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BRIDGING THE MUTUAL KNOWLEDGE GAP: COORDINATION AND THE COMMERCIALIZATION OF UNIVERSITY SCIENCE

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We examine why commercialization of interdisciplinary research, especially from distant scientific domains, is different from commercialization of inventions from specialized or proximate domains. We argue that anticipated coordination costs arising from the need to transfer technology to licensee firms and from the need for an inventor team's members to work together to further develop a technology significantly impact commercialization outcomes. We use a sample of 3,776 university invention disclosures to test whether variation in the types of experience of the scientists on a team influences the likelihood that an invention will be licensed. We proffer evidence to support our hypotheses that anticipated coordination costs influence whether an invention is licensed and that specific forms of team experience attenuate such coordination costs. The implications of these findings for theories of coordination, innovation, and entrepreneurship are discussed.

Organizations exist to achieve joint action, defined as individuals working together to achieve a desired outcome. Coordination is the problem of aligning actions so they are synchronized to achieve this objective. The ability of interdependent actors to coordinate actions stems from adequate mutual knowledge that enables individuals to act as if they can predict others' actions (Camerer, 2003; March & Simon, 1958; Puranam, Raveendran, & Knudsen, 2012). The traditional view is that coordination problems are strictly a consequence of misaligned incentives and that, when appropriate incentives are provided, such problems should disappear (Holmstrom & Milgrom, 1994). This incentive-based approach conflicts with findings that coordination problems persist even when incentives are aligned (Camerer, 2003; Faems, Janssens, Madhok, & Van Looy, 2008; Gulati, Lawrence, & Puranam, 2005). Specifically, scholars from the knowledge-based view (KBV) argue that a significant proportion of joint production failures in organizations occur because of *inability* to synchronize joint efforts (Grant, 1996; Heath & Staudenmayer, 2000; Postrel, 2009), either because of inadequate mutual knowledge or difficulty in creating such knowledge. In the context of commercializing discoveries, we examine how different

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kinds of inventor experience help mitigate coordination problems under varying levels of mutual knowledge.

The scientific discovery process has increasingly become a team production function, with a gradual shift in the locus of invention from solo inventors to teams and networks of inventors (Paruchuri, 2010). Using a comprehensive sample of 19 million publications and 2 million patents spanning five decades, Wuchty, Jones, and Uzzi (2007) found that teams generate far more innovations than solo inventors, that large teams are commonplace, and that teams generate more heavily cited (more impactful) research. From an examination of patent records, Singh and Fleming (2010) confirmed that teams are more likely to produce breakthrough inventions than solo inventors. Given a large scientific base, longer educational training in progressively narrower specializations is necessary to push the knowledge frontier (Jones, 2009). Consequently, the proliferation of team-based inventions is driven largely by two trends: first, the need for specialization to push the scientific frontier and second, the need for interdisciplinary work to solve challenging scientific and practical problems. Whereas teams facilitate and focus use of collective knowledge to solve a problem, concomitant coordination costs incurred when teams perform these complex tasks hinder team activity (Cummings & Kiesler, 2005; Guimerà, Uzzi, Spiro, & Nunes Amaral, 2005). Though solving complex scientific problems can enhance social benefit (Basalla, 1988), the productivity of such efforts is necessarily diminished by their attendant coordination losses (Phelps, 2010; Weitzman, 1998). Therefore, how to gainfully combine different knowledge domains is a core problem in both the innovation and organization literatures (Vural, Dahlander, & George, 2013; Zahra & George, 2002).

Drawing from the knowledge-based view, we approach technology commercialization as a joint production effort involving multiple specialists who are required to coordinate effort to perform complex tasks (Grant, 1996; Kogut & Zander, 1992; Lawrence & Lorsch, 1967). Though knowledge integration can be difficult and costly (Kapoor & Lim, 2007), it is essential for the commercialization of impactful technology (George, Kotha, & Zheng, 2008; Kotha, Zheng, & George, 2011), although this facet is often neglected. Studies that draw on evolutionary theories argue that the inventions that build on the same knowledge domain have limited upside potential, whereas those that build on different, complementary knowledge domains could potentially be valuable (Fleming, 2001, 2004; Fleming & Sorenson, 2004; Makri, Hitt, & Lane, 2010). For example, combining knowledge domains such as molecular biology and photolithography can yield fundamental breakthroughs such as DNA arrays that transform genetic sequencing and mapping capabilities.

Scholars from organization theory, social psychology, and sociology have pointed out that it is extremely difficult for specialists from different knowledge domains to work together fruitfully. This is because specialists have different knowledge, beliefs, languages, and norms of working, so that it becomes difficult for them to understand each other and effectively complement each others' knowledge (Cronin & Weingart, 2007; Dougherty, 1992; Heath & Staudenmayer, 2000; Latour, 1986). This suggests that the most desirable recombinations may also be difficult to fructify (Fleming, 2004; Phelps, 2010; Vural et al., 2013). The desirability-difficulty trade-off makes it challenging, ex ante, to understand how the likelihood of commercialization varies with the underlying science distance. *Science distance* in an invention is the distance between multiple knowledge domains on which the invention is based. We argue that anticipated coordination costs in the joint production task of technology commercialization help explain why commercialization of interdisciplinary research, especially from distant domains, differs from the commercialization process for inventions from specialized or proximate domains.

