Knowledge Spillovers and Alliance Formation

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Abstract

Our study examines the conditions under which firms enter into strategic alliances subsequent to knowledge spillovers. We propose that spillovers serve as signals of knowledge dependence and potential complementarity, encouraging alliance formation to enable better learning and limit appropriation. We posit that the likelihood of a knowledge alliance subsequent to a spillover is contingent on the specialization of each of the firms in the knowledge involved in the spillover. We also hypothesize that the effects of such specialization on knowledge alliance formation are moderated by technological ties and geographic distance between the dyad involved in the spillover. Our results demonstrate significance for the effects of specialization, supporting learning and appropriation motivations. Technological ties strengthen while geographic distance weakens the relationship between specialization and alliance formation.

Keywords: Knowledge spillovers, alliance formation, specialization, patents, biotechnology

1. Introduction

Alliances are a critical source of external knowledge for the firm (Hamel, Doz and Prahalad, 1989; Khanna, Gulati and Nohria, 1998), enabling the development of new products and capabilities (Rothaermel, and Deeds, 2004). Alliances arise when firms recognize opportunities for resource complementarity that are best exploited for rents through cooperative forms of governance rather than through market means or acquisition (Madhok and Tallman, 1998). One signal of opportunity is provided by knowledge spillovers, the unintentional and uncompensated exchange of knowledge among firms (Malmberg and Maskell, 2002). Knowledge spillovers signal opportunities for access to external knowledge (Yang, Phelps and Steensma, 2010), by both originator and recipient, in the technological area of the spillover as well as in areas complementary to the spillover. Recent research provides evidence of firm recognition of this learning opportunity leading to the formation of alliances subsequent to knowledge spillovers (Stuart and Podolny, 2000, Stuart, 1998), but at the same time, spillovers themselves offer costless access to external knowledge (Zucker, Darby & Armstrong, 1998).This raises the question of why and when would firms replace a knowledge spillover with an alliance.

As knowledge is a strategically important resource that contributes to firm competitive advantage (Grant, 1996), understanding the dynamics and management of knowledge transactions is important. Knowledge spillovers offer costless and ungoverned access to knowledge developed outside the firm, and are the basis for an extensive literature addressing the drivers and outcomes of uncompensated geographically localized knowledge exchanges (Zucker et al., 1998) in industry clusters (Tallman, Jenkins, Henry and Pinch, 2004). Spillovers clearly offer an important channel to access external knowledge. Many studies also have considered the effect of firm-specific knowledge stocks, similarities, and complementarities between two firms considering alliance (Inkpen, 1998; Rothaermel and Boeker, 2008). However, these studies typically present the focal firm with the option of either allying or choosing not to share knowledge, ignoring the alternative of unintended and uncompensated knowledge flows. From a knowledge-based perspective, the bundling of complex, organizationally embedded knowledge and the creation of new joint knowledge is enabled by structured forms of governance (Kogut and Zander, 1992). Integrated structures, whether they are joint ventures or contractual alliances, improve coordination of knowledge and technology sharing, potentially enhancing the value of shared knowledge (Oxley and Wada, 2009; Diestre and Rajagopalan, 2012). However, these integrated structures also bring with them risks of partner appropriation of the shared knowledge and administrative costs to minimize those risks, requiring a complex net value calculation to determine whether or not to ally (Madhok and Tallman, 1998). Our research addresses the transformation of a costless flow of knowledge from spillovers into a structured relationship for systematic knowledge transfer. This provides a fundamental view of the benefits of an alliance structure, since any transactional costs clearly are greater than costless access through knowledge spillovers, and the limitations of spillovers as means of knowledge transfer. Thus, our primary research question is, "What internal and external conditions increase or decrease the likelihood that two firms will enter into an alliance subsequent to a knowledge spillover between them?"

We adopt the opportunity, motivation and ability framework with its implications for successful knowledge management (Argote, McEvily and Reagans, 2003) to explore the transformation of a knowledge spillover into an alliance. Opportunity for, access to, and control of complementary technological resources is signaled by the knowledge spillover. We then go on to consider the motivation and ability of both parties to the potential alliance, in contrast to studies of alliances that take a 'focal firm' perspective (Ahuja, 2000; Das and Teng, 2000). Alliances are formed only when the interests of both partners are aligned favorably, suggesting a perspective of 'it takes two to tango'. We assess participants' motivation and ability by considering their technology strategies, i.e., the specialization of each firm in the technological area of the knowledge spillover. We posit that specialization results in differential learning possibilities and appropriation concerns on the parts of the originator and the recipient of the spillover. We further posit that the effect of technology strategy is shaped by boundary conditions of technological ties and geographic distance, between the members of the dyad involved in the spillover, that have implications for knowledge absorption and leakage.

2. Spillovers, dependencies and alliances

Knowledge spillovers represent the unintended and uncompensated flow of knowledge from an originator firm to a recipient firm that then uses the knowledge for its own innovative purposes (Griliches, 1992; Arrow, 1962). For example, in the late 1980s, Abbott Laboratories invented a novel material and device useful in solid-phase binding assays to determine the presence or amount of an analyte in a test sample, and applied for a patent to cover this invention. Since the invention, a number of firms from a variety of U.S. and overseas locations, including Boehringer Mannheim, Miles Inc., Mochida Pharmaceutical, Hybritech, and SmithKline Diagnostics have utilized knowledge derived from Abbott's invention to create their own inventions[i]. In this case, knowledge spillovers occurred from Abbott to each of these firms as they capitalized on Abbott's invention to further their own innovation efforts without compensating Abbott for its original investment.

Firms typically review the knowledge development efforts of others as they search for useful external knowledge to reduce their costs of innovation (Appleyard, 1996). Similarly, researchers, engineers and managers actively monitor how their ideas diffuse and are extended by others through mechanisms like patent citations (Garud and Rappa, 1994; Yang, Phelps and Steensma, 2010). Thus, spillovers appear to serve as signals of knowledge and technology opportunities for both the recipient and originator.

Knowledge obtained through a spillover and incorporated into innovative technologies by the recipient firm creates dependency on and potential for complementarity with additional knowledge resources possessed by the originator. While the knowledge spillover leads to disclosure of specific information embodied in the patent[ii], the high degree of tacitness embodied in a technological innovation (Teece, 1986, pg 287) generally means that this is incomplete disclosure. Since the recipient relies on an idea generated by the originator (Jaffe and Trajtenberg, 1999) and often needs additional tacit knowledge to fully absorb the idea (Zahra and George, 2002), this creates a dependency for the recipient. Indeed, knowledge spillovers have been used to document dependency on basic science or specific technologies (Carpenter and Narin, 1983).

Complementarity refers to mutual dependence and the ability to reinforce each other's performance outcomes (Milgrom and Roberts, 1990). The potential for the recipient to utilize additional knowledge resources – in the form of tacit knowledge associated with the spillover as well as other articulated and tacit knowledge – of the originator, in combination with its own knowledge base to enhance its innovative outcomes, creates possibilities for complementarity. The originating firm also will recognize similar possibilities for complementarity that could benefit it through access to the recipient's knowledge base and through some means of appropriating at least part of the value of its lost knowledge. One way to accommodate mutual dependencies formally and to capitalize on complementarities is through the creation of inter-firm alliances (Gulati, 1995; Contractor, Beldona and Kim, 2011). In accordance with prior literature, alliances are defined here as formalized co-operative relationships between firms that involve sharing, exchange or co-development and can encompass contractual arrangements or equity sharing (Gulati and Singh, 1998; Madhok and Tallman, 1998; Phene and Tallman, 2012). Our research focuses on a subset of these alliances, knowledge alliances whose objectives explicitly involve knowledge access, knowledge sharing or collaborative research and development.

Under what circumstances do firms involved in knowledge spillovers shift the costless transaction to an alliance structure that entails administrative costs? The fundamental issue of transaction cost economics is the governance and organization of transactions (Williamson, 1975). The choice of internalizing a transaction within a hierarchy or an intermediate form of governance, such as an alliance or joint venture, is determined by the conditions of the transaction (Williamson, 1979). From a knowledge based perspective, arms' length ties do not allow complementarities to develop between knowledge resources; hierarchical forms are required (Kogut and Zander, 1992) to mitigate the uncertainties of markets. If the knowledge requires only partial contact between firms, or involves only a part of their knowledge bases, semi-hierarchical governance forms such as contractual or equity-based alliances may provide adequate integration with lower organizational and managerial costs than full internalization. To quote Oxley and Wada (2009, p. 635), "As external knowledge sources are increasingly global and diverse, inter-firm alliances have become popular mechanisms by which firms access external knowledge."

Early explanations for alliance formation focused on a cost-benefit analysis weighing the potential benefits from co-operation against the costs of managing the alliance (Buckley and Casson, 1988). Alliances are inherently more expensive than are spillovers, as they involve the use of managerial and technical workers' time and require some capital investment. They may also create additional costs and risks of unwanted opportunism by the partner, involuntary leakage of technology, withholding of resources and efforts by partners due to difficulties of measurement and monitoring in alliances, and costs of supporting transfer of tacit knowledge (Gulati and Singh, 1998; Pisano, 1989). Thus, transforming a spillover to an alliance requires the expectation of some specifiable benefits at the firm level to cover the transactional costs associated with the alliance.

These benefits are likely to be conferred by successful management of knowledge by the firm, a function of opportunity, ability and motivation (Argote, McEvily and Reagans, 2003). The knowledge spillover offers originators and recipients an opportunity to consider an alliance, as well as an incentive to avoid formal entanglement. For the originator, two views of alliances offer benefits to justify the costs of an alliance. First, the knowledge spillover signals the presence of complementary technology resources available from the recipient that could, through an alliance, enhance the competitive advantage of internal knowledge assets (Narula and Santangelo, 2009). Second, an alliance could enable the originator to appropriate some portion of the rents earned by the recipient from this current uncompensated transfer of knowledge and also to manage future spillovers preemptively. Alliances allow originators to apply measures of intellectual property protection (royalties, specified recourse, limits to search) through contracts or shared equity that go beyond those available from the inter-organizational trust and negative reputational effects in social networks and beyond the uncertain property rights conferred by patents[iii] (Thambisetty, 2007).

The spillover of such knowledge also points to opportunities for the recipient for learning and collaborative development with the originator. However, while a spillover may provide one piece of technical component knowledge, successful application of this knowledge may well require, or at least be eased by, access to related tacit knowhow or complementary technologies from the originator that can be expressly obtained through a formal alliance agreement. At the same time, the recipient has an incentive to avoid the transfer of any rents from its knowledge bundle, including the spillover, to the originator, and so may wish to avoid deeper or formal ties. Thus, in the case of both members of a spillover dyad, learning and appropriation concerns of the firms may increase or decrease their inclination to transform the spillover into an alliance.

