample. The inter-rater reliability was 98%, well above the recommended 70% (Cohen et al. 2003). The resulting variable is an annual count of the total number of such exploration alliances entered by an incumbent firm in our sample. Further, we collected the annual number of biotech-related *acquisitions* made by incumbent firms from the SDC Platinum database (Laamanen & Keil, 2008; Puranam & Srikanth, 2007). Finally, to construct the independent variables and test the hypotheses, we calculated interactions between the two types of external knowledge sourcing and the two sets of internal knowledge sourcing properties discussed above. Before entering them into interactions, we standardized all variables, and also controlled for the direct effects of the independent variables that make up the interaction effects.

Control Variables

We include a rich and fine-grained set of control to limit the threat of endogeneity (Hamilton and Nickerson, 2003). In particular, we control for the effect of the firm's overall *innovative performance* by including as a right-hand side variable the flow of its overall patents (including biotech patents). We also control for the firm's relative focus on the generation of biotech knowledge by including a *biotech focus* ratio, the number of biotech patents divided by total patents. We include the total number of inventors for each firm to control for other aspects of a firm's existing knowledge-producing resources. This metric also provides a fine-grained measure of the firm's innovation-related *network size.* All time varying control variables are tracked annually, and are lagged by one year. In addition, we control for the firm's geographic origin (*EU, US*). Finally, we include indicator variables that control for firms that were a result of an horizontal merger (*merged firm*) and firms that are dedicated pharmaceutical firms, that is, not diversified conglomerates (*Pharma*).

Estimation

The dependent variable is a nonnegative count variable with overdispersion and therefore, we used negative binomial models. Both fixed- and random- effects specifications would allow us to limit any remaining unobserved heterogeneity (Hamilton and Nickerson, 2003). We conducted a Hausman test which suggested that there are no significant differences between the two estimation methods. Nevertheless, we chose to rely on a firm fixed-effects specification to conduct a conservative within-firm analysis and control for firm-level unobservable factors. As a robustness check, we also used the random-effects specification and the results remained robust.

RESULTS

Table 1 depicts descriptive statistics and bivariate correlations for the variables. Correlations among our independent variables are below the recommended ceiling of 0.70. To further evaluate the threat of collinearity, we estimated the variance inflation factors (VIFs) for each coefficient, with the maximum estimated VIF being 1.64, which is well below the recommended threshold of 10 (Cohen *et al*., 2003). Table 2 depicts the results of our fixed-effect negative binomial regression predicting the number of incumbent firm-level biotech patents. In Models 2 and 3, we tested Hypothesis 1 by assessing the interactions between external knowledge sourcing and recombinative potential (average path length and clustering). In Models 4 and 5, we tested Hypotheses 2 by inserting the interactions between external knowledge sourcing and coordination costs (average ties per patent and per inventor). Models 1 and 6 are control models. Model 1 is the baseline model with only control variable included, while Model 6 is the complete model with all interactions inserted simultaneously.

Insert Tables 1-2 about here

We find strong support for our Hypothesis 1 regarding the negative moderation effect of internal recombinatory knowledge potential. In Model 2, exploration alliances are less effective when combined with high internal average path length ($p < 0.01$) and clustering ($p < 0.05$). In Model 3, acquisitions are less effective when combined with high average path length ($p < 0.05$). These results are robust in the complete specification (Model 6), except for the interactions with acquisitions as method to source external knowledge. This might explained by the fact that strategic alliances in biotech are more aimed towards explicit knowledge transfer than acquisitions of biotech start-ups, which may contain a stronger tacit dimension of knowledge (Higgins and Rodriguez, 2006; Rothaermel and Deeds, 2004).

We find some support for our Hypothesis 2 regarding the negative moderation effect of internal coordination costs. In Model 4, exploration alliances are less effective when combined with a high level of average ties per patent ($p < 0.01$) and acquisitions are less effective when combined with a high level of average ties per inventor ($p < 0.05$), see Model 5. The results in support for Hypothesis 2 are even stronger in the complete estimation because, in addition to the results obtained in Models 4 and 5, the interaction between exploration alliances and average ties per inventor is also significant ($p < 0.05$, see Model 6).

Insert Figures 2-6 about here

Taken together, the pattern of results suggests a view which is consistent with our theory. To provide a more intuitive and clear understanding of these results and uncover additional insights, we display graphically the statistically significant interaction results in Figures 2-6. Figures 2-3 display the interactions between exploration alliances and average path length, and exploration alliances and clustering, respectively. We see that exploration alliances have a strong positive effect only under conditions of low internal recombinative potential and almost no effect when coupled with strong internal recombinative potential. In Figure 4, we see that acquisitions have a negative effect when coupled with high recombinative potential and a slight positive effect for low recombinative potential. In Figure 5, we depict a striking result: if coordination costs are low then exploration alliances have a strong positive effect. If, however, coordination costs are high then exploration alliances are actually harmful for the generation of biotech patents. In Figure 6, we depict a similarly result for the case of acquisitions, again with a reversal of slopes as we move from low to high coordination costs and assess the contingent effect of acquisitions. If internal knowledge network coordination costs are low, then acquisitions have a positive effect on generating new knowledge. In contrast, when in internal

knowledge network coordination costs are high, the effect reverses, with external knowledge sourcing through acquisitions decreasing a firm's ability to generate new knowledge. In summary, we find consistent support the contingency model between internal recombinatory potential and coordination costs, on the one hand, and external knowledge sourcing, on the other.