Using insights from the KBV on coordination costs and from individual/group learning theories on the role of experience in reducing coordination costs, we add to the literatures on the production and commercialization of science as well as to broader discussions of coordination in teams. We contribute to the innovation literature by distinguishing between two sources of coordination costs in technology commercialization: Coordination costs arise both from the need to coordinate *across* inventor-licensee teams and from the need to coordinate *within* an inventor team for further refinement and modification of its invention to facilitate commercialization. Whereas prior work on coordination in teams and in interfirm technology relationships has generally referred to the importance of prior joint work experience, we identify two specific types of experience—licensing experience and collaboration experience—as reducing the anticipated coordination costs[1] for inventions characterized by differing levels of mutual knowledge.

We tested our predictions using event history models that estimate the licensing hazard of 3,776 unique inventions from a large US research university disclosed between 1981 and 2007. This study is among the first large-sample, longitudinal, empirical tests of coordination among scientific teams and its implications for commercialization. We add a complementary perspective to prior work by highlighting the coordination-related aspects of combining distant knowledge domains in producing the type of inventions that are valuable (Fleming, 2001; Kapoor & Lim, 2007). Unlike prior work on technology commercialization, which has largely ignored nonpatented inventions (e.g., Shane, 2002; Vural et al., 2013), this study addresses the commercialization of both patented and not-patented inventions. This comprehensive sample raises the quality of theoretical and practical discourse beyond inventions for which intellectual property rights have been secured through patents, and this extension has important implications for the commercialization of scientific knowledge and the practice of technology transfer.

THEORY AND HYPOTHESES

The theory development is structured as follows. First, we observe that the commercialization of inventions comprises two tasks: (1) effective knowledge transfer and coordination between an inventor team and subsequent (downstream) parts of the same or different organization and (2) effective knowledge transfer and coordination within the inventor team to further develop and modify the invention as required for successful commercial application. We hypothesize that these coordination costs and the value of an invention vary systematically with science distance and affect the likelihood of licensing. Next, we propose that learning from *prior licensing experience* helps attenuate coordination costs between inventor team and licensee firm (henceforth, *firm-team coordination*). Finally, we posit that learning from *prior collaboration experience* helps mitigate coordination costs between members of the inventor team (henceforth, *within-team coordination*).

Commercialization of University Research

Scholars following an evolutionary economics tradition have argued that inventions are created by recombining existing knowledge (Basalla, 1988; Fleming, 2001; Schumpeter, 1934). Though inventors can combine any two pieces of knowledge, what actually gets combined is constrained by the localness of search and the social construction of what pieces can be gainfully combined (Basalla, 1988; George et al., 2008; Kotha et al., 2011). Studies have argued that breakthrough inventions are typically the result of combining distant knowledge domains and are rarely produced by recombining proximate knowledge domains (Fleming, 2001, 2004; Fleming & Sorenson, 2001; Vural et al., 2013). Our focus, however, is not the discovery of, but rather the commercialization of, such inventions. Inventions that recombine elements from the same technological domain are likely to be incremental, and they are therefore less valuable to a firm seeking commercial benefits than are inventions that combine relatively more distant domains that offer the potential for breakthroughs. Therefore, from a commercial value perspective, inventions that combine proximate knowledge domains are less likely to be licensed than those that combine more distant knowledge domains.

Increasing science distance, however, creates a concomitant coordination problem. For a typical university invention, licensing is only the first stage in a long process of commercialization. From on a survey of 62 American universities, Jensen and Thursby (2001) concluded that most university technology is embryonic and requires significant further work for successful commercialization. They report that about 75 percent of inventions were no more than a "proof of concept" at the time of licensing; 48 percent did not have a prototype; and manufacturing feasibility was known for only 8 percent of inventions. The authors concluded that "at the time of license, most university inventions are at such an early stage of development that no one knows if they will eventually result in a commercially successful innovation or not. Moreover, they are so embryonic that further development with the *active involvement by the inventor* is required for any chance of commercialization" (Jensen & Thursby, 2001: 240; emphasis added). Examples abound of the time and effort required to

[1] We use "coordination costs" as a convenient shorthand to denote both the cost of generating adequate predictive knowledge (Puranam et al., 2012) and the cost of the "wasted effort" that arises from misaligned actions (Postrel, 2009).

move inventions to commercial viability (Clarysse, Wright, Lockett, Van de Velde, & Vohora, 2005; George, Zahra, & Wood, 2002; Jain, George, & Maltarich, 2009). As a professor at St. Mary's Hospital, part of Imperial College London, Alexander Fleming discovered that a mold inhibited the growth of bacteria in 1928. Although the significance of this discovery was immediately felt, attempts to treat human subjects failed owing to insufficient quantities of the drug being produced. Commercial production of penicillin was achieved only in the early 1940s, when its chemical structure was decoded.

The issue of further development effort required of university inventions continues to remain a challenge today and gives rise to firm-team and within-team coordination costs. The firm-team coordination cost arises from the need for adequate knowledge transfer and synchronization between inventor team and licensee firm to help the firm understand the value of the invention and work jointly toward commercialization. The within-team coordination cost arises from the need for the members of the inventor team to work together to integrate their knowledge to further develop the invention to create working prototypes and establish manufacturing scale. Below, we argue how jointly considering the likely value from a recombination and the two types of coordination costs involved in its commercialization help us understand the likelihood of licensing for university-generated technologies.