These concerns are determined by the ability and motivations of the dyad firms to participate in the learning and knowledge management process. Ability and motivation to engage in learning are in turn enhanced by firm absorptive capacity, driven by the existence of prior related knowledge that the firm has accumulated (Cohen and Levinthal, 1990). The technology strategy of the firm, that is, the extent of its specialization in the area of the spilled over knowledge, points to a stock of related knowledge that will enhance firm motivation and ability to engage in learning. We posit that technological specialization creates asymmetric motivations for the originator and recipient to engage in an alliance. Firms focus their attention on and specialize in core technology areas that are important to their innovation agendas and to firm success (Phene, Tallman and Almeida, 2012; Granstand, Patel and Pavitt, 1997). The unintended exposure of core technologies in which the firm specializes is therefore likely to inspire more aggressive efforts to engage in learning and collaborative development, as well to contain costs and recoup losses, encouraging alliance formation by the originator.

Dyads engaged in spillovers exist in settings that may increase or decrease the influence of firm-specific conditions. As Sorenson and Stuart (2008) propose, interorganizational ties emerge atop a landscape of settings. Prior direct ties and proximity mechanisms are important factors in the process through which dyadic ties are formed (Rivera, Soderstrom and Uzzi, 2010). In the case of knowledge spillovers, technological ties defined as prior knowledge flows and geographic distance (at the other end of the spectrum from proximity) between the dyad members should therefore directly influence alliance formation. We expect them to moderate the effects of specialization on alliance formation, because of their ability to influence learning ability (Argote et al, 2003), and therefore to magnify incentives and concerns associated with specialized knowledge. Technological ties enable similarity of knowledge processing systems and dominant logics in terms of problems pursued (Lane and Lubatkin, 1998) by increasing absorptive capacity (Cohen and Levinthal, 1990) for each others' knowledge and by encouraging the development of shared knowledge through common practice (Brown and Duguid, 1991). Likewise, studies of geographical clusters suggest that co-location or geographic proximity and associated social networking enable the development of common architectural knowledge which enhances the comprehension and incorporation of spilled over knowledge (Tallman et al., 2004), while geographic distance inhibits knowledge flows (Jaffe et al, 1993).

How do technological ties and geographic distance moderate the relationship between firm specialization and alliance formation? First, an originator may be more sensitive to and concerned with knowledge leakage in an area of specialization under conditions of dyad proximity. This is because a recipient in such a dyad is better equipped to capitalize on knowledge gained from the spillover as a consequence of improved absorptive capacity due to prior ties and proximity. In addition, firms in such dyads are more likely to be aware of each other's knowledge development efforts (Saxenian, 1994). Loss of specialized knowledge to a technically tied or geographically proximate recipient is perceived as a greater threat than loss of such knowledge to a less technically tied or more distant recipient. Second, in such a dyad, an originator is better poised to learn from the recipient due to higher absorptive capacity. In this situation the originator may perceive greater potential for reverse learning from a recipient particularly when specialized technologies are involved. Therefore dyad proximity through technological ties or lower distance is likely to magnify the effects of originator specialization on alliance formation.

These conditions of proximity that increase motivation for the originator are likely to magnify the resistance by the recipient of specialized knowledge to alliance formation. In contrast, in dyads that are not tied or are distant, specialization of either partner will have a weaker influence on alliance formation. This model is expressed graphically in Figure 1 and is developed in detail in the following sections.

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Insert Figure 1 here
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3. Knowledge and the firm – Specialization and transactional difficulty

As proposed above, a firm-specific concern in the case of knowledge spillovers relates to the extent of specialization by members of the dyad in the knowledge involved in the spillover. On the one hand, Stuart and Podolny (2000) suggest that specialization may make alliance activity less likely due to fears that alliances will expose core proprietary knowledge. However, specialization also has important implications for partnership opportunity, signaling the presence of complementary knowledge assets and better coordination ability. Specialization has been demonstrated to facilitate coordination of learning processes in interfirm cooperation (Cantwell and Colombo, 2000), which is an important consideration in the creation of alliances (Inkpen, 1998; Heiman and Nickerson, 2004). Specialization therefore appears to create contradictory pulls, increasing concerns for protection from intra-alliance interactions and enabling coordination in alliances to gain the benefits of complementary technology opportunities.

If an originator firm is spilling knowledge from one of the technological areas in which it specializes (i.e. an area where most of its technological activity is concentrated), it is more likely to view the recipient firm as a potential alliance partner for dual reasons of learning and control. Specialization in a core area of knowledge is a consequence of deliberate and significant resource allocation by the firm to that technological area. The use of the specialized knowledge of the originator by the recipient signals the presence of learning and collaborative opportunities for the originator in that technological area as well as in complementary and related technological areas. Informal relational mechanisms may not be sufficient for providing mutual learning opportunities (Heiman and Nickerson, 2004; Narula and Santangelo, 2009). Learning through random spillovers is uncertain and an originator may therefore not rely on this option, for learning in or related to a key technology area. In contrast, alliances allow for closer coordination and enable mutual learning and joint knowledge development (Madhok and Tallman, 1998). Just as the presence of complementary resources and skills enhances incentives to ally (Arora and Gambardella, 1990), we expect that spillovers in the originator's area of specialization increases motivation to ally due to complementary learning opportunities.

In addition to learning opportunities, alliances can offer the originator firm some opportunity to manage the appropriation of the returns to proprietary knowledge. In the case of a spillover absent an alliance, proprietary knowledge has already been compromised and exposed. However, there is still potential for the originator to ensure that current and future exchanges are controlled. Even though we consider knowledge spillovers represented by patent citations that reflect codified and protected knowledge, ability to appropriate the returns to knowledge continues to be a concern. As the example of the Abbott patent demonstrates, several firms were able to capitalize on (and appropriate) Abbott's knowledge, as represented by its patent, for their own objectives. Patents provide specified rights that allow for a temporary monopoly on the invention (either product or process) defined by the claims that the patent makes (Pressman, 2011), but firms can design around the claims laid out by the patent to create new products or processes and avoid infringement of patents (Teece, 1986; Pressman, 2011, page 428). Indeed, inventing around patents is a common problem (Oxley, 1999; page 40) and Teece (1986) concludes that patents offer little protection and do not work in practice as they do in theory.

Thus, recipient firms involved in knowledge spillovers can benefit from the articulated and protected knowledge of the originator without necessarily infringing on the patent. Additionally, flows of tacit and articulated knowledge tend to be closely linked and complementary (Mowery, Oxley and Silverman, 1996), further enhancing originator concerns regarding appropriation. Although knowledge has already spilled over, there is an opportunity and motivation for the originator to use an alliance to appropriate returns that may result from the development of such knowledge by the recipient for either a future product or new knowledge and to pre-emptively manage future spillovers.

For the originator, relying on mechanisms of social sanction or on the uncertain property rights conferred by the patent represented in the knowledge spillover (Teece, 1986; Thambisetty, 2007) is risky. Alliance contracts, on the other hand, specify property rights over inputs and outputs (Grandori, 2010) and lay down general principles and codes of conduct (Grandori and Furlotti, 2006), thereby enabling originators to wall off and prevent access to critical technology and reducing the leakage of technology unrelated to the alliance activity (Oxley and Wada, 2009). The key here is that a formal alliance offers the originator the opportunity to control the knowledge exchange (Narula and Santangelo, 2009) and prevent future losses while the uncompensated, uncontrolled spillover of this knowledge provides no such opportunity (Zucker, Darby and Armstrong, 1998).

Therefore, despite concerns that alliances entail additional costs and risk the loss of knowledge beyond that intended to be shared between partners (Gulati and Singh, 1998), an originator firm is likely to consider an alliance subsequent to a spillover for dual reasons - in order to further pursue learning opportunities with its partner and to exert some amount of control over the current and future exploitation of its knowledge. We suggest that the benefits outweigh the costs of a formal tie in instances involving originator specialization and propose that greater specialization by the originator in the area of the knowledge spillover increases the likelihood of alliance formation subsequent to a spillover.

H1: The greater the specialization of the originator firm in the technological area of a knowledge spillover, the greater the likelihood of a knowledge alliance between the originator and recipient firms subsequent to the spillover.

On the other side of the knowledge transaction, recipient firms are not likely to be concerned about the possibility that they might be misappropriating the knowledge of an originating firm or its related returns, so long as they are not subject to legal penalties. Indeed, for the firm receiving a spillover of technology, bolstering its technology at no cost might be considered the great benefit of such relationships (Arrow, 1962), particularly if the incoming knowledge is in one of its own areas of specialization. Thus, from an appropriation perspective the recipient firm in a specific dyadic transaction has little motivation to agree to an alliance or other formal mechanism for knowledge transfer and control since it can only result in its having to share its profits from the application of that knowledge. Alliances that involve knowledge transfer often require sharing of future innovations resulting from the original knowledge transfer, so the recipient firm could well find that its own future recombination-of-knowledge based innovations (Kogut and Zander, 1992) would have to be shared with its partner, the originator firm.

From an organizational learning perspective, recipient firms are likely to be concerned with two issues related to ability to learn – first whether they can effectively understand and apply the spilled over knowledge, and second the additional complementary opportunities for learning from the originator. If the knowledge is in one of the areas of specialization of the recipient firm, the recipient's absorptive capacity (Cohen and Levinthal, 1990) for the spilled over knowledge as well as for complementary knowledge is likely to be high. The absorptive capacity of the firm for external technological knowledge is dependent to a significant extent on the degree of its knowledge in a particular technological field (Schoenmakers and Duysters, 2006). Further the development and accumulation of tacit knowledge (Polanyi, 1966) related to the technology is also dependent on specialization (Enright, 1991). Thus a recipient with greater specialization will possess well-developed internal mechanisms for understanding and exploiting spillover knowledge.

In addition, the recipient's capacity to capitalize on complementary learning opportunities available at the originator is also expected to be high. Makri, Hitt and Lane (2010) show that in acquisitions knowledge complementarities between firms point to the presence of common knowledge stocks or greater absorptive stock, which in turn helps each of the firms recognize the value of complementary opportunities and assimilate them. We expect a similar situation in the case of alliances. Therefore the extent of specialization by the recipient in the technological area of the knowledge sector is likely to indicate the possession of sufficient articulated and tacit knowledge to enable the recipient both to utilize the knowledge involved in the spillover and to capitalize on complementary learning opportunities. The recipient is less likely to need access to supporting knowledge in this case than in the case of knowledge spillovers in areas where it is less specialized and that are less familiar to its own employees.

Madhok and Tallman (1998) propose that relational investment in cooperative ventures is largely about smoothing the way for knowledge transfer by increasing mutual absorptive capacity. However, in the case of spillovers of specialized knowledge, the recipient is readily able absorb and apply spilled over knowledge and exploit complementary learning opportunities, by relying on the large and very familiar body of knowledge in the recipient's specialty field. Therefore, and contrary to the motivations of the originating firm, the receiving firm is less likely to want to formalize a knowledge exchange through an alliance that entails additional costs in one of its areas of specialization.

H2: The greater the specialization of the recipient firm in the technological area of a knowledge spillover, the lower the likelihood of a knowledge alliance between the originator and recipient firms subsequent to the spillover.