DISCUSSION

Incumbent firms in high-tech industries often face competence-destroying technological change. In their effort to adapt and develop new knowledge in a novel paradigm, incumbent firms have several corporate strategy options available to them: internal knowledge development and a wide array of external knowledge sourcing strategies including alliances and acquisitions. In this study, we made an effort to address a critical question: how effective is external knowledge sourcing under different internal knowledge generation regimes? In particular, we developed a conceptual framework suggesting that the effectiveness of external sourcing partly depends on the state of the internal knowledge production process. In particular, we studied firms' internal knowledge networks in a fine-grained manner, highlighting opposing forces: value creation through recombinatory knowledge generation and costs through coordination burdens. Incumbent firms generally develop new knowledge gradually in any emerging technological paradigm.

Our central thesis is: if incumbents already possess a strong potential for internal knowledge recombination or a high level of coordination costs in the internal knowledge generation process, then external sourcing (either via alliances and/or acquisitions) will be less effective in delivering the necessary new knowledge generation. This core argument is based on a simple but powerful idea: if incumbents can generate new knowledge internally then any external sourcing that also leads to new knowledge trajectories, might potentially be substituting

for knowledge paths suggested by internal development. Similarly, if incumbents are able to generate new knowledge internally and face high coordination costs then any external source adds to the coordination burden and might have compensating knowledge producing effects. We submit that this is one of the first studies that compares and contrasts the benefits and costs of internal firm knowledge networks in the context of external knowledge sourcing. We applied social network concepts and analysis to the emerging internal knowledge networks of incumbents when adapting to a technological discontinuity in order to capture the emergence of two critical firm-level knowledge properties: internal recombinatory potential and internal coordination burden.

We tested our theoretical framework in the global pharmaceutical industry. Pharmaceutical incumbents were forced to adapt to a changing paradigm with the emergence of biotechnology. To do so, they followed a wide array of knowledge sourcing strategies, which included internal development, alliances with sources of biotech knowledge, and outright acquisitions of biotech targets. The results provided robust support for our theoretical framework. Exploration alliances and acquisitions were indeed less effective as knowledge building mechanisms when incumbents had internally the potential for knowledge recombination and already faced high coordination costs. Our core tenet that the effectiveness of external sourcing is contingent upon the state of a firm's internal knowledge process resonates with the recent study by Arora, Belenzon, and Rios (2014) demonstrating that firms with centralized R&D derive more value from internal R&D, but less from external R&D via mergers and acquisitions. While Arora et al. (2014) focused on acquisitions, we also look at strategic alliances in a fine-grained manner. Perhaps more importantly, rather than focusing on the internal firm organizational structure, we take a novel look deep inside the firm and unearth

structural features of firm-specific knowledge networks that moderate the effectiveness of external sourcing strategies. Moreover, our study also resonates with Hoang and Rothaermel (2010) who looked, albeit at the R&D project than the firm-level of analysis, at the interactions of different types of external and internal knowledge by evaluating some 400 R&D projects.

We submit that this study makes several contributions to different lines of research. First, we contribute to the literature on knowledge sourcing and the degree of complementarity between external and internal knowledge sourcing. We build on the finding that incumbent firms are more likely to engage in concurrent sourcing (Parmigiani, 2007; Parmigiani and Mitchell, 2009). We also build on a growing line of work that seeks to identify the factors that affect the relationship between internal and external knowledge sourcing (Cassiman and Veugelers, 2006; Jacobides, 2008; Rothaermel and Hess, 2007) by highlighting important characteristics of the firm's internal knowledge base. Our conceptual framework and results are consistent with related work suggesting that it is differences in internal knowledge bases that dictate boundary choices (Jacobides and Hitt, 2005; Jacobides and Winter, 2005; Kogut and Zander, 1992). Our framework is also consistent in its objectives with Capron and Mitchell (2009), who show that the effectiveness of external renewal modes in building new knowledge bases is contingent upon the firm's internal social context. We submit that it is the internal social context within which a firm's knowledge generation takes places, and in turn, influences the effectiveness of external sourcing. We demonstrated that characteristics deep within firms—its potential for new knowledge generation and the associated coordination costs—are important factors in influencing whether external and internal sourcing mechanisms complement or substitute for each other.