Science Distance and Coordination Costs in Commercialization

Several studies have argued that combining more distant knowledge domains is more risky than combining more proximate knowledge domains, but a few of these distant combinations result in fundamental breakthroughs of immense value (Ahuja & Lampert, 2001; Fleming, 2001; Fleming & Sorenson, 2001; Foster, 1986; Katila & Ahuja, 2002; Utterback, 1994). Inventions that recombine distant knowledge domains can be valuable because recombining different disciplines can introduce pluralism in mental models and facilitate problem solving (Amabile, 1988). Increasing variety in problem solving also concomitantly increases the likelihood that solutions can be found for challenging problems (Fleming, 2007; George et al., 2008; Singh & Fleming, 2010). However, many of these recombinations have little value because inventors have limited knowledge of the nature of interdependence between elements from two distant domains and ex ante have inaccurate expectations regarding their potential value. In contrast, inventors typically have some idea of the nature of interactions between two moderately distant domains and can make informed choices regarding which experiments are more likely to succeed (Basalla, 1988). For example, as Fleming and Sorenson (2004) pointed out, inventors typically use science as a "map" to indicate regions of potentially valuable combinations in their search attempts. Since there is little interaction between distant sciences, scientific research is likely to provide a crude map. In contrast, the search space for recombinations involving proximate domains, though well understood, tends to be saturated, since a lot of experimentation has already occurred (Ahuja & Katila, 2001; Fleming, 2001; Rosenkopf & Almeida, 2003; Rosenkopf & Nerkar, 2001; Vural et al., 2013). Therefore, any recombination involving proximate domains is likely to yield incremental improvements.

Fleming and coauthors examined how the value of an invention covaries with the knowledge distance between the sciences on which it is founded. Drawing on patent data analysis, Fleming (2004) argued that inventions that arise from proximate knowledge domains have limited upside potential. In contrast, when distant domains are combined, the average value of such inventions is lower, but the variance increases, with a small number of inventions becoming extremely valuable. Fleming (2001) found that patents belonging to a single patent class have significantly fewer forward citations. Fleming and Sorenson (2001) similarly showed that interdependence between the knowledge bases that underlie a patent positively impacts patent value, but the square of interdependence negatively impacts that value; an inverted U-shaped effect is shown. They measured interdependence as the density of citations between two knowledge domains; the higher the cross-citation, the closer the knowledge domains and the more familiar specialists in one domain are with advances in the other domain. Kotha et al. (2011) also showed that the knowledge distance of a firm, calculated on the basis of its patenting profile, has a positive impact on both innovative output and innovation quality, but the squared term for distance has a negative impact on both innovative output and innovation quality. Taken together, the evidence suggests that if potential licensee firms were concerned only about the value of inventions, researchers would on average see an inverse U-shaped relationship between an invention's science distance and its hazard (likelihood) of licensing.

Next, we argue that this potential relationship between science distance and licensing of an invention is reinforced when the coordination costs involved in commercializing academic inventions are considered. Since most university inventions lead their industry by several years (Bayus & Agarwal, 2007), a technology transfer organization and an inventor team need to educate a potential licensee firm regarding the prospective value of inventions. Apart from being the target of an effort to convey invention value, the licensee needs to be reassured that the inventor team will fully engage with the commercialization process, is committed to generating further add-on inventions, and will work with the firm's employees to transfer adequate knowledge to make the required modifications for scale-up and manufacturing (Dechenaux, Thursby, & Thursby, 2009; Jensen & Thursby, 2001). Our premise is that if potential coordination costs are perceived to be high for an invention relative to its perceived value, firms are unlikely to license such inventions.

When an invention combines proximate domains, a firm is more likely to possess the requisite absorptive capacity to evaluate its commercial potential (Cohen & Levinthal, 1990). It is also more likely to have scientists and engineers who possess the requisite knowledge to work with inventors, to understand the nuances of the invention, and to further develop it for commercial application. From a within-team coordination cost perspective, inventors from the same or proximate disciplines are likely to have shared knowledge and common training that will allow them to easily work together. Though both types of coordination costs are lower when science distance is low relative to when science distance is high, they may not be trivial. There are multiple demands on academic scientists' time (Mowery, Nelson, Sampat, & Ziedonis, 2004), and given the considerable distance between typical industry and academic knowledge frontiers (Bayus & Agarwal, 2007), considerable effort may be needed in firm-team coordination. Yet such proximate inventions may not have much value for firms because they may lie adjacent to existing technology portfolios or be perceived as marginal improvements. Firms are thus more selective in commercializing proximate inventions (Rosenkopf & Nerkar, 2001). Consequently, jointly considering the potential value of an invention and the likely coordination costs for its commercialization, it is likely that low science distance inventions have a lower likelihood of licensing than distant inventions.

In an invention that combines distant scientific knowledge, coordination costs are likely to be much higher (Lockett, Siegel, Wright, & Ensley, 2005; Schilling & Phelps, 2007; Siegel, Waldman, Atwater, & Link, 2003). First, from a firm-team coordination cost perspective, it becomes more difficult to educate a potential licensee firm regarding the benefits of the invention, because the average licensee firm may not possess the requisite absorptive capacity in all the different knowledge domains. This is especially difficult since, as noted above, the knowledge underlying academic inventions on average leads the industry by several years. Whereas firms may recognize the potential of breakthrough inventions, they may not have the ability to evaluate their commercial potential in the medium term. This is a nontrivial problem, since even breakthrough technologies have valuable and less valuable patents. This difficulty is compounded by managerial coalitions and dominant paradigms of "what works" in their industry, which are likely to hinder the adoption of these inventions (Kaplan, Murray, & Henderson, 2003). Second, when distant domains are combined, the lack of absorptive capacity makes it more difficult to transfer the underlying tacit knowledge from these domains to licensee scientists and engineers (Lane & Lubatkin, 1998). Given these high costs and the large effort needed to develop an invention for commercialization, a firm may not choose to license it unless the value of the invention outweighs the cost of this effort.