4. Knowledge spillover context – The effects of technological ties and geographic distance

In the previous section, we proposed that specialization of the member firms in a spillover dyad in the technological area of the spillover will influence the propensity for these firms to engage in an alliance subsequent to a knowledge spillover. We also believe that the contexts – technological and geographic – of the ties existing between the firms at the time of the spillover will moderate the relationship between specialization and alliance formation.

4.1. Technological ties

Given our focus on knowledge, we examine technological ties represented by prior knowledge flows between the dyad firms. Repeated knowledge flows between the originator and recipient are likely to have enhanced the receptivity and absorptive capacity of each for the other's knowledge by developing shared tacit architectural understandings of the applications of technology and increasing similarity of knowledge stocks (Mowery et al., 1996; Tallman and Phene, 2007; Lane and Lubatkin, 1998; Brown and Duguid, 1991). Our model controls for the direct effects of such ties on alliance formation, which have been demonstrated (Stuart and Podolny, 2000). In an extension of this prior research, we propose that previously existing technological ties between firms will moderate the effects of specialization on the likelihood of alliance formation post-spillover.

Existing technological ties, or previous citations by the originator and recipient to each other's patents, are directly related to the issue of spillovers and mutual dependencies. An originator is likely to perceive a recipient in a technologically tied dyad as a valuable opportunity because of the potential for the originator to engage in reverse learning from the recipient. Such a recipient is simultaneously perceived as a significant threat by the originator, due to the recipient's likely ability to utilize acquired knowledge effectively. Increasing levels of technological ties raise originator perceptions of threats and opportunities, more so when the spilled knowledge is in a core or critical part of the originator's knowledge base[iv].

Loss of specialized knowledge through a spillover to a technologically tied recipient is a worrisome prospect for the originator in contrast to loss of specialized knowledge to a less tied recipient on several counts. The technologically tied recipient has the ability to effectively utilize the specialized knowledge to mount a more urgent, proximate, competitive threat in the technological domain that is vital to the originator. A recipient who has fewer technological ties may be unable to use the specialized knowledge because of lower shared knowledge and mutual absorptive capacity. Additionally, even if such a recipient is able to utilize some of the specialized knowledge, it may be put to use in a different technological domain, resulting in a less direct competitive challenge in a domain that is peripheral to the originator. Thus, spillover of specialized knowledge to a technologically tied recipient increases appropriation concerns on the part of the originator.

This direction of argument also holds for reverse learning by the originator. An opportunity to engage in reverse learning through a formal alliance offers greater potential and benefits in the case of specialized knowledge spilled over to a technologically tied recipient. The originator has higher expectations of the extent and ease of learning from recipients that have greater technological ties to them than from those that have fewer ties when specialized knowledge is involved. Consequently spillover of specialized knowledge to a technologically tied recipient offers greater learning potential for the originator.

As discussed in the hypothesis for specialization (H1), specialization of originator in spilled over knowledge leads to greater learning potential for and increased appropriation concerns by the originator increasing alliance formation. In the case of spillovers of specialized knowledge to technologically tied recipients, both learning potential by and appropriation concerns of the originator are further magnified, and together positively moderate the effects of specialization on alliance formation.

H3A: The positive relationship between originator specialization and knowledge alliance formation subsequent to the spillover will be made stronger by increasing technological ties between the originator and recipient.

We predicted that the closer a spillover was to the core area of specialization for the knowledge recipient the less likely the recipient was to enter into an alliance. The negative effects of recipient specialization on alliance formation are likely to be increased by the extent of technological ties between the recipient and dyad. Technological ties raise the absorptive capacity of the recipient for spillovers from the originator beyond what its specialization already offers (Mowery et al., 1996), as they enhance the commonality of knowledge processing systems and dominant logics (Lane and Lubatkin, 1998), conferring additional advantages to assimilation by the recipient. From the perspective of the recipient, this makes a formal alliance between technologically tied dyads for the purpose of consolidating already familiar knowledge even less likely to create value beyond the original learning from the spillover. An alliance in these circumstances may also raise concerns for a potential threat from an originator, uniquely positioned by its technological ties, gaining better access to the recipient's specialized knowledge, thus leading to a reversal of the current roles in which the recipient benefits at the cost of the originator. The ease of utilizing specialized knowledge in a technologically tied dyad also makes the financial and opportunity costs of a formal alliance unpalatable.

In contrast, a lack of shared tacit understandings and a lower absorptive capacity for spillovers of technology from originators with few prior ties suggest that when the incoming spillover is in a core area for the recipient, an alliance may be beneficial for the recipient in enabling the transfer of supporting or complementary knowledge. The opportunity to effectively utilize specialized knowledge by using an alliance with an originator in a less technologically tied dyad also will make the recipient less resistant to the possible costs of sharing future revenue that the alliance entails and to the actual costs of setting up an alliance. We therefore expect the negative relationship between recipient specialization and alliance formation to be made stronger by technological ties, such that increasing the extent of technological ties increases the negative effect of recipient specialization on alliance formation.

H3B: The negative relationship between recipient specialization and knowledge alliance formation subsequent to the spillover will be made stronger (more negative) by increasing technological ties between the originator and recipient.

4.2. Geographic distance

In a similar manner to prior technological ties, research documents the frequent interactions enabled by geographic proximity (Saxenian, 1994). Greater proximity or lower distance allows firms to experience economic benefits from "agglomerative efficiencies" in transactions because of such things as infrastructural development, an experienced set of suppliers and a common labor pool. Consequently, such firms tend to share both structural understandings and technical knowledge about the products and processes that are involved in the industry (Tallman et al, 2004). Geographic proximity facilitates knowledge exchanges through interactions enabled by social networks and the movement of labor (Saxenian, 1994; Zucker, Darby and Armstong, 1998). Thus, geographic proximity increases, while geographic distance limits, the awareness of mutual knowledge dependencies, a common architectural knowledge, and increased absorptive capacity for spilled technology. A recipient in a geographically proximate dyad (similar to one in a technologically tied dyad) is therefore likely to be perceived by an originator as an opportunity to learn from and a threat to contend with, in contrast to a recipient in a geographically distant dyad. As Narula and Santangelo (2009: 395) say, "co-location…implies potential threat to the competitive advantage of collocated rivals, which strategic partnering may prevent".

We propose that geographic distance moderates the effects of specialization on alliance formation such that it weakens the positive effects of originator specialization and the negative effects of recipient specialization. Originating firms will recognize that spillovers of specialized knowledge to other geographically proximate recipients are likely to result in direct and similar applications by the recipients because of similarities in understanding due to close, cooperative and competitive interactions (Maskell, 2001). The originator will respond particularly aggressively to protect its exposed intellectual property in cases where spillover of its specialized knowledge is involved *and* where the recipient is geographically proximate, since this situation presents an immediate threat that could erode its competitive position in that knowledge space. The originator will also be alert to the potential for a nearby recipient to generate rents from the application of the spillover knowledge and be motivated to appropriate at least some part of those rents. Individual scientists in clusters do not give away their intellectual property to co-located firms, but tend to enter into contractual arrangements with these firms (Zucker et al, 1998) and the probability of such joint research arrangements rises contingent on the quality of the scientists' work (Zucker et al, 2002). The potential for reverse learning from a recipient utilizing specialized knowledge in a geographically proximate area offers the originator an additional opportunity to recoup some of the loss from the uncompensated knowledge spillovers. Finally, physical proximity and similar practice are likely to keep costs of investment in the alliance low and increase the effect of specialization on alliance formation.

On the other hand, in the case of spillover of specialized knowledge to a geographically distant firm, distance and resultant differences in knowledge capabilities (highlighted earlier) between the firms make it less likely that the recipient will use the specialized knowledge in a manner similar to the originator. Consequently such spillovers present a weaker threat and simultaneously weaker opportunity for the originator. The costs of alliance formation and management across a greater distance will further offset any perceived benefits of control or learning. Geographic distance will therefore serve to weaken the effects of originator specialization on alliance formation, making a specialized originator less disposed towards an alliance with a geographically distant recipient in a knowledge spillover.

H4A: The positive relationship between originator specialization and knowledge alliance formation subsequent to a spillover will be made weaker by greater geographic distance between the originator and the recipient.

Specialization by recipient firms in the knowledge involved in the spillover makes them resistant to knowledge alliance formation. We expect this relationship to be strengthened in the case of geographic proximity between dyad members and correspondingly weakened in the presence of geographic distance. The benefits of capitalizing on uncompensated spillovers from the originator and utilizing specialized knowledge that is central to the recipient are magnified by geographic proximity. Proximity increases the ability of the recipient to fill gaps in its knowledge through shared tacit understanding and mutual absorptive capacity with knowledge originators. The threat to competitive advantage of the originator discussed earlier works in favor of the recipient. In fact, an alliance formed under such cases makes the recipient vulnerable to future potential loss of its own specialized knowledge to an originator prepared for effective reverse learning by proximity. Consequently, the recipient stands to gain even less from alliance formation when specialized knowledge is involved and the originator is geographically proximate, therefore increasing the negative effects of recipient specialization on alliance formation in geographically proximate alliances.

However, when a recipient uses specialized knowledge from a geographically distant originator, it may be difficult to fill any gaps in the use of this knowledge that arise as a consequence of the differential development of knowledge processing systems across distances. Technical knowledge, although within the specialization domain of the recipient, may require additional understanding of complementary or tacit knowledge possessed by the originator. In such a case, reverse learning by the originator may also be hindered by distance, protecting the recipient's specialized knowledge, should it choose to enter an alliance, in comparison to a proximate case. Therefore the negative effects of specialization of the recipient in the area of knowledge spillover on alliance formation are likely to be reduced for geographically distant originators. We therefore propose that geographical distance weakens the reluctance of a recipient to form an alliance in its area of specialization, subsequent to a spillover.

H4B: The negative relationship between recipient specialization and knowledge alliance formation subsequent to a spillover will be made weaker (less negative) by the geographic distance between the originator and the recipient.

5. Data and methods

5.1 Data

An extensive literature documents the phenomenon of knowledge spillovers, alliances and regional clusters in the U.S. biotechnology industry (Powell, Koput and Smith-Doerr, 1996), consequently we use this setting for our study. Patent data is used to track knowledge spillovers and innovation in the biotechnology industry. Firms file patents to protect their intellectual property but another firm can then use the information from the public disclosure to create a new invention as long as it cites the original patent. No payment of a fee or compensation is required for citations. Patenting is important in the biotechnology industry and the U.S. is a significant source of these patents (Shan and Song, 1997). Patent documents provide us with information regarding the firm that produces the innovation (assignee), the location of innovation (inventor location), the technology class, the timing of innovation (application date of the original patent) and timing of spillover (application date of citing patent). Patent citations reference any and all relevant previous patents and represent the existing knowledge that a patent builds on. Despite findings regarding noise in patent citation data due to patent examiner added citations (Alcacer, Gittelman and Sampat, 2009), several studies assert the validity of citations as representations of knowledge spillovers and flows (Yang, Phelps and Steensma, 2010; Duguet and MacGarvie, 2005).