Second, we make a contribution to the burgeoning literature on social and knowledge networks and their effects on firm-level performance heterogeneity. Rather than looking at the individual level of analysis to identify certain structural roles held by key knowledge workers such as star scientists in a firm's knowledge network (Grigoriou and Rothaermel, 2014; Nerkar and Paruchuri, 2005; Paruchuri, 2010), however, we focus on a firm-level of analysis to unearth certain structural characteristics of a firm's entire internal knowledge network that influences firm-level performance.

One of this study's novelties is the application of social network analysis to incumbents' internal knowledge networks in order to capture overall firm-level knowledge properties. To move from internal knowledge network structure to firm-level knowledge properties, we rely on recent theoretical insights in the concept of multilevel emergence (Kozlowski et al., 2013). We also build on recent work that describes specifically how lower-level network interactions result in the emergence of higher-level firm level properties such firm-level human capital or network-level outcomes (Moliterno and Mahony, 2011; Ployhart and Moliterno, 2011). By doing so, we extend our collective understanding of the type of inferences that one can make when examining the structure of a firm's internal knowledge network by adding recombinative potential and coordination costs to the factors considered in prior work such as knowledge transfer or sharing (Brown and Eisenhardt, 1997; Reagans and Zuckerman, 2001; Reagans and McEvily, 2003; Reagans et al., 2004; Lazer and Friedman, 2007; Yayavaram and Ahuja, 2008). Our approach to study the structure of internal knowledge networks to extract information about knowledge recombination and coordination is also consistent with recent work in the field (Kleinbaum and Stuart, 2014) that seeks to understand coordination costs based on a firm's network structure.

Finally, by connecting knowledge network structure to firm-level knowledge creation we also help to close a gap in knowledge network research, as identified by Phelps et al. (2012).

Limitations and Future Research

As any study, this one is not without limitations. First, we emphasized the knowledge-sourcing component embedded in alliances and acquisitions. These corporate strategy levers, however, can be motivated by a slew of strategic objectives other than knowledge sourcing such as market consolidation, transaction costs, real options, pre-emption of competitors, cost savings, or foreign market entry to name a few (McGahan and Villalonga, 2005). We made every effort, however, to address this problem by focusing on exploration alliances only, which carry a stronger knowledge orientation component as they are partnerships with sources of biotech knowledge, and acquisitions by pharmaceutical incumbents that directly involve (small) biotech firms, where a stronger case that knowledge acquisition is the driver can be made. Still, even these modes do not always occur simply for knowledge development. Nevertheless, we submit that these are important venues for knowledge flows as documented in prior research (Higgins and Rodriguez, 2006; Rothaermel and Deeds, 2004), and therefore, we submit that our arguments of a knowledge substitution mechanism between internal and external sources of knowledge should hold.

Second, we relied on inventor ties to develop intrafirm knowledge networks. We chose co-inventor networks to capture the applied stage of the knowledge production process. This enabled us to create a tighter theoretical and more proximate empirical link between new knowledge development and some of its key drivers. We relied on interpersonal collaboration and the structure of the network to proxy for recombinative potential and coordination costs. Co-patenting has been shown to include significant knowledge transfer among the inventor involved

(Singh, 2005). Future research can uncover additional ways of capturing these attributes and capture other sources of internal production costs such as internal social frictions (Capron and Mitchell, 2009), social envy and comparison costs (Nickerson and Zenger, 2004), as well as organizational structure (Arora, et al. 2014). Moreover, future research may also focus on informal ways to generate new knowledge as well as on generating tacit rather than explicit knowledge (captured in patents), as done in this study.

Third, the number of patent counts in a new technological paradigm as dependent variable to proxy new knowledge generation is also not without criticism. Again, we are neglecting informal and tacit sources of knowledge generation which are often quite important to firm-level performance. Although patenting is prevalent and quite important in the pharmaceutical industry as documented in the detail survey by Cohen, et al. (2000), patenting does not always occur for knowledge generation. Firms, for example, patent for a number of different reasons such as competitor pre-emption, legal strategy, signaling, and so forth. Moreover, there are other important sources of internal network formation such as publication co-authorships or informal collaboration among scientists that our study neglects. Given these other sources of knowledge generation, however, implies that patent counts as proxy for new knowledge generation would actually be a conservative estimate because we cannot capture informal knowledge generation effectively. If anything, using patent counts alone as proxy for knowledge generation would actually bias our estimates downwards, and thus making it harder for us to find statistically significant relationships.

Finally, we did not include any measures for the costs of external knowledge sourcing modes. It is widely documented that both alliances (e.g., knowledge misappropriation, choosing the right partner) and acquisitions (e.g., overpayment, post-acquisition integration), however,

have costs. Acquisitions, in particular, can be costly and acquirers often overpay for targets. Future research should address this issue to provide an even more fine-grained understanding of the benefits and cost of external sourcing strategies vis-à-vis internal knowledge networks.