In addition, since the average licensee firm typically does not possess adequate knowledge to further develop such an invention to make it commercially viable, this burden usually falls on the inventor team (Dechenaux et al., 2009). When distant knowledge domains are combined, intrateam coordination costs are also likely to be higher because inventors from multiple domains are unlikely to have high levels of shared knowledge (Cronin & Weingart, 2007). First, scientists from distant domains are less likely to share a common language that allows them to effectively communicate their ideas between themselves. Second, different disciplines vary in their dominant logics regarding the nature of science and the most profitable avenues for further explorations to solve problems. For example, Knez and Camerer (1994) discussed how experiments are conducted for differing reasons using varied methods by psychologists and economists. Finally, disciplinary training and the scientific communities in different disciplines also typically adopt different approaches regarding acceptable trade-offs in research methods. Since much of this knowledge is tacit and taken for granted, it becomes cumbersome for specialists from multiple knowledge domains to coordinate among themselves in further developing their inventions.

Even though the members of an innovating team have coordinated among themselves to create a focal invention, the low level of mutual knowledge among specialists remains a coordination challenge in the commercialization process. Team members need to carry forward their ideas from proof-of-concept stage to creating a prototype, then on to manufacturing scale (Jensen & Thursby, 2001). Typically, at this stage, interdependence between various elements that are combined becomes tighter as solutions have to be optimized for scale efficiencies. For example, there was a time lag of about a decade after the discovery of human embryonic stem cells for it to show commercial promise. A significant roadblock was the fragility of the cell lines themselves and the difficulty in propagating adequate quantities of the cells for commercial applications. The inventor team generated further inventions in the manufacturing processes to cultivate these cells to be more robust for commercial applications (Jain & George, 2007). The inventor teams needed to invest significantly to learn and solve these additional problems. Therefore within-team coordination is likely to remain a severe challenge for diverse teams even though they have already worked together to create the focal invention. For a firm, even though a distant recombination is valuable, it may be reluctant to license because of high anticipated within-team coordination costs. In sum, the lower average value of inventions that combine distant domains when they are compared with those that combine moderately distant domains, and the high anticipated coordination costs, together reduce the hazard of licensing for a high-science-distance invention.

A recombination of moderately distant knowledge domains is likely to be more valuable than those that recombine proximate or very distant sciences (Fleming & Sorenson, 2001; Kotha et al., 2011; Vural et al., 2013). These moderately distant inventions are also less likely to suffer from very high coordination costs because there are overlaps in the knowledge base, and scientists need to invest less effort to communicate the benefits of their inventions. Adequate absorptive capacity may also help a firm's scientists to understand the improvement necessary for commercialization and significantly reduce the knowledge transfer effort compared to that needed for distant inventions (Lane & Lubatkin, 1998; Phelps, 2010). Firms are more likely to see moderately distant recombinant inventions as extensions of their product lines and capabilities (Katila & Ahuja, 2002). Dominant paradigms and managerial coalitions are therefore less likely to interfere with adoption of these new technologies. These effects on average reduce the firm-team coordination costs for inventions combining moderately distant sciences as compared with inventions combining distant sciences.

Within-team coordination costs are also correspondingly lower in moderately distant inventions. When knowledge domains are only moderately distant, different specialists in an innovating team are more likely to have some degree of shared knowledge. For instance, they are more likely to read each others' journals and are conversant with scientific norms and paths of progress in the different fields—that is, they share a common language that facilitates exchanging ideas and integrating knowledge. Therefore, potential licensee firms are likely to conclude that within-team coordination costs are manageable in moderately distant inventions and that further development for commercialization is feasible. In sum, the higher average value of moderately distant combinations and the lower anticipated coordination costs relative to the invention value together, on average, increase the hazard of licensing for an invention that combines moderately distant knowledge domains over that of one involving very proximate or very distant combinations. Drawing on these arguments, we posit:

Hypothesis 1. The relationship between inventor science distance and licensing likelihood is curvilinear and is such that the slope is positive from low to moderate science distance and negative from moderate to high science distance.

Prior Licensing Experience and Firm-Team Coordination Costs

Because new technology can be difficult to describe and evaluate, it takes significant effort to convince a potential licensee of the value of an invention. Successful commercialization also requires significant further development, often to create prototypes, experimenting to ensure stability, robustness, and refinement to ensure manufacturability to sufficient scale; these modifications likely will draw on the commercialization expertise of the licensee firm (Jensen & Thursby, 2001). From the perspective of the inventor team, we argue below that the firm-team coordination costs are lower for a team with prior experience in commercialization.

Inventor teams with prior licensing experience are likely more aware of firm-team coordination challenges and the need to invest significant time and resources in commercializing their inventions. Licensing experience likely provides inventors with an understanding of the state of the art in an industry and the primary concerns that drive industrial R&D (Owen-Smith & Powell, 2003). In other words, licensing experience provides higher levels of shared knowledge between an inventor team and a licensee firm, enabling them to more clearly explain the technology and tailor their knowledge transfer efforts to the needs of the licensee firm (George, 2005). Prior licensing experience is also likely to provide the inventor team with the knowledge and routines needed to better interact with their industry partners. An inventor team that has limited commercialization experience may not anticipate the effort involved in transferring knowledge and coordinating actions with a licensee and may be unable to communicate the value of an invention persuasively to counter dominant logics. These teams are also unlikely to have routines in place to effectively transfer tacit knowledge to licensee firm scientists and engineers. These coordination challenges may lead the licensee firm to take a skeptical view of the team's capacity to assist with commercialization. This suggests that inventor teams with high licensing experience are likely to have greater odds of licensing than teams with limited experience.