Our data sources included the BioScan directory, an industry reporting service by American Health Consultants that provides comprehensive information on biotechnology firms, the SDC database on joint ventures and alliances, company press releases and the Fleming Patent Dataverse for patent information. We constructed our sample to include all U.S. biotechnology firms listed in Bioscan as operating in the human diagnostics and therapeutics segment[v]. We then identified every biotechnology patent[vi] (called original patent) under the U.S. patent system and originating from a U.S. inventor location that this set of firms applied[vii] for in 1990, resulting in a set of 455 original patents filed by 102 firms. We then identified all biotechnology patents citing (citing patents[viii]) the original patent, where the assignee of the citing patent was a for-profit firm with a U.S. inventor location resulting in a sample of 1714 observations, involving 102 originators(i.e. assignees of originating patent) and 233 recipients (i.e. assignees of citing patent). Our level of analysis is the knowledge spillover, i.e., a unique combination of an originating patent filed in 1990 and a citing patent filed within 8 years of the originating patent. Our sample represents 317 unique firms[ix] and 617 unique dyads of firms and consists of the entire population of patent citations for the 1990 set of original patents, between firms within this industry[x]. Our study encompasses a time frame that incorporates two windows. The first allows for the observation of spillovers of the original patent within 8 years of 1990, and the second window for the observation of a knowledge alliance within 5 years of the spillover date. Thus the duration of our study covers a period from 1990 to 2003.

5.2 Variable operationalization

Dependent variable: Knowledge alliance formation. We collected data on alliance formation from three sources, Bioscan, one of the two[xi] most comprehensive, consistent and accurate publicly available data sources documenting alliance activity in the biotechnology industry (Hoang and Rothaermel, 2005), the SDC database and corporate press releases. Our study covers all strategic alliances and includes contractual agreements and also alliances that involve equity investments. We first identified whether the two firms involved in a spillover entered into a strategic alliance in the five years subsequent to the spillover date (i.e., the date of the citing patent)[xii] by considering our three sources. If any of these sources indicated the formation of an alliance, we next collected additional data on the objectives of the alliance. Alliance objectives were classified as knowledge related if they involved a) knowledge access such as the 1998 alliance that allowed Immunex access to Genetics Institute's library of novel secreted human proteins or b) knowledge sharing or collaborative research and development such as the 1996 alliance between Schering and Smithkline Beecham for co-operation in the development of small molecule drugs and a gene sequence databases. We coded knowledge alliance formation as 1 if a) a strategic alliance was formed between the firms involved in the spillover within 5 years of the date of the citing patent and b) the alliance was formed for purposes involving knowledge access, knowledge sharing or collaborative research and development. This variable takes a value of 0 in all other cases, such as alliances formed purely for non-knowledge related objectives such as marketing, manufacturing or financing. Our sample involved 161 instances of alliance formation, out of these 109 were knowledge alliances[xiii].

Independent variables

Specialization of originator and recipient in technological area of the spillover. We determined the technology class of the originating patent and constructed our measure of specialization[xiv] by the originating firm, as the percentage of the originating firms' patents in that technology class in the five years prior to the spillover[xv]. Specialization was constructed in a similar manner for the recipient firm.

Moderating variables

Technological ties between dyad members. For each observation in our sample, we identified all patents filed by both originator and recipient, in any technology class, in the two years prior to the knowledge spillover. We then considered the citations made by this set of patents and identified those citations that were made by dyad members to each other. Prior knowledge flows is a count of prior citations by the originator and recipient to each other and measures the extent to which an originator and recipient have built on each other's knowledge.

Geographic distance between dyad members We collected information on the latitude and longitude of the inventor locations[xvi] for the originating and citing patents in our sample from the Fleming Patent Dataverse. Geographic distance between dyad members is measured as the geodesic distance scaled in hundreds of miles between the inventor locations of the originating and citing patent involved in the knowledge spillover[xvii].

Firm, knowledge, and dyad specific controls. We incorporate several controls related to the firms, the knowledge and the dyad involved in the spillover. Firm co-operative capabilities enable the recognition of alliance opportunities (Kale et al, 2002). We therefore include controls for the *number of prior alliance partners of the originator and recipient* in the five years prior to the spillover. Interfirm co-operative activities can be attributed to the participant firms' internal resource conditions (Gulati, 1998), in particular their innovative track records (Stuart, 1998). The *knowledge stock of the originator and recipient* sends a signal of their viability for interfirm learning, and associated prestige as potential alliance partners. We measured knowledge stock as the total number of patents filed by the originator (and recipient) firm in the five years prior to the spillover. Prospects for alliance can increase with age as the firm has a longer track record that potential partners can evaluate. On the other hand, younger firms in this industry may be attractive alliance partners since they can provide useful new leads for innovation.

We therefore control for *age of the originator and recipient* measured as the number of years from firm founding date to the date of the spillover[xviii].

We measure the *value of the knowledge involved in the spillover* between the two firms. This is operationalized as the number of citations received by the original patent (not including self citations) up to the date of the spillover. Higher value, represented by citations (Trajtenberg, 1990) may signal the presence of other equally valuable knowledge in the originator firm and therefore is likely to favorably influence the recipient firm towards alliance formation. We control for the *time lapse for the spillover* as the difference between the date of the spillover and the application date of the original patent. A longer time lapse may signal lower economic value, as technology changes rapidly in this industry and may therefore reduce the likelihood of an alliance.

Our next set of controls relates to the dyad of originator and recipient firms in each observation. This industry is characterized by a clear distinction in the nature of firms, pharmaceutical firms and dedicated biotechnology firms (DBFs). Alliances between pharmaceutical companies and DBFs are common since they offer firms access to complementary resources (Arora and Gambardella, 1990). We include a control to determine whether the knowledge spillover involves a *dyad of a heterogeneous nature* (i.e. a pharmaceutical DBF combination), coded as 1 or a homogeneous nature (i.e. both firms are pharmaceutical companies or both are DBFs), coded as 0. We used information regarding the prior alliance partners for each originator and recipient dyad to construct controls for common alliance partners and prior alliances. Studies suggest that firms choose to pursue alliances with those firms that are relationally embedded through prior direct ties and structurally embedded through connections to common partners (Gulati and Garugiulo, 1999). We therefore control for the *number of common alliance partners* shared by the originator and recipient firms in the five years prior to spillover. We also control for the number of *prior alliances between the originator and recipient firms* that existed between the originator and recipient firms in the five years prior to the spillover. Since our sample involves 617 unique dyads and 1714 observations, we have instances where the same dyad is observed in the sample albeit with a different combination of originating and citing patents. We therefore constructed a binary variable for *repeated entry by a dyad* in the sample[xix] that takes on a value of 0 when the dyad enters our sample for the first time, and a value of 1 for every subsequent entry by the same dyad. *Dyad relative specialization* was calculated by considering the absolute value of difference between specialization of the originator and the recipient firm in the technology class of the spillover relative to each other[xx]. Higher values of this variable represent differences in the focus of the two firms involved in the specific area of the knowledge spillover. Greater *technological distance between the originator and recipient*[xxi] is likely to reduce the likelihood of alliance formation due to perceived challenges of enabling learning. We measure technological distance in terms of the differences between the firms' technological positions. Following Jaffe (1989), we use the distribution of the firms' patents over five biotechnology-related patent classes to characterize their technological positions. The technological distance between the firms is then calculated as:

$$\left(\sum_{k=1}^{N}(P_{no} - P_{nr})^2\right)^{1/2}$$

P_{no} is the percentage of originator firm's patents in the technology class n in the five years prior to application date of the citing patent and P_{nr} is the percentage of the recipient firm's patents in the technology class n in the five years prior to the application date of the citing patent.

5. 3 Methods

We use an event study approach to examine the likelihood of knowledge alliance formation subsequent to a knowledge spillover. Event history models model the hazard rate of an event while considering both the occurrence and the timing[xxii] of the event (Allison, 1984) and allow us to account for knowledge alliances formed within different years of the spillover (Cui, Calantone and Griffith, 2010). This method also has the advantage of permitting the analysis of right-censored variables (Allison, 1984), as in our data some knowledge spillovers do not result in an alliance. It is difficult to make a realistic assumption of the baseline hazard function for alliance formation and the Cox model avoids bias as it does not specify the form of the baseline hazard. We therefore follow prior researchers who have used the Cox model because of its appropriateness for analysis of alliance related decisions (Yeniyurt, Townsend, Cavusgil and Ghauri, 2009; Cui, Calantone and Griffith, 2010, Xia, 2011) and adopt the following Cox model formulation:

$$h_T(t) = \lambda_{0T}(t) \exp\{\beta X(t)\}$$

where λ_{0T} is the unspecified baseline hazard, X(t) is the vector of covariates at time t.

6. Findings

Tables I and II present the descriptive statistics for our sample.

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Insert Table I and II here
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Table III presents our findings regarding the effect of specialization on the likelihood of knowledge alliance formation, and Table IV presents the interaction effects and the fully specified model.

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Insert Tables III and IV here
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The findings for specialization demonstrate partial support for our hypotheses. With the exception of Model 2 of Table III, we find that specialization of the originator firm has a significant and positive impact on alliance formation, subsequent to a spillover, as hypothesized. Hypothesis 1 receives partial support. Specialization of the recipient firm has a negative and significant impact on alliance formation across all models, confirming Hypothesis 2. An evaluation of the coefficients[xxiii] suggests that a unit increase in the specialization of the originator firm increases the rate of alliance formation by 6.39% while a unit increase in the specialization of the recipient firm reduces the rate of alliance formation by 6.01%[xxiv]. The corresponding effect size in terms of an increase by one standard deviation for the originator specialization results in a significant increase of 353% in alliance formation. Similarly an increase by one standard deviation for recipient specialization decreases alliance formation by 84%. Our findings indicate that originators are more likely to pursue, and recipients more likely to avoid, alliances when specialized knowledge is involved.

We find that the interaction of technological ties and specialization of the originator is significant and positive, in Models 5 and 9 in Table IV. Hypothesis 3A is supported as technological ties increase the positive effects of specialization of originator on alliance formation. In contrast, Hypothesis 3B receives partial support, as the interaction between technological ties and specialization of the recipient is not significant in Model 6, but becomes significant in Model 9, operating as expected to increase the resistance of a specialized recipient to alliance formation. The pattern of findings for geographic distance are similar to technological ties with significant negative coefficients for the interaction with originator specialization (H4A) in both Models 7 and 9 and a significant positive coefficient on the interaction with recipient specialization (H4B) in Model 9. The findings suggest that geographic distance weakens the effects of originator and recipient specialization on alliance formation, as hypothesized. Interpreting the coefficient of an interaction between two continuous variables in non-linear models is tricky and the use of marginal effects at representative values is recommended (Long and Freese, 2006; Buis, 2010; Williams, 2011). To interpret the coefficient on the four interactions in Model 9, we follow these prescriptions and present the marginal effects of specialization on alliance formation at representative values of technological ties and geographic distance[xxv]. These effects are presented graphically in Figures 2-5.