Managerial Implications

We conclude with several managerial implications in general, and for corporate strategy in particular. First, we provide managers with a fresh tool of evaluating the state of their firm's internal knowledge base using social network concepts. Second, we offer theory and evidence on the important role of the firm's internal recombinative potential and coordination costs when it comes to evaluating the effectiveness of external knowledge sourcing strategies.

Perhaps more important for corporate strategy, we show that external sourcing strategies are less effective when coupled with an internal potential to generate knowledge or with high internal coordination costs. The benefits to an external sourcing mode, however, may be overstated when coupled with a solid state of internal knowledge recombination potential or high coordination costs. Therefore, it is critical to know that if an external sourcing mode is chosen for its knowledge benefits and is evaluated vis-à-vis its commensurate costs. Both the benefits and cost of external sourcing as well as internal sourcing must be taken into account when organizing for new knowledge generation.

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Table 1. Descriptive statistics and correlation matrix

		Mean	SD	1	2	3	4	5	6	7	8	9	10	11	12	13
1	Biotech patents	24.75	28.97													
2	Merged firm	0.15	0.36	0.36												
3	EU	0.30	0.46	0.17	0.09											
4	US	0.34	0.47	0.22	0.17	-0.47										
5	Pharma	0.49	0.50	0.01	0.00	-0.02	-0.06									
6	Total patents	82.92	105.40	0.56	0.09	0.22	0.19	-0.35								
7	Biotech focus	0.50	0.46	0.10	0.14	0.04	-0.12	0.30	-0.34							
8	Network size	140.72	132.53	0.80	0.42	0.21	0.06	0.00	0.43	0.12						
9	Exploration alliances	0.90	1.81	0.41	0.29	0.02	0.16	0.00	0.15	0.10	0.47					
10	Acquisitions	0.33	1.20	0.34	0.30	0.03	0.14	0.07	0.11	0.10	0.38	0.38				
11	Average path length	2.55	1.21	0.56	0.27	0.07	0.03	0.01	0.26	0.14	0.64	0.32	0.26			
12	Clustering	0.85	0.09	-0.25	0.00	-0.02	-0.31	-0.01	-0.22	0.02	-0.11	-0.03	-0.04	-0.03		
13	Average ties per inventor	4.31	2.44	-0.01	0.00	0.05	-0.42	0.03	-0.15	0.16	0.18	0.01	-0.01	0.25	0.14	
14	Average ties per patent	9.55	14.86	0.07	0.04	0.01	-0.19	-0.05	-0.02	0.06	0.24	0.07	0.06	0.17	0.03	0.52

N = 1756 observations

Table 2. Fixed-Effects Negative Binomial Regression Predicting Number of Biotech Patents

Variable	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6	
Constant	Incl.		Incl.		Incl.		Incl.		Incl.		Incl	
Year Effects	Incl.		Incl.		Incl.		Incl.		Incl.		Incl.	
Merged firm	0.120	***	0.062	*	0.070	**	0.096	***	0.100	***	0.040	
	(0.041)		(0.038)		(0.038)		(0.040)		(0.039)		(0.037)	
EU	-0.795	***	-1.173	***	-1.121	***	-0.834	***	-0.862	***	-1.095	***
	(0.153)		(0.196)		(0.194)		(0.162)		(0.164)		(0.203)	
US	-0.534	***	-0.915	***	-0.947	***	-0.000	***	-0.501	***	-0.773	***
	(0.148)		(0.196)		(0.193)		(0.193)		(0.161)		(0.205)	
Pharma	0.338	***	0.049		0.057		0.171		0.183	*	0.063	
	(0.111)		(0.128)		(0.127)		(0.116)		(0.116)		(0.132)	
Overall innovative performance	0.004	***	0.003	***	0.003	***	0.003	***	0.003	***	0.002	***
	(0.001)		(0.000)		(0.000)		(0.000)		(0.000)		(0.000)	
Biotech focus	0.333	***	0.299	***	0.283	***	0.331	***	0.313	***	0.282	***
	(0.019)		(0.020)		(0.021)		(0.020)		(0.020)		(0.021)	
Network size	0.001	***	0.001	***	0.001	***	0.002	***	0.002	***	0.002	***
	(0.000)		(0.000)		(0.000)		(0.000)		(0.000)		(0.000)	
Exploration alliances	0.000		0.045	***	-0.005		0.026	***	0.002		0.028	***
	(0.006)		(0.012)		(0.009)		(0.010)		(0.010)		(0.007)	
Acquisitions	-0.053	***	-0.023	***	-0.013		-0.044	***	-0.014		-0.012	
	(0.010)		(0.009)		(0.015)		(0.011)		(0.011)		(0.013)	
Average path length			0.147	***	0.133	***					0.133	***
			(0.013)		(0.014)						(0.013)	
Clustering			-0.051	***	-0.046	***					-0.044	***
			(0.014)		(0.014)						(0.014)	
Average ties per inventor							0.185	***	0.182	***	0.131	***
							(0.018)		(0.018)		(0.024)	
Average ties per patent							-0.154	***	-0.154	***	-0.151	***
							(0.021)		(0.022)		(0.020)	
Exploration alliances X			-0.047	***							-0.042	***
Average path length			(0.008)								(0.008)	
Exploration alliances X			-0.031	**							-0.024	*
Clustering			(0.015)								(0.016)	
Exploration alliances X							0.001				-0.034	**
Average ties per inventor							(0.016)				(0.016)	
Exploration alliances X							-0.067	***			-0.043	***
Average ties per patent							(0.015)				(0.014)	
Acquisitions X					-0.014	**					0.006	
Average path length					(0.008)						(0.007)	
Acquisitions X					-0.006						0.004	
Clustering					(0.019)						(0.019)	
Acquisitions X									-0.043	**	-0.027	*
Average ties per inventor									(0.019)		(0.018)	
Acquisitions X									-0.014		-0.007	
Average ties per patent									(0.014)		(0.011)	
No. of observations / groups	2426 / 106		1751 / 96		1751 / 96		2356 / 106		2356 / 106		1751 / 96	
Chi square	2248.82***		2233.99***		2153.03***		2537.70***		2489.22***		2471.54***	