Hypothesis 2a. The greater the prior licensing experience of an inventor team, the greater the licensing likelihood for an invention, ceteris paribus.

Next, we argue that the prior licensing experience of an inventor team moderates the relationship between science distance and the hazard of licensing by differentially changing anticipated firm-team coordination costs for inventions at low, medium, and high science distance. At medium science distance, firm-team coordination costs are neither low nor high, as they are in the corresponding low and high science distance inventions. As discussed earlier, the greater a team's prior licensing experience, the lower the likely firm-team coordination costs.

However, inventions that recombine moderately distant knowledge domains are on average more valuable (Fleming, 2004; Fleming & Sorenson, 2001). Furthermore, firms may perceive these moderate distance inventions as logical extensions to their current work and therefore perceive these inventions to be more valuable. To realize this perceived value, licensee firms may be more willing to undertake the additional firm-team coordination costs when working with an inventor team with low prior licensing experience. Therefore, taking a firm-team coordination cost perspective, we argue that teams with high licensing experience are unlikely to have a significant advantage over teams with average licensing experience; similarly, teams with low licensing experience are unlikely to have a significant disadvantage when compared to teams with average prior licensing experience. In other words, for medium science distance inventions, higher licensing experience is unlikely to be associated with significantly higher odds of licensing.

High science distance inventions are characterized by a significant need for knowledge transfer and coordination in multiple knowledge domains between an inventor team and a licensee firm. This is likely to be difficult because the internal organization architecture of firms reflects prevalent combinations and links between fields rather than novel and infrequent combinations (Henderson & Clark, 1990). Inventor teams with high levels of prior licensing experience are likely to have lower firm-team coordination costs. These teams can rely on routines and processes developed from previous interactions to more effectively convey their knowledge to an industry's participants. Their prior experience interacting with the industry is also likely to enable them to better understand and act upon the concerns of licensee firms about improving inventions for commercial use. Therefore, at high science distance, increase in prior licensing experience from average to high is likely to be associated with a significant increase in the hazard of licensing.

On the other hand, a team with low levels of licensing experience is likely to lack the tools, routines, and processes that enable an invention team to relate to and address the concerns of a licensee firm and therefore is likely to face significant firm-team coordination costs. The typical licensee firm understands the crucial role played by an inventor team in transferring knowledge and developing an invention, and it therefore, may look for a positive track record among the inventors for licensing (Mowery & Rosenberg, 1998). Therefore, the licensing likelihood for an invention at high science distance is likely to significantly decrease as licensing experience decreases from mean to low.

Firm-team coordination costs for low science distance inventions, though lower than at medium and high science distance, are still likely to be challenging because academic inventions typically lead industrial research by a significant margin. Since low science distance inventions are on average incremental improvements that have lower value than moderate science distance inventions, licensee firms are likely to license only those inventions that they believe can be commercialized with very little additional cost. Since teams with high prior licensing experience have low firm-team coordination costs, their low science distance inventions are likely to have a higher hazard of licensing when compared with the inventions of teams with average experience. Similarly, since teams with low prior licensing experience on average have high firm-team coordination costs, their low science distance inventions are likely to have a lower hazard of licensing than those of teams with average experience. Putting the above arguments together:

Hypothesis 2b. Prior licensing experience moderates the curvilinear relationship between inventor science distance and licensing likelihood: the inverted U-shaped pattern is amplified when experience is low and neutralized when experience is high.

Prior Collaboration Experience and Within-Team Coordination Costs

Within-team coordination costs arise from the need for members of an inventor team to jointly work to further develop their inventions for successful commercialization. Commercialization requirements impose significant coordination needs on inventors to configure subsystems for prototypes and achieving efficient scale (Jensen & Thursby, 2001). These concerns may differ from typical early stage invention concerns such as demonstrating proof of concept. For example, in drugs research and development, early concerns as to the efficacy of the active ingredient in a medicine are supplanted later on by concerns about finding formulations that help the body absorb the medicine with few side effects (Henderson & Cockburn, 1996). Therefore, even teams that have worked together in developing a focal invention need to invest in significant learning to solve these commercialization problems; this gives rise to within-team coordination costs (Hoang & Rothaermel, 2005).

Coordination problems that arise when specialists from different disciplines work together have been studied by scholars in diverse streams of research, including organization theory, social psychology, and sociology. Lawrence and Lorsch (1967) argued that organizations need to straddle the differentiation-integration trade-off and proposed that mechanisms such as cross-functional training and experience working in multifunctional teams can help resolve the most difficult coordination problems. In our context, studies of coordination problems that arise when multiple specialists work together in scientific labs have shown that these teams incur significant coordination problems that are mitigated by specialists' working together and developing degrees of shared knowledge (Knorr-Cetina, 1999).

Social psychologists have also extensively studied this issue, comparing the information gains from diversity, especially functional diversity, and the concomitant process losses that arise from the difficulty diverse individuals have in working together (Van Knippenberg & Schippers, 2007). In our setting, within-team coordination requires that scientists relate to each other's needs and requirements and understand the trade-offs they have to make and the consequences of such trade-offs. These inventors need to develop shared knowledge regarding the challenges in further development, decide on future directions for development, and agree on a division of labor based on who is best equipped to solve specific challenges. They may need to understand specific tools and methods proposed by members and dovetail their own effort to match those of their colleagues, all of which increase within-team coordination costs (Cronin & Weingart, 2007; Heath & Staudenmayer, 2000).