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Insert Figures 2-5 here
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Figure 2 demonstrates that an increase in specialization by the originator of one standard deviation results in an increase in alliance formation by 6.1% when no technological ties exist between the dyad[xxvi]. As the technological ties increase, the effect of originator specialization strengthens such that when technological ties are at their maximum absolute value of 40, a one standard deviation increase in originator specialization increases alliance formation by 89.79%. Figure 3 indicates that when recipient specialization increases by one standard deviation, alliance formation decreases by 12.72% in the absence of technological ties. As the technological ties increase, the effect of recipient specialization on alliance formation strengthens (becoming more negative) such that at the maximum value of 40 for technological ties, a one standard deviation increase in recipient specialization decreases alliance formation by 112.48%. Thus technological ties operate as a moderator, strengthening the effects of originator and recipient specialization on alliance formation.

Figure 4 indicates that when a dyad is geographically proximate (i.e. distance between them is zero), a one standard deviation increase in originator specialization increases alliance formation by 56.12%. As geographic distance increases, the effect of originator specialization on alliance formation weakens, so that when distance between the dyad is at a high of 2,400 miles, a one standard deviation increase in originator specialization leads to an increase in alliance formation by only 2.44%. Figure 5 demonstrates that when there is no geographic distance between a dyad, a one standard deviation increase in recipient specialization decreases alliance formation by 65.12%. With increasing geographic distance, the effect of recipient specialization on alliance formation weakens, so that when distance between the dyad is at 2,400 miles, a one standard deviation increase in recipient specialization leads to a decrease in alliance formation by just 17.76%. These results offer support for the moderating effect of geographic distance which weakens the influence of specialization on alliance formation.

Of our control variables, we find positive direct effects of technological ties, alliance partners of originator firm, value of knowledge and prior alliances and negative effects of geographic distance, technological distance, dyad relative specialization and time lapse, consistent with our expectations. Alliance formation is negatively influenced by the knowledge stock of the originator firm, contrary to expectations. Larger stocks may represent significant internal knowledge resources leading to a lower reliance on external collaboration for knowledge resources.

To ensure the validity of our results, we conducted several additional tests[xxvii]. First, out of the 109 instances of knowledge alliances we have 8 instances that involve alliances with more than two partners. To determine if the results were sensitive to the inclusion of multi-partner alliances, we conducted robustness tests by excluding the 8 multi-partner observations, and find that our results are identical. Second, we constructed a binary measure of geographic proximity that determined whether the dyad in each of our observations represented knowledge spillover within or across clusters (based on metropolitan statistical areas). Our results are robust to the use of the binary measure of proximity in place of the continuous geographic distance measure. Third, we ran our data using several alternate techniques, rare event logistic regression (King and Zeng, 2001), binary logistic regression and complementary log-log models instead of the Cox event study model and find identical results. Fourth, our sample involves instances where the same dyad of an originator and recipient firm is observed in the sample albeit with a different combination of originating and citing patents. While our model incorporates a control for such repeated entry, the intragroup correlation between observations represented by the same dyad may lead to clustered standard errors. Further, this dyad level clustering is nested within the firm level. We therefore use a technique[xxviii] that accounts for intragroup correlation, corrects clustered standard errors at the firm level[xxix], and presents robust standard errors (Cleeves, Gould, Gutierrez and Marchenko, 2008). Our results are robust using this technique. Fifth, our sample construction permits us to observe spillovers involving citing patents filed between 1991 and 1998. We included 7-year dummies for the year of the citing patent with 1991 as the base year instead of our time-lapse variable. Again our results are robust. Sixth, our measure of relational proximity considers prior knowledge flows between the firms in the two years prior to the year of the spillover. We also constructed alternative operationalizations that considered prior knowledge flows on the basis of 3, 4 and 5 years prior to the spillover and found robust results. Seventh, we tested our model by excluding the control for technological distance between originator and recipient and find that our results are robust.

7. Discussion and Conclusions

Our study explored the conditions under which knowledge spillovers lead to alliance formation within an opportunity, motivation and ability framework (Argote et al., 2003). Theoretically, we extend research on the organization of transactions by evaluating the conditions under which the knowledge transaction shifts from a spillover to an alliance. As Williamson (1979, pg. 239) states, "Use of a complex structure to govern a simple relation is apt to incur unneeded costs and use of a simple structure to govern a complex transaction invites strain." Our study suggests that the benefits of learning and limiting appropriation by governing the knowledge opportunity signaled by the spillover, through an alliance mechanism, justify the use of this structure. The focus on the technology strategy of both participants in the spillover; a two to tango perspective and their corresponding asymmetric motivations, allows us to make a contribution to the alliance formation literature. Empirically, our study offers new insights on the influences of specialization, technological ties and geographic distance on knowledge alliance formation, by demonstrating their complex, interactive effects.

Our study complements a number of streams of research in spillovers, inter-organizational learning, the role of geography, and alliance formation. In the knowledge spillover arena, the focus has been on economic impacts on society and benefits for the recipient firm (Romer, 1990, Arrow, 1962). Our research extends this literature on knowledge spillovers by presenting a model that demonstrates effects of spillovers on co-operative strategies by the originator and recipient, responding to the call for greater examination of knowledge spillovers (Jaffe and Trajtenberg, 2002). Larsson, Bengtsson, Henriksson and Sparks (1998) point to the need to consider the strategic and dynamic aspects of inter-organizational learning. Our study proceeds in this direction and examines a process of learning that evolves from knowledge spillovers to strategic alliances and explores the effects of internal and external contextual conditions on the process. Yang et al (2010) propose and find support for originator firms benefiting through opportunities for vicarious learning from spillover knowledge pools. They suggest that this line of research may be extended by exploring how other inputs influence the ability to exploit spillover knowledge pools. Our focus on alliance formation subsequent to spillovers suggests that the process of capitalizing on knowledge spillovers may have an intermediate step of alliance formation in response to the most viable signals for knowledge exchanges. Thus, originator firms may establish alliances in those cases where they perceive the benefits from the spillover pool to be significantly larger than the potential costs inherent in an alliance and where they aim to transform vicarious learning to interactive and experiential learning by forging a formal connection with the recipient firm. Rothaermel and Boeker (2008) suggest that studies on alliance formation explore the interactions between dyad characteristics and firm level factors. Our study responds to this call by examining the moderating effect of the relational and geographic proximity on the relationship between firm specialization and alliance formation.

In Gulati's (1998) critique of the alliance literature, he asserts that studies have focused on the competence of the firm as a factor that propels entry into an alliance but have placed less emphasis on factors that lead to alliance opportunities in the first place. Mitsuhashi and Greve (2009) suggest that current research offers limited guidance for managers in selecting promising alliance partners and for growing their alliance networks. Our study is a step forward in understanding how and when common knowledge interests might lead to alliance formation as it focuses on conditions when spillovers signal alliance opportunities and lead to the identification of new partners. Rosenkopf and Schleicher (2008, pg 29) assert that, "alliances can be compared to the most visible tip of an iceberg above the water surface that rests upon a large body of ice (informal relations) hidden beneath the surface." They suggest that future research should explore other forms of informal relationships besides participation in cooperative technological organizations and board interlocks, and their influence on decision making by managers. Our research addresses this call by evaluating knowledge spillovers which are the outcomes of informal relationships of inventor mobility and social networking and exploring the influence of spillovers on alliance formation decisions. Our results provide support for their claim that formal interorganizational relationships reflected in alliances are the result of informal networks in which the firms and their managers and scientists participate. In this respect our study provides an interesting complement to work (Gomes-Casseres, Hagedoorn and Jaffe, 2006; Mowery, Oxley and Silverman, 1996) that has focused on the character of knowledge flows between partner firms after alliances have been established. Research by Katila, Rosenberger and Eisenhardt (2008) suggests that the pivotal issue of potential resource misappropriation at the stage of relationship formation has been largely ignored. Our theoretical focus on the perceptions of firms regarding appropriation prior to alliance formation addresses this gap. This is particularly relevant to the issue of spillovers of specialized knowledge in technologically or geographically proximal relationships. Our research suggests that originator firms have alternatives to deal with spillovers beyond acceptance of loss of knowledge or exit from the cluster. Appropriation of some of the current value lost through spillover and pre-emptive management of future spillovers may be enabled by the formation of an alliance. Our study offers an alternative response for originators, when writing off intellectual property is not acceptable and relocation is not possible; consistent with transactional and resource based models of the alliance and with interesting implications for both theory and practice.

Our study has several limitations. We examine the conditions under which spillovers result in knowledge alliances. Although we do not examine whether spillovers lead to alliances, a question that has been explored by prior research (Stuart and Podolny, 2000; Stuart, 1998), we determined if this was the case by conducting a subsample test. We compared a subsample of observations, drawn by using stratified sampling, to a control group of observations without spillovers constructed by using propensity score matching. We found that the rate of alliance formation in the control group (without spillovers) was one third that of the rate in our subsample, suggesting that spillovers do increase propensity to ally. We use patent data to represent knowledge spillovers between firms. Some knowledge spillovers may not be captured as they may not result in patent citations. Our sample is limited to originating patents applied for in 1990, a single year focus partly to accommodate the windows of observation for citations and for alliance formation resulting in coverage of years from 1990 to 2003. Given the emphasis on patenting in this industry (Shan and Song, 1997), a single year focus is unlikely to create a bias, however it would be interesting to extend the study to multiple years. We focus on spillovers between originators and recipients in a single year, but many of our dyads demonstrate prior knowledge interactions as is common in this close knit industry (Powell, Koput and Smith-Doerr, 1996). The inclusion of our control for prior spillovers between the firms (technological ties) controls for the likelihood that the alliance is formed in response to an earlier spillover. We are not able to map an alliance to a specific spillover (or its originating patent) since this poses serious data challenges (Sampson, 2007).

Our study also raises questions that offer potential for future research. Knowledge spillovers are enabled by different mechanisms, such as inventor mobility, social networking and participation in conferences (Rosenkopf and Almeida, 2003; Saxenian, 1994), to name a few. Future research could explore if the type of mechanism through which the spillover occurs is one of the conditions that influences alliance formation. Spillovers in this industry also involve entities other than firms, such as universities, health laboratories and other research organizations (Audretsch and Stephan, 2002). An interesting question to explore would be whether the conditions that determine alliance formation with firms subsequent to spillovers also influence alliance formation with other entities. We used proxies for assessing learning potential and appropriation concerns. Future studies could assess managerial perceptions of learning and appropriation and then evaluate their influence on alliances subsequent to a spillover to provide a more complete picture. Our study provides a pattern of alliance formation in the biotechnology industry where co-operative behavior is prevalent (Powell, Koput and Smith-Doer, 1996) and a strong intellectual property protection regime exists. A question for future researchers to consider is whether these patterns are similar in industries that demonstrate less co-operative behavior and a weaker protection regime.