Notes: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$; standard errors in parentheses

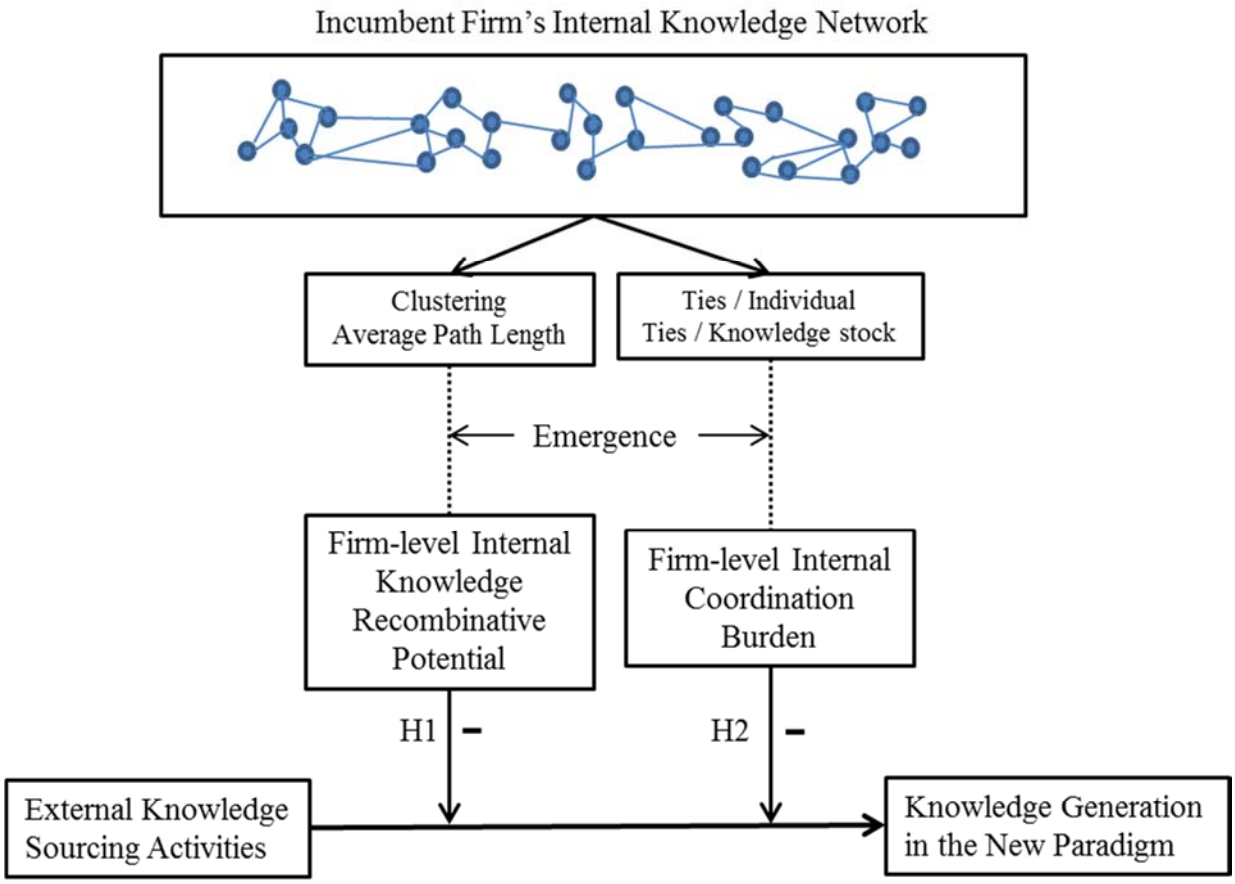


Figure 1. The conceptual model