Prior collaboration experience alleviates within-team coordination costs by enabling participants to generate shared mental models (Klimoski & Mohammed, 1994; Mohammed & Dumville, 2001). Prior experience increases both aspects of shared mental models—that is, it provides both a shared representation of a task, called a task mental model, and shared understanding of the distribution of expertise in a team, called a team mental model or transactive memory system (Liang et al., 1995; Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000). Recent work has suggested that coordination utility of a transactive memory system is not limited to the task on which it was obtained but is transferrable to distinct but related tasks (Lewis, Belliveau, Herndon, & Keller, 2007; Lewis, Lange, & Gillis, 2005). Collaboration experience also allows a team to develop a shared language and routines that facilitate coordinating future work. Finally, teams with prior collaboration experience also share tacit knowledge on tools and techniques, and their uses and constraints, thus enabling inventors with prior collaboration experience to substantially reduce intrateam coordination costs.

Our theoretical concern is the reduction in coordination costs that accompanies an increase in mutual knowledge among interdependent individuals. Our specific argument is that when more members of an inventor team have worked together before, the greater the development among them of shared mental models, shared language, and shared routines for achieving coordination. The density of prior collaborative ties among an inventor team captures our core theoretical construct. In contrast, most prior work on the effects of prior experience has measured intensity of prior collaboration. Intensity of collaboration measures the number of prior interactions, but this need not be an accurate indicator of increase in mutual knowledge in a team. For example, in a five-member team, if two members have worked together ten times before, and none of the others have worked together, these two members are the only ones who likely have common ground. In contrast, if all five team members have worked together before, but only twice for each dyad, this team's prior experience count is still 10; however, a team with the latter experience pattern is likely to have much greater common ground that enables them to reduce coordination costs more effectively. In other words, we expect that the density of prior collaborations among a inventor team leads to increase in common ground and a corresponding decrease in coordination costs, even if we control for the intensity of prior experience. Drawing on the arguments above, we hypothesize:

Hypothesis 3a. The greater the prior collaboration experience within an inventor team, the greater the licensing likelihood for an invention, ceteris paribus.

Next, we posit that collaboration experience moderates the relationship between science distance and licensing by differentially changing anticipated within-team coordination costs for inventions at low, medium, and high science distance. Parallel to our arguments for licensing experience, first take the case of a moderate-science-distance invention for which prior collaboration experience increases from average to high. At moderate science distance, within-team coordination costs are significant, but manageable. Inventors are likely to share some common ground regarding underlying knowledge domains and may be able to build on this preexisting knowledge to modify their invention for commercialization. This is especially likely to be true if the inventors have some level of prior collaboration experience. Teams with low prior collaboration experience undoubtedly face higher within-team coordination costs than teams with high experience. However, inventions that recombine moderately distant knowledge domains are on average more valuable (Fleming & Sorenson, 2001) and, as argued above, are also likely to be perceived to be more valuable. Given this high value estimation, firms may be willing to incur the additional coordination costs associated with commercializing an invention from a team with low experience. Since the knowledge domains are marginally distant, licensee firms may also believe that these additional costs may be low. Therefore, taking a coordination costs perspective, we argue that teams at moderate science distance, with high collaboration experience, are unlikely to have a large advantage over teams with average experience; and also, teams with low collaboration experience are unlikely to have a significant disadvantage.

At high science distance, within-team coordination costs are likely to be extremely high (Makri et al., 2010; Schilling & Phelps, 2007; Siegel et al., 2003). Unlike the moderate-distance case, the high-distance case is likely to involve very little common ground between scientists from very different disciplines (Cronin & Weingart, 2007; Dougherty, 1992). It is likely to be quite difficult for inventors to understand the nuances of sciences with very little overlap and build on them substantially to create new knowledge (Heath & Staudenmayer, 2000; Huber & Lewis, 2010). As argued above, teams with high level of collaboration experience are likely to have developed requisite common ground among all experts, reducing anticipated within-team coordination costs. Therefore, at high science distance, increasing collaboration experience from average to high is likely to have significant positive impact on the hazard of licensing. Conversely, decreasing collaboration experience from average to low is likely to exacerbate within-team coordination costs. Therefore, at high science distance, decreasing collaboration experience from average to low is likely to be associated with a lower hazard of licensing.

When an invention has low science distance, teams with high collaboration experience are, for similar coordination cost reasons, likely to be very efficient in working together in further developing it. Because low science distance inventions, on average, have lower value than moderate science distance inventions, licensee firms are likely to license only those inventions that they believe can be commercialized with little additional cost. Therefore, for low–science-distance inventions, teams with high collaboration experience are likely to have a higher hazard of licensing than teams with average levels of experience.

Similarly, given an invention at low science distance, even though inventors are fairly familiar with each other's knowledge domains, they still need to invest considerable time and effort in further developing the invention for successful commercialization (Jensen & Thursby, 2001). Inventors with no prior experience are unlikely to have developed shared routines and have limited knowledge of each other's skills, expertise, and idiosyncratic preferences, likely resulting in increased costs of further collaboration. Given that inventions at low science distance, on average, have lower value than inventions at moderate science distance (Fleming & Sorenson, 2001), and that academic inventors have competing demands on their time (Mowery et al., 2004), a licensee firm may believe that an inventor team will not invest the requisite effort in collaboration to further develop an invention for commercialization. Therefore, reducing collaboration experience from average to low is likely to reduce the licensing hazard for low science distance inventions. Given the above arguments, we predict that:

Hypothesis 3b. Prior collaboration experience moderates the curvilinear relationship between inventor science distance and licensing likelihood: The inverted U-shaped pattern is amplified when collaboration experience is low and neutralized when collaboration experience is high.