Our study has practical implications for firms to better manage knowledge spillovers by simultaneously protecting their core knowledge and increasing inter-organizational learning through alliances with new partners. It identifies conditions under which managers may be best served in capitalizing on opportunities presented by knowledge spillovers by partnering with spillover participants. Spillover roles in signaling opportunities and influencing strategic choices for collaboration may ultimately result in long-term positive effects for the originator firm. Our results suggest that managers of originator firms should actively track and pursue recipients of the originator's specialized spillovers as alliance partners, particularly when the recipients are technologically tied or geographically proximate. Recipients, on the other hand, are likely to avoid alliances under the same circumstances. These circumstances suggest that managers on either side of the bargaining process must be prepared to negotiate intensely and effectively in order to enable alliance formation. One strategy for managers may be to seek out alters (either originator or recipient) in dyads where the spillover represents knowledge that manager's firm specializes in but the alter's does not. This prescription suggests that alliance formation after a spillover may be most viable when the two firms in the spillover have complementary technological interests (necessitating the use of each other's knowledge) but not similar specializations. An alternate strategy suggested by our results is for managers to seek out specific alters in a specialized knowledge spillover dyad, who are less technologically tied or who are geographically distant in order to reduce resistance (on the part of the recipient) to and retain incentives (for the originator) for alliance formation.

In conclusion, our study offers a theoretical perspective on the transformation of knowledge transactions from spillovers to alliances and demonstrates that firm knowledge management efforts are driven by their technology strategies, and moderated by their technological and geographic ties to potential partners. We propose and support a model that demonstrates the limitations of spillovers as primary channels for knowledge transfer. We confirm that alliances work to enhance learning, but we also show that their use supports the importance of controlling knowledge appropriation and future applications on the part of potential partners. While spillovers may indicate the opportunity for a knowledge-based connection, the motivations and ability of dyad firms to follow through have both positive (learning) and negative (appropriation) aspects. We believe that our framework offers an increasing level of sophistication in our understanding of the forces acting on knowledge transactions between firms.

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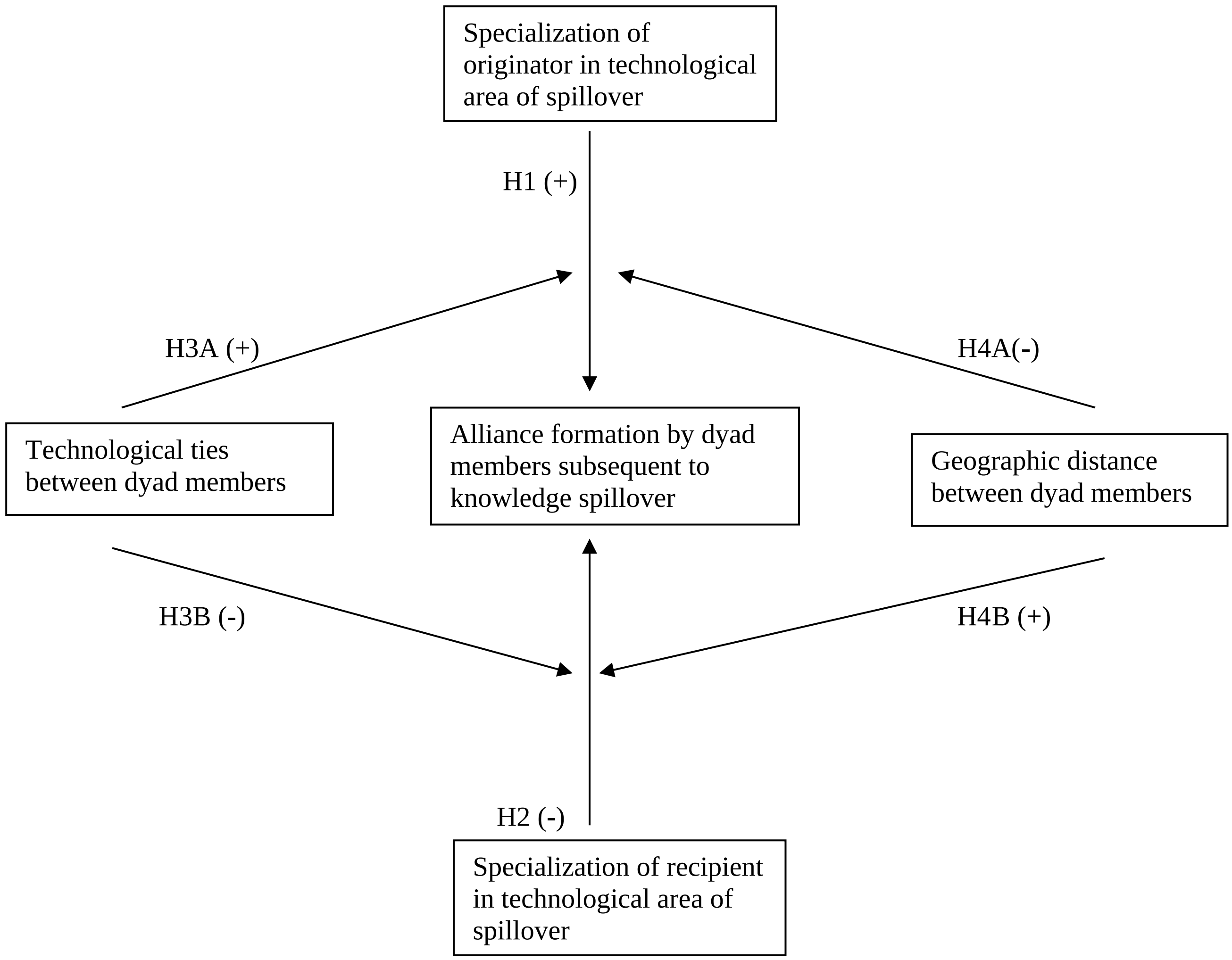
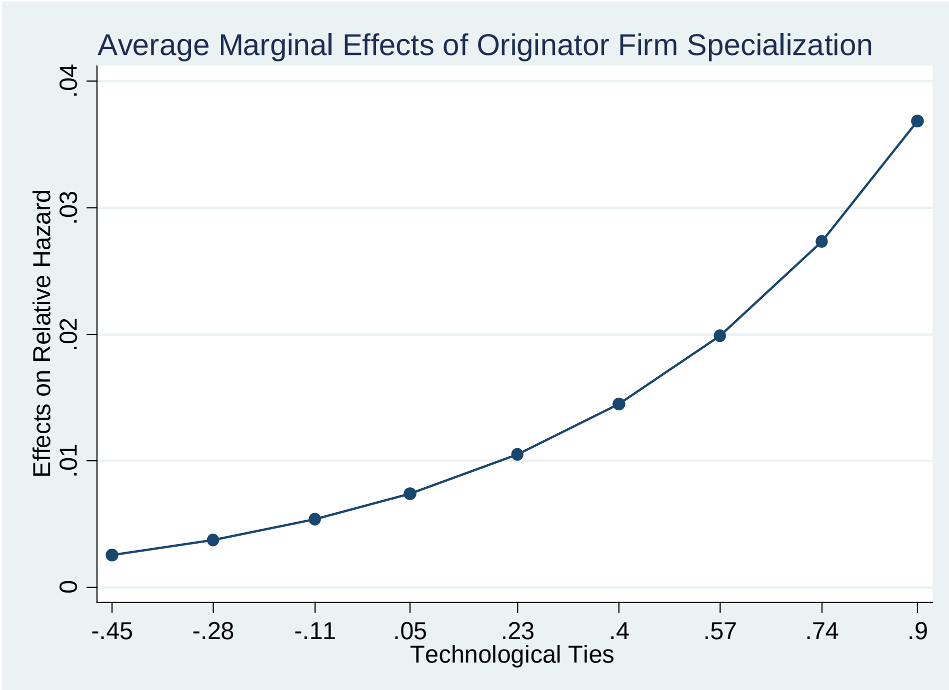
Figure 1 – Theoretical Model



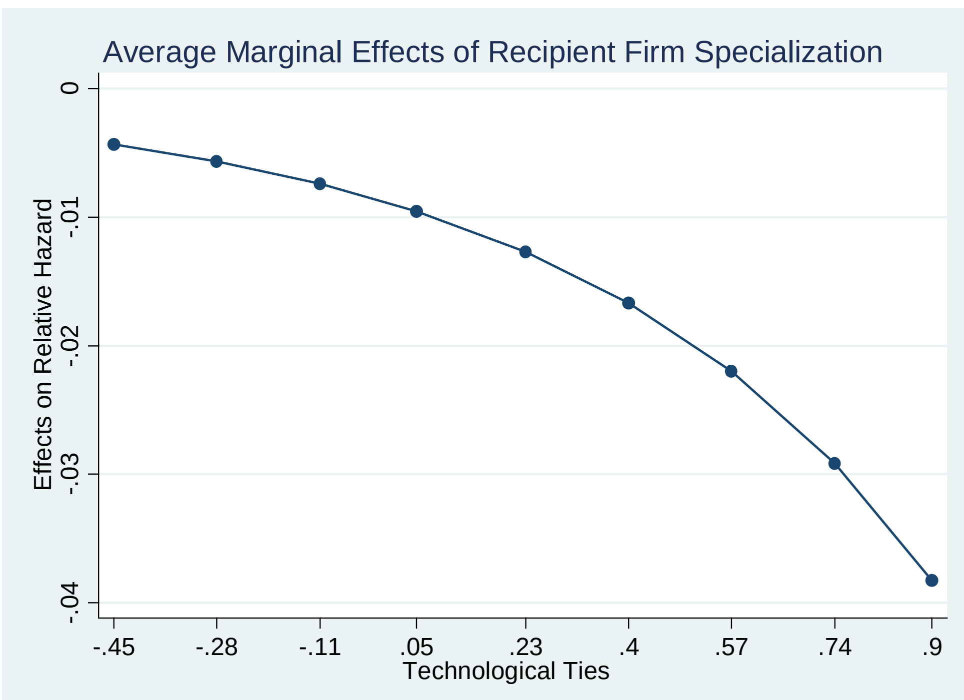
Note: The signs on the relationships are those expected on the coefficients of the independent variables and interaction terms in the regression model.