Figure 2. Interaction between exploration alliances and average path length

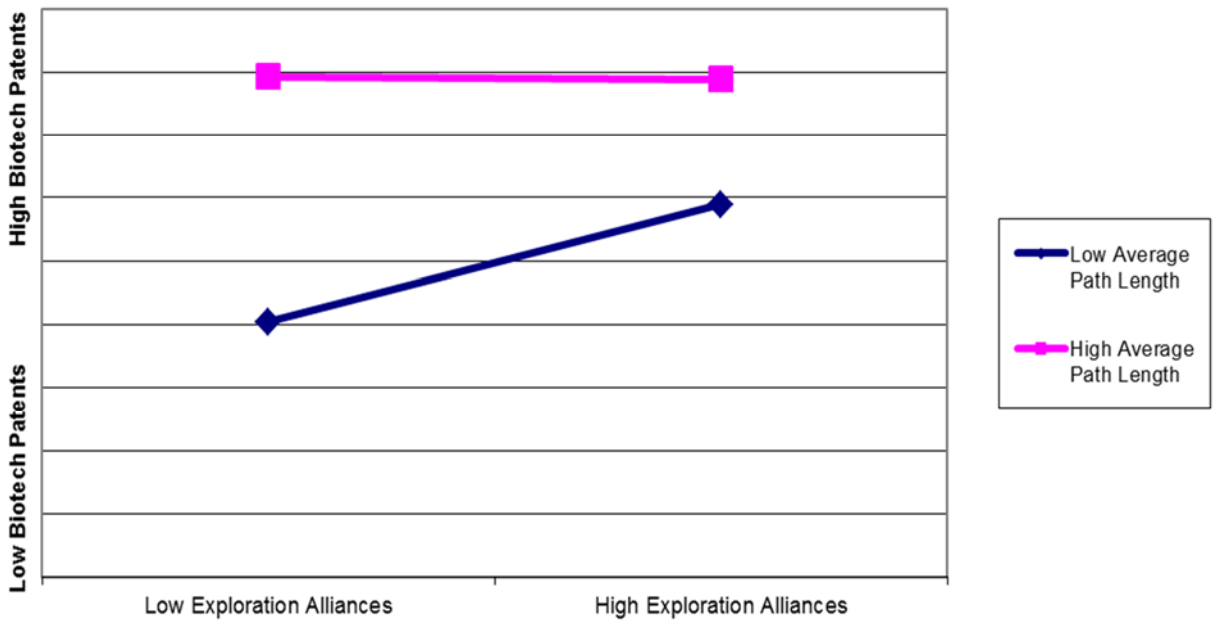


Figure 3. Interaction between exploration alliances and clustering