METHODS

The research site for testing our hypotheses was the technology transfer office (TTO) of a large US university. Established in 1925, this TTO receives over $50 million in licensing and other annual income. The members in our research team visited the TTO frequently and conducted extensive interviews with managers from the four major functional areas: intellectual property, licensing, legal, and general administration. Almost all university employees disclose their inventions to the TTO. The intellectual property right managers (IPMs) liaise with the inventors and educate them on the need for, and the process of disclosure. This TTO prides itself in its outreach efforts to achieve comprehensive disclosures, even of risky inventions. When a disclosure is made, the TTO records the names of all the inventors, and the principal investigator is typically assigned the role of the first inventor. The IPMs then interview the inventors and write a report that evaluates the commercial potential of the invention. A decision about pursuing patent protection and commercialization is taken on the basis of this disclosure report at a monthly review meeting. The TTO records all disclosures and decisions including whether to patent, how widely to patent, and whether to seek licensing without patent protection. By documenting archived paper records and computerized databases, we constructed this data set and gathered additional data as described next.

Sample

The data for this study, collected in 2006 and 2007, include disclosures made to this university TTO between 1981 and 2006. We started at 1981 to reflect a dramatic change in institutional environment with the passing of the Bayh-Dole Act. This act enabled university faculty to benefit from the intellectual property (IP) created by government-sponsored research and obliged universities to ensure that such output be transferred as goods and services back into the economy. Although we record all disclosures from 1981 onward, we include all relevant information regarding inventors and TTO, such as experience, since 1960. From 1981 to 2006, inventors in teams of two or more disclosed 3,776 unique inventions to the TTO. Of the 3,776 disclosures, 755 (20%) were licensed; of these, 431 inventions were licensed once, and the rest were licensed multiple times. Of these 3,776 disclosures, 874 were patented, 339 (or 38%) of which were licensed. Of the remaining 2,902 disclosures that were not patented, 416 (14%) were licensed.

Estimation Strategy and Dependent Variable

To estimate the impact of inventor characteristics on technology licensing, we used an event history methodology. For all disclosures, we collected disclosure date and licensing dates. About 80 percent of all disclosures were not licensed at the end of the study period. Since survival models control for right censoring, they were the most appropriate model to use in this study. They also control for multiple failure events, which was important for our estimation, since in our data 43 percent of licensed disclosures were licensed multiple times. Our dependent variable is the licensing odds for a given invention.

The estimation strategy was based on the steps recommended by Cleves, Gould, Gutierrez, and Marchenko (2010) and Kleinbaum and Klein (2012). First we focused on the underlying theoretical rationale—that is, the drivers of the distributional form of licensing hazard. An invention disclosed to the TTO is unlikely to be licensed instantly; hence with time the hazard of licensing may increase. In our data, the average licensing time is about 7.8 years, and the modal licensing time is 4 years. However, after a given time, inventions that have not been licensed have a lower hazard of licensing. We checked to see if the underlying distribution of licensing hazard was indeed initially increasing and then decreasing, and we found this to be the case. This distributional form meant we had to use parametric estimations that fit non-monotonic hazard functions. We used a log-logistic model to estimate the survival odds that best fit this hazard function. We conducted tests to see if the log-logistic form was appropriate and found this to be the case. Survival odds are the inverse of licensing odds that we use to state our hypothesis and are similar in theory and interpretation to (the inverse of) the hazard of licensing (Kleinbaum & Klein, 2012). That is, coefficients that are negative and significant imply that an increase in the independent variable leads to an increased hazard of licensing. We tested to see whether our results were sensitive to the specific parametric assumption and found that they were robust to multiple distributional specifications and also to nonparametric estimations.

Explanatory Variables

Science distance. Our theory suggests that the more distant the knowledge domains that are combined in an invention, the more difficult it is to license that invention. We captured the breadth of knowledge domains that are combined by considering how many different specialists contributed to an invention. We assigned its inventors to specializations on the basis of the schools and departments in which these scientists were employed.[2] A simple construction of science distance is to code an invention as "proximate" if its inventors are employed in the same department/school, and as "distant" if they are employed in different schools. This simplicity may overstate science distance; for example, it masks the fact that scientists in biology and medicine may share a larger overlap in mutual knowledge than scientists in physics and biology. Therefore, we replaced the coarse category classification with a fine-grained measure of distance between sciences based on the prevalence of cross-disciplinary research between any given pair of sciences.

Sociology of science has long focused on studying the relationship between sciences. One tool often used for this purpose is citation analysis. The more field A draws from field B, the lower the knowledge distance between fields A and B. To map the knowledge distances between sciences, we followed Leydesdorff and Rafols (2009). To understand cross-disciplinary citation patterns, they first classified 6,164 journals into 172 subject categories used by the Institute of Science Information (ISI).[3]

[2] Recent work to capture the knowledge distance between scientists has focused on the patent subcategories in which their discoveries are classified (Fleming & Sorenson, 2001; Tzabbar, 2009), the intuition being that if two scientists file in the same category, their knowledge bases overlap. The distance between the categories is measured using the citation proportion between all patents in one subcategory with the other patent subcategory. We do not use the patent-based measure but rely on the intuition behind these measures. The reasons we do not use the patent-based measure are (i) about 77 percent of the inventions in our data are not patent protected and (ii) recent evidence (Alcácer & Gittelman, 2004) suggests that assignment of a patent to subclasses is done by patent appraisers, and the inventors may not see their work as being in a particular category.

[3] Interdisciplinary journals complicate the story, as they are hard to assign to a unique science category. Scholars have followed one of two approaches: either

They did not conduct this analysis at the journal level because the matrix was sparse; out of the nearly 38 million possible dyads (6,164 × 6,164), only 3 percent had values greater than zero. The authors used the 172 subject categories listed by ISI in 2006[4] as the starting unit of analysis. Journals are assigned to a subject category by ISI staff based on a list of factors that include the journal's coverage and main audience. The average number of journals per category is 56.3, and the range by category varies from a low of 5 to a high of 262. Even with the reduced set of 172 subject categories, the revised matrix of citation patterns between the 172 × 172 categories results in nearly 30,000 cells, most of which are zero. The authors collapsed the 172 subject categories into 14 broad categories via cluster analysis and recommended that analysis of the citation pattern between the 172 subject categories identified by ISI and the 14 broad categories yielded the best results for measuring knowledge distance between sciences.

The values in the cells in this 172×14 matrix range from 0 (which indicates no citations between journals in category i to the journals in category j) to a high of .91 (which indicates that 90 percent of the citations in category i are to journals in category j). We calculated science distance as one minus the proximity value calculated using the science proximity matrix described above, so that high values indicate high science distance representing limited cross-citation between two fields.

To use this scientific distance matrix, we had two graduate students with engineering or science undergraduate degrees classify all inventors in our database into the 172 scientific specializations, using the department and school in which each inventor worked. In the few cases in which the coders disagreed, we consulted experts to resolve the difference. We measured science distance at the level of inventor team. We aggregated the dyadic distance of every pair of inventors and averaged it across all dyads to get a team-level measure of science distance. Science distance is bounded by 0 and 1, with 0 indicating that all inventors are in domains with high knowledge overlap and 1 indicating little overlap between inventors' knowledge domains. In our sample, the average science distance for a team is 0.3, with a standard deviation of 0.4.

Prior licensing experience. Prior licensing experience for a team was measured as the total number of prior licenses held by its members from 1960 until the time of licensing or censoring, as appropriate, divided by team size. The variable has a mean of 14.5 licenses and standard deviation of 27.9. An alternative measure of prior licensing experience, the cumulative count of the licensing experience of all inventors in a team without standardizing, yielded the same results in our estimations.

Prior collaboration experience. Inventors with large stocks of common ground are more able to coordinate with each other in further improving an invention. We used prior joint work experience as a proxy for preexisting stocks of common ground that can be leveraged in this coordination situation. For good intrateam coordination, it is best if all the members of a team have adequate shared knowledge in the form of a common language, rules and routines, and common understanding of decision premises. For this purpose, we were interested in the completeness of shared experience (Latour, 1986) rather than in a simple count of prior shared experience, as we argued in the hypothesis development section. We measured prior collaboration experience as the proportion of dyads in an inventor team with prior collaboration experience. Specifically, we counted the dyads who had worked together prior to licensing date or censoring date (as appropriate) and divided this count by the total possible number of dyads in an inventor team. This variable ranges from 0 to 1, where 0 implies no inventors have worked together before and 1 implies that all the inventors have worked together before. Its mean is 0.6 and its standard deviation is 0.4.

Control Variables

Following prior research, we constructed a host of control variables derived from the patents that

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ignore interdisciplinary journals altogether and concentrate on the top few journals in each science or include the interdisciplinary journals in only one science category.

[4] We use a static measure of science distance instead of a truly time-varying measure from 1981 through 2006. ISI has published data classifying journals into subject categories only since 1997; therefore it is empirically difficult to obtain this information before 2006. However, Rafols, Porter, and Leydesdorff (2010) suggested that at higher levels of aggregation such as ours, science distance measures are very robust. Also, since we used data from the end of our sample period in 2006, we are more likely to understate than overstate science distance. This is more likely to downward bias our coefficients and work against our finding any results in support of our hypotheses.

underlay the inventions (Elfenbien, 2007; Shane, 2002). We also used a number of non-patent-based measures for all the inventions, including whether each focal invention was patented. For inventions that were not patented, we set the control variables derived from patents to be zero. We also used an alternative approach to derive the mean value for these variables based on observed values of all other variables used in the estimation. The results for the theory variables are similar under both these approaches.

Quality of invention. To understand why some disclosures are licensed, we needed to control for the quality of each studied invention. Ziedonis (2007) suggested that the number of citations received by a patent is a good indicator of economic potential. We counted the total citations a patent had received, excluding self-citations, up to 2007.

Stage of development of invention. Most university disclosures are at an early stage in the technology commercialization cycle and include no commercial prototype or field data (Thursby & Thursby, 2002). Ziedonis (2007) used the number of other patents that a focal patent cited as a measure of whether the patent was radical or was built on existing technologies and further along the commercialization cycle. Similarly, we counted the number of backward citations of a focal patent as a measure of its stage of development.

Inventor academic prestige. Elfenbein (2007) reported that inventors' academic prestige was positively linked to licensing outcomes. To control for the quality of inventors, we collected data on the academic publications of the members of each inventor team.

Government-funded intellectual property. We used an indicator variable to determine whether intellectual property (IP) associated with or constituting a sampled invention was funded by a government agency. Government-sponsored scientific projects may likely push