Figure 2 - Effects of originator specialization on alliance formation at different levels of technological ties



Note: Standardized values of technological ties used

Figure 3 - Effects of recipient specialization on alliance formation at different levels of technological ties



Note: Standardized values of technological ties used

Figure 4 - Effects of originator specialization on alliance formation at different levels of geographical distance

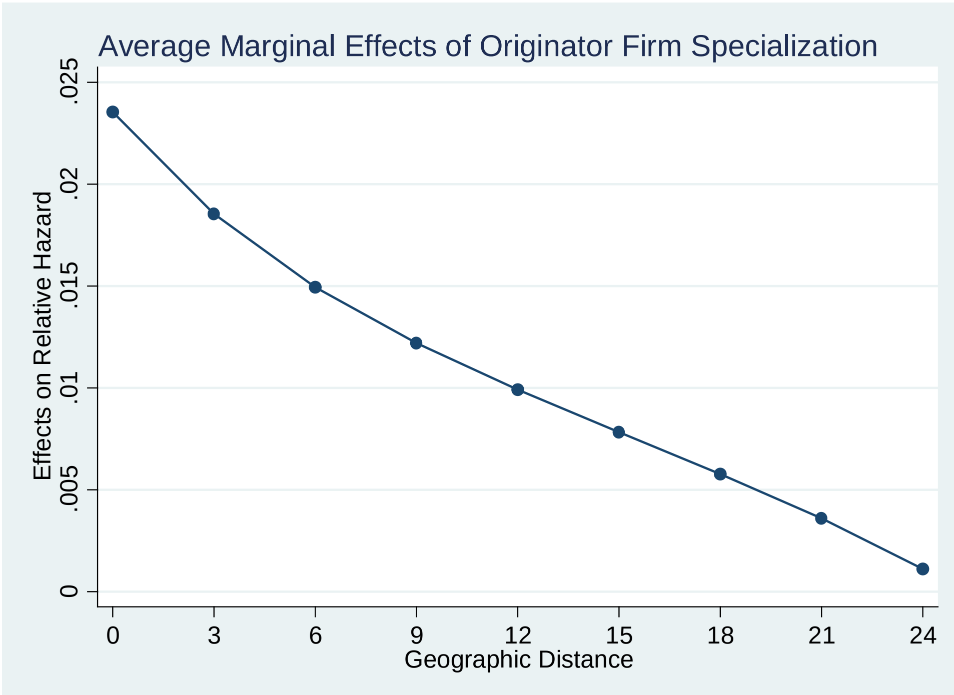


Figure 5 - Effects of recipient specialization on alliance formation at different levels of geographical distance

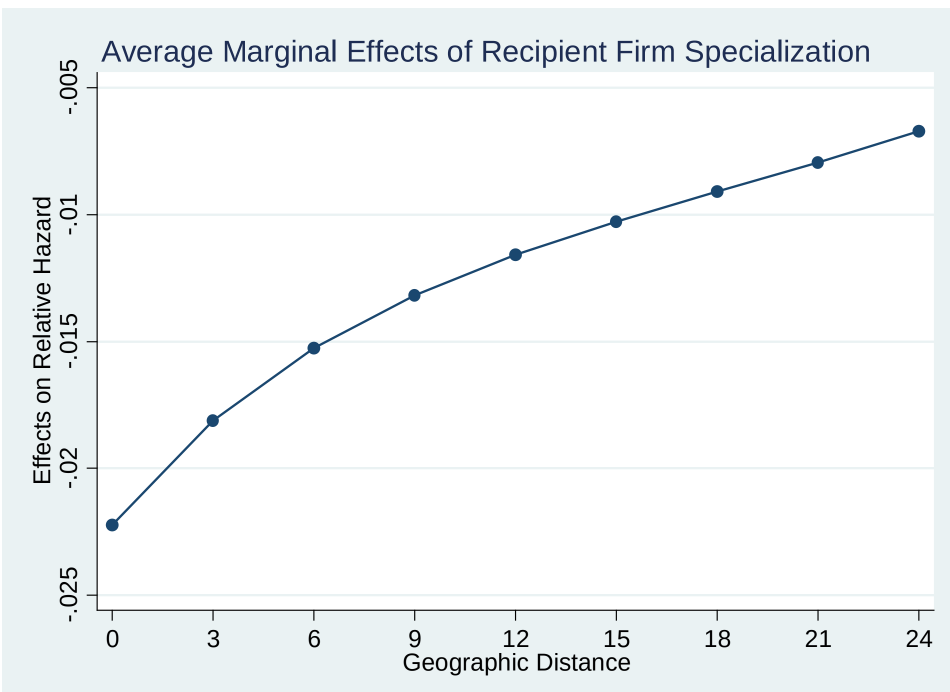


Table I Summary statistics – Means and standard deviations

Variable	Mean	Std. Dev.
Dependent variable		
Knowledge alliance formation	0.0635939	0.2440994
Independent variables		
Specialization of originator	29.98	24.42
Specialization of recipient	29.89	29.61
Moderating Variables		
Dyad technological ties [a]	13.27655	29.53375
Dyad geographical distance	10.50	9.79
Firm controls		
Originator firm alliance partners	8.080513	8.203728
Recipient firm alliance partners	5.565344	7.332929
Originator firm knowledge stock	474.1534	744.0598
Recipient firm knowledge stock	320.6989	645.8194
Originator firm age	73.13	54.79
Recipient firm age	55.92	57.37
Knowledge controls		
Value of knowledge	15.46908	15.26759
Time lapse	5.243874	1.820949
Dyad controls		
Heterogeneous dyad	0.4014002	0.4903247
Common partners	0.1417736	0.5999363
Prior alliances	0.0303384	0.1814877
Repeated entry of dyad in sample	0.6400233	0.4801333
Dyad relative specialization	27.22553	22.89323
Technological distance	51.86306	34.12861

[a] Mean and standard deviation of actual values reported in Table 1. Standardized values used in other tables

Table II Summary statistics – Correlations

		1	2	3	4	5	6	7	8	9	10	11
1	Knowledge alliance	1.0000										
2	Spec. of originator	0.0451	1.0000									
3	Spec. of recipient	-0.1298	0.1431	1.0000								
4	Technological ties	0.1408	-0.0147	0.2033	1.0000							
5	Geographic distance	-0.0772	0.0091	0.0740	-0.0634	1.0000						
6	Orig firm partners	0.0155	-0.1050	0.0519	0.0077	-0.0764	1.0000					
7	Recip firm partners	0.0177	-0.0264	-0.0838	0.0294	-0.0643	0.2827	1.0000				
8	Orig firm knowl stock	-0.1090	-0.3259	0.2092	-0.0035	0.0405	0.2391	-0.0055	1.0000			
9	Recip firm knowl stock	-0.0143	-0.0425	-0.2269	0.0534	-0.1049	-0.0251	0.2751	-0.0086	1.0000		
10	Orig firm age	-0.1293	-0.1611	0.0943	-0.0871	-0.1163	0.4180	0.0847	0.3583	0.0596	1.0000	
11	Recip firm age	-0.0132	0.0321	-0.1519	-0.0232	-0.2467	0.0399	0.4478	0.0483	0.4418	0.2521	1.0000
12	Value of knowledge	0.1192	-0.1135	0.0040	0.3312	-0.0671	-0.1207	-0.2175	-0.0447	-0.1828	-0.2483	-0.3613
13	Time lapse	-0.0874	-0.1131	0.1529	0.2078	0.0424	0.4639	0.2633	0.0861	-0.1099	0.0469	-0.1261
14	Heterogenous dyad	-0.0183	-0.0636	-0.0328	-0.1757	0.2200	0.0721	-0.1841	0.1329	-0.1140	0.1196	-0.3326
15	Common partners	0.0739	-0.0062	-0.0238	0.0845	-0.0582	0.3453	0.3821	0.0165	0.0887	0.1094	0.1726
16	Prior alliances	0.0750	-0.0404	-0.0104	-0.0114	0.0323	0.0932	0.1055	0.0285	0.0355	-0.0454	0.0154
17	Rep entry of dyad	0.0560	-0.0754	0.1164	0.2430	-0.0159	0.0950	0.0474	0.0995	-0.0358	0.0049	-0.1299
18	Dyad relative spec.	-0.0497	0.3453	0.4148	-0.0026	0.1179	-0.1254	-0.1574	0.1542	-0.0866	-0.0930	-0.1033
19	Tech. distance	-0.0319	-0.1392	-0.3644	-0.0890	0.1091	-0.0557	-0.1733	-0.0055	-0.0492	-0.0852	-0.1775

Continued…

		12	13	14	15	16	17	18	19
12	Value of knowledge	1.0000							
13	Time lapse	0.1319	1.0000						
14	Heterogenous dyad	0.1324	0.1100	1.0000					
15	Common partners	-0.0681	0.1997	-0.1539	1.0000				
16	Prior alliances	-0.0723	0.0094	-0.0254	0.0623	1.0000			
17	Rep entry of dyad	0.3172	0.2741	0.0884	0.0131	-0.0086	1.0000		
18	Dyad relative spec.	0.0303	0.0180	0.1401	-0.0747	-0.0482	0.0229	1.0000	
19	Tech. distance	0.1959	0.0354	0.2912	-0.0837	-0.0793	-0.0128	0.2402	1.0000

Table III: Specialization and knowledge alliance formation

		Model 1	Model 2	Model 3	Model 4
Independent variables					
Specialization of originator firm	H1		0.010		0.042***
			(0.006)		(0.011)
Specialization of recipient firm	H2			-0.037***	-0.055***
				(0.006)	(0.009)
Controls					
Technological ties		0.447***	0.455***	0.669***	0.779***
		(0.076)	(0.075)	(0.087)	(0.089)
Geographic distance		-0.030**	-0.030**	-0.017	-0.015
		(0.011)	(0.011)	(0.012)	(0.012)
Originator firm alliance partners		0.091***	0.093***	0.070***	0.067***
		(0.017)	(0.017)	(0.017)	(0.018)
Recipient firm alliance partners		0.025	0.024	0.028	0.019
		(0.018)	(0.018)	(0.019)	(0.018)
Originator firm knowledge stock		-0.003***	-0.002***	-0.002***	-0.002***
		(0.001)	(0.001)	(0.000)	(0.001)
Recipient firm knowledge stock		-0.0002	-0.0002	-0.0002	-0.0003
		(0.0002)	(0.0002)	(0.0002)	(0.0002)
Originator firm age		-0.007**	-0.007**	-0.004	-0.004
		(0.002)	(0.002)	(0.003)	(0.003)
Recipient firm age		0.004	0.004	0.002	0.002
		(0.003)	(0.003)	(0.003)	(0.003)
Value of knowledge		0.016*	0.018*	0.011	0.017
		(0.008)	(0.008)	(0.009)	(0.009)
Time lapse		-0.487***	-0.491***	-0.440***	-0.436***
		(0.063)	(0.064)	(0.065)	(0.066)
Heterogeneous dyad		0.693**	0.656**	0.480	0.399
		(0.253)	(0.254)	(0.257)	(0.259)
Common alliance partners		0.099	0.082	0.112	0.087
		(0.138)	(0.142)	(0.136)	(0.147)
Prior alliances		1.013**	1.050**	0.947*	1.120**
		(0.357)	(0.355)	(0.372)	(0.366)
Repeated entry of dyad in sample		0.563*	0.603*	0.437	0.424
		(0.254)	(0.254)	(0.259)	(0.256)
Dyad relative specialization		-0.014*	-0.023**	-0.001	-0.039***
		(0.006)	(0.008)	(0.006)	(0.012)
Technological distance		-0.005	-0.002	-0.017***	-0.014**
		(0.004)	(0.004)	(0.004)	(0.004)
LR ChiSq		182.72***	184.99***	222.73***	240.61***
N		1714	1714	1714	1714