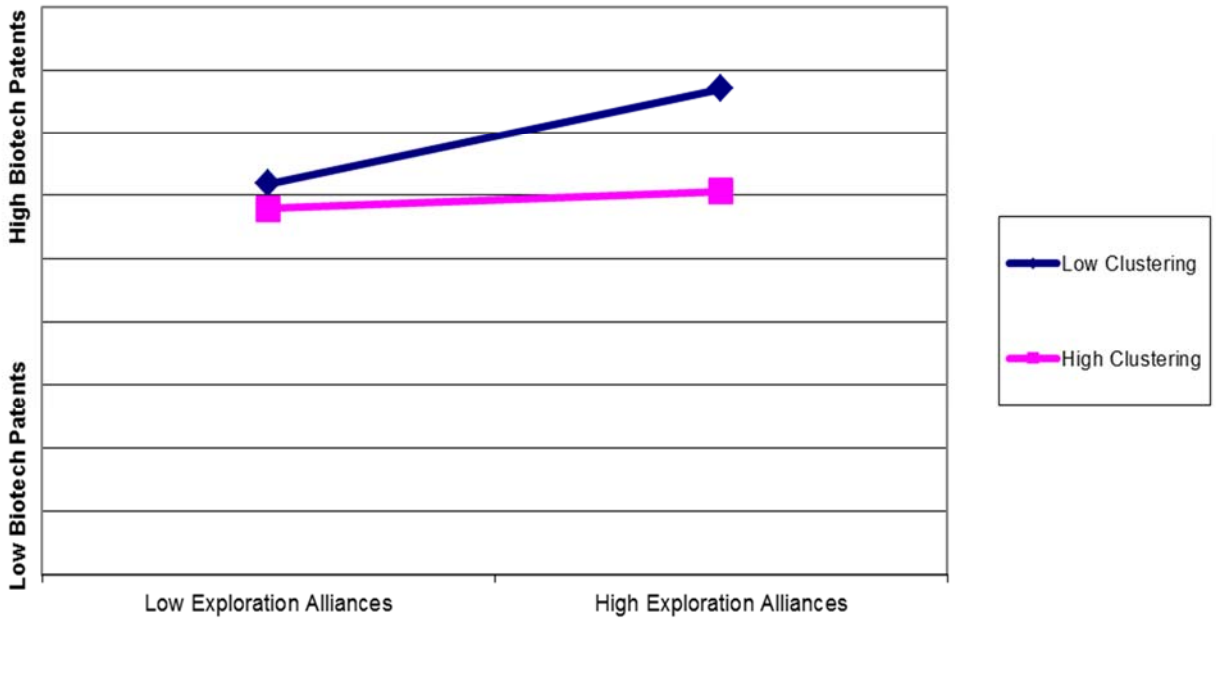


Figure 4. Interaction between acquisitions and average path length

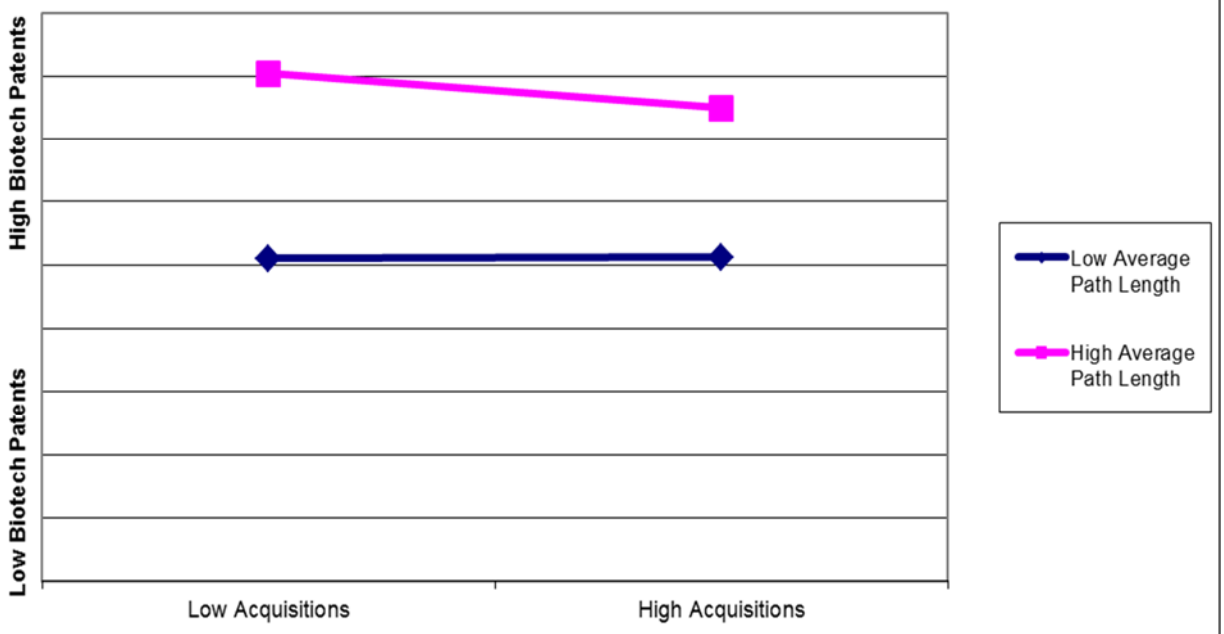
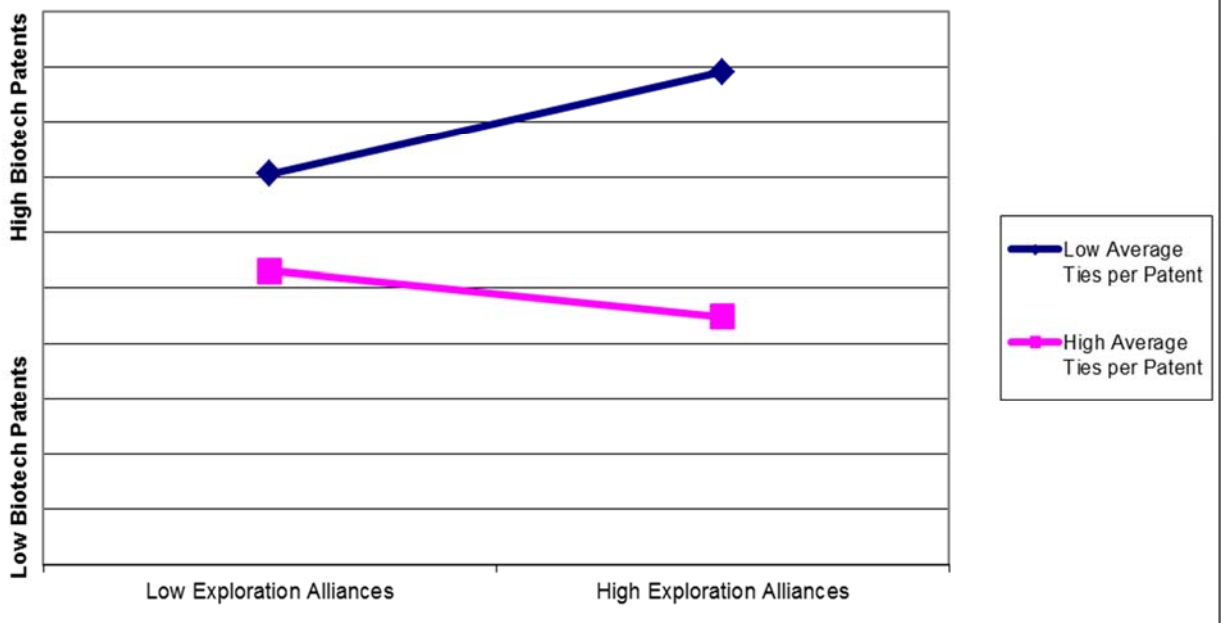


Figure 5. Interaction between exploration alliances and average ties per patent



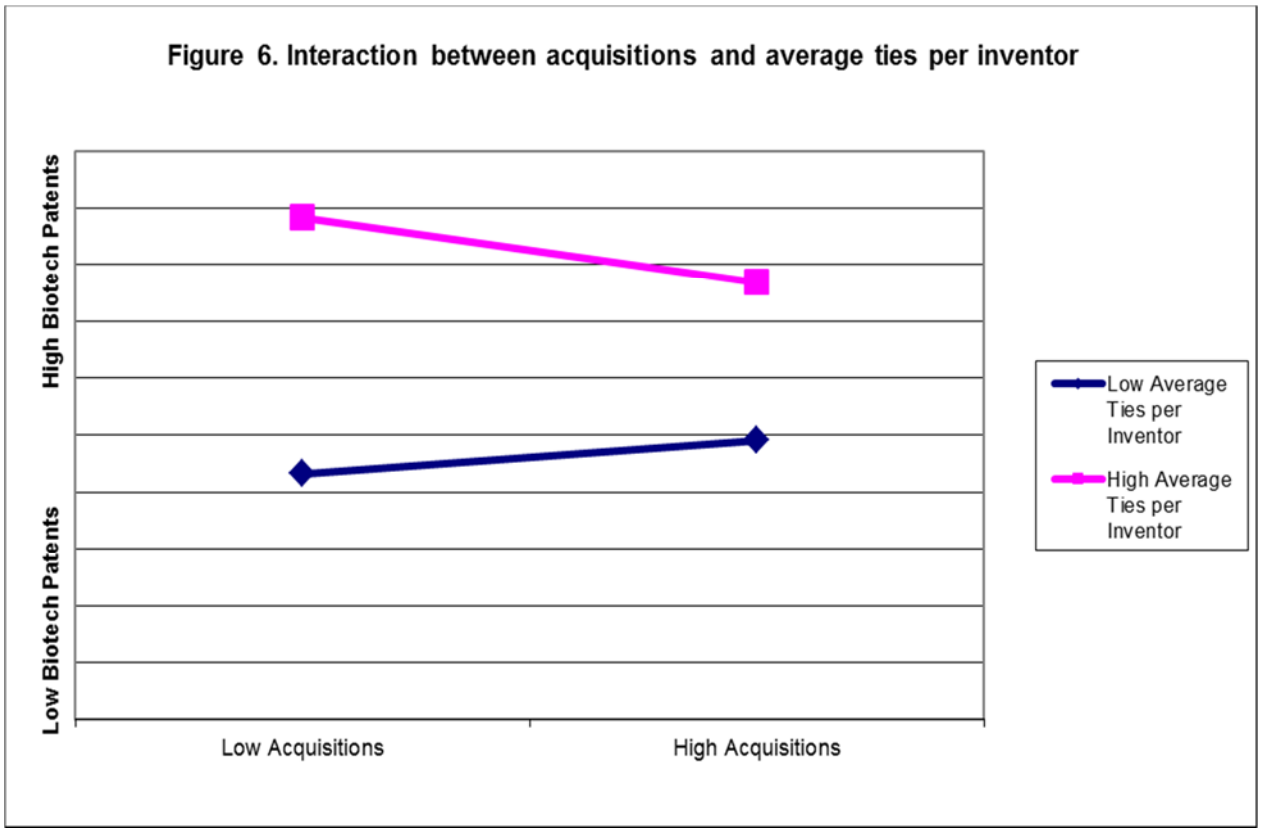


Figure 6. Interaction between acquisitions and average ties per inventor
High Biotech Patents
Low Biotech Patents
Low Acquisitions
High Acquisitions
Low Average Ties per Inventor
High Average Ties per Inventor