Standard errors in parentheses, *p<0.05, ** p<0.01 *** p<0.001

Table IV– Moderating effects of technological ties and geographic distance

		Model 5	Model 6	Model 7	Model 8	Model 9
Interactions						
Tech. ties * Spec of orig.	H3A	0.010*				0.022***
		(0.004)				(0.005)
Tech ties * Spec by recip.	H3B		-0.003			-0.016***
			(0.002)			(0.003)
Geo distance * Spec. of orig.	H4A			-0.002***		-0.003***
				(0.001)		(0.001)
Geo distance * Spec of recip.	H4B				0.001	0.002**
					(0.001)	(0.001)
Independent variables						
Specialization of originator firm	H1	0.049***	0.033**	0.059***	0.043***	0.062***
		(0.012)	(0.011)	(0.012)	(0.011)	(0.014)
Specialization of recipient firm	H2	-0.065***	-0.045***	-0.057***	-0.061***	-0.062***
		(0.011)	(0.011)	(0.010)	(0.011)	(0.015)
Controls						
Technological ties		0.456*	0.880***	0.800***	0.766***	0.571***
		(0.178)	(0.109)	(0.090)	(0.090)	(0.159)
Geographic distance		-0.015	-0.012	0.058**	-0.027	0.056*
		(0.012)	(0.012)	(0.022)	(0.017)	(0.022)
Originator firm alliance partners		0.067***	0.065***	0.065***	0.065***	0.039
		(0.018)	(0.018)	(0.019)	(0.018)	(0.021)
Recipient firm alliance partners		0.006	0.022	0.028	0.019	0.012
		(0.019)	(0.018)	(0.018)	(0.018)	(0.020)
Originator firm knowledge stock		-0.002**	-0.002***	-0.002**	-0.002***	-0.002**
		(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Recipient firm knowledge stock		-0.0003	-0.0003	-0.0003	-0.0003	-0.0002
		(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
Originator firm age		-0.004	-0.004	-0.004	-0.004	-0.004
		(0.003)	(0.003)	(0.002)	(0.003)	(0.003)
Recipient firm age		0.002	0.002	0.002	0.002	0.002
		(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Value of knowledge		0.019*	0.018*	0.024**	0.015	0.028**
		(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
Time lapse		-0.394***	-0.441***	-0.425***	-0.427***	-0.288***
		(0.067)	(0.067)	(0.066)	(0.066)	(0.072)
Heterogeneous dyad		0.231	0.411	0.247	0.399	-0.174
		(0.269)	(0.259)	(0.267)	(0.259)	(0.289)
Common alliance partners		0.073	0.097	0.055	0.086	0.034
		(0.155)	(0.146)	(0.157)	(0.145)	(0.175)
Prior alliances		1.172**	1.081**	0.920*	1.108**	0.919*
		(0.372)	(0.362)	(0.382)	(0.369)	(0.381)
Repeated entry of dyad in sample		0.364	0.413	0.350	0.416	0.107
		(0.257)	(0.256)	(0.255)	(0.256)	(0.262)
Dyad relative specialization		-0.048***	-0.029*	-0.041***	-0.041***	-0.041**
		(0.014)	(0.013)	(0.012)	(0.012)	(0.014)
Technological distance		-0.013**	-0.014***	-0.015**	-0.014**	-0.011*
		(0.005)	(0.004)	(0.004)	(0.004)	(0.005)

LR ChiSq		247.22***	242.67***	255.19***	241.62***	290.30***
N		1714	1714	1714	1714	1714

Standard errors in parentheses, *p<0.05, ** p<0.01 *** p<0.001

Notes

[i] Abbott's invention was filed by the company as patent 4916056, a remarkably influential invention that led to a number of subsequent citations.

[ii] The knowledge spillover does not represent Arrow's conceptualization of an information paradox for several reasons. Technological knowledge is very different from information, because it has elements of tacit, organization-specific and cumulative aspects of knowledge that create a situation of incomplete disclosure (Dosi, Malerba, Ramello and Silva, 2006). Additionally, the value of the information provided in the patent is unclear in terms of its technological worth (Thambisetty, 2007). Patents vary in their worth and are less valuable as signals of quality of underlying invention (Trajtenberg, 1990). In effect, in the patent spillover the recipient is still unsure about the value of the information even after acquisition.

[iii] Patents offer no guarantee of an exclusionary right, but merely a right to try to exclude (Lemley and Shapiro, 2005) others from specific information embodied in the patent

[iv] We do not dispute the direct effects of technological ties on alliances. However firms are limited in the resources that can be allocated for alliance formation and are therefore likely to emphasize alliance formation with recipients that use specialized knowledge from and are technologically tied to them

[v] Our sample of 102 firms is representative of the number of firms in the human diagnostics and therapeutics segment in this industry for the time period under consideration. The biotechnology industry is comprised of firms operating in very different segments, including agriculture, food and brewing, veterinary, and human diagnostics and therapeutics (Powell et al, 1996). Since these segments differ researchers (Shan, Walker and Kogut, 1994; Phene, Fladmoe-Lindquist and Marsh, 2006) have recommended restricting samples to specific sectors in order to examine firm strategies. We follow this approach and focus on firms in the human diagnostics and therapeutics segment

[vi] Biotechnology patents were identified as those patents where the first technology class was a biotechnology class. We use Granstrand, Patel and Pavitt's (1997) study that classified patent technology classes into 34 industry fields and identified biotechnology patents as those from five technology classes (424, 435, 436, 514 and 530).

[vii] The norm in patent data is to rely on the application (also termed as the file) date rather than the grant date, because it is a more accurate representation of when the innovation is created and when the spillover occurred (Almeida, 1996), due to the lags between application and grant dates (Clarkson and Toh, 2010).

[viii] Citing patents were considered for a period of 8 years and did not include self-citations

[ix] Some originators may be recipients (and vice versa) in other sample observations, consequently the number of unique firms in the sample is less than the total of unique originators and recipients.

[x] Our sample does not include citations to non-corporate entities such as Universities and it does not include citations outside industry domains.

[xi] The other source is the Recombinant Capital Database. Hoang and Rothaermel (2005) find an intersource reliability of greater than 0.90 between the reporting of alliances in the two sources.

[xii] In the biotechnology industry there is a substantial time lag between patent filing and commercialization. This is particularly evident for our sample of firms in the human diagnostics and therapeutics segment due to the clinical trials required prior to regulatory approval. The complete R&D cycle from discovery to product launch can take between 10 to 20 years (Hine and Kapeleris, 2006). The focus of our study is the lag between patent citation and alliance formation. The appropriate lag in this case may be shorter since a) it already allows for the time lag from the originating patent application date to the citing patent application date, that ranges from 1 to 8 years and b) many alliances are formed prior to and in anticipation of product launch. Powell et al (1996) point to the use of alliances for knowledge related purposes including R&D in the biotechnology industry. We focus on knowledge related alliances and in this context an eight year time lag between citation and alliance formation appears reasonable.

[xiii] Our results are robust to the use of alliance formation (any type of alliance) instead of knowledge alliance formation.

[xiv] We use the term specialization to describe areas of technology that are the focus of the knowledge activities, as measured by patent counts, of the firm in question, as opposed to a qualitative judgment of firm innovation.

[xv] The rationale for using a stock rather than an annual measure is fairly well established in the patent literature (Henderson and Cockburn, 1994) and a five year measure is the norm in studies using patent data (Almeida and Phene, 2004).

[xvi] The inventor location from the patent document allows us to pinpoint the location of innovation in contrast to the assignee location that typically represents firm headquarters. This is particularly useful to identify the originating

and recipient location of the knowledge spillover in the case of large firms with multiple research locations. We follow prior research (Almeida, 1996) that uses inventor location to identify the source of innovation.

[xvii] We use the Vincenty program in Stata to calculate geodesic distance from the latitude and longitude of the two locations

[xviii] We also collected information on originator and recipient firm size (measured as the log of number of employees). These measures are highly correlated with age at 0.83 for originator and at 0.87 for recipient. We therefore include only originator and recipient age in our models. Our results are robust when we use originator and recipient firm size instead of age.

[xix] We thank an anonymous reviewer for this suggestion

[xx] We thank an anonymous reviewer for this suggestion

[xxi] Technological distance represents the difference/similarity between originator and recipient patent portfolios, which is different from our technological ties measure that reflects the extent to which the two rely on each other for their knowledge building. Two firms could be technologically similar yet not draw on knowledge from the other, resulting in fewer technological ties and vice versa. Technological distance is also distinct from the dyad relative specialization measure. The former focuses on difference or similarity of the two firms across all their knowledge areas, while the latter represents the extent to which they overlap in the knowledge area of the spillover.

[xxii] Our data records alliance formation in a particular year (not at the exact date), resulting in time being measured in discrete time units (corresponding to years) rather than as a continuous variable. Although the use of binary logistic or complementary log log models is suggested in these cases (Allison, 1982; Powers and Xie, 2000), discrete time methods virtually always give similar results to continuous time methods and the discrete time model converges to a proportional hazards model (Allison, 1984).

[xxiii] Calculations of effect sizes are based on the fully specified Model, i.e. Model 9 in Table IV

[xxiv] The tables present the co-efficients for our models using the nohr (i.e. no hazard ratios) option in Stata. The nohr option returns co-efficients not hazard ratios. To interpret these co-efficients, it is first necessary to calculate the hazard ratio by using the following formula: Hazard ratio for a variable = Exp(Co-efficient of variable * Desired units of change in variable). Next the effect on the variable is calculated as a) 100 – Hazard ratio* 100 (if the hazard ratio is less than 1) or b) Hazard ratio * 100 – 100 (if the hazard ratio is more than 1). The difference is the expected percentage decrease (in a option)/ increase (in b option) in rate of the dependent variable (Cleves, Gould, Gutierrez, Marchenko; 2008)

[xxv] In order to select the representative values for technological ties and geographic distance, we considered the mean and standard deviation of these variables and created a range that would encompass this spectrum.

[xxvi] We use standardized values of technological ties in our models. The standardized value of -0.45corresponds to an absolute value of 0 for this variable and the standardized value of 0.9 corresponds to an absolute value of 40.

[xxvii] These tables are not presented due to space considerations but are available from the authors on request

[xxviii] We use the vce(cluster) option in our modeling package, Stata.

[xxix] Cameron, Gelbach and Miller (2011) note that in the case of nested two way or multiway clustering, “one simply clusters at the highest level of aggregation” (page 238). Our sample represents multi way clustering – at the firm, dyad and spillover level. The highest level of clustering is at the firm level, and the dyad and spillover are nested within this level (i.e. there can be no dyad or spillover cluster without a common firm). We therefore cluster at the firm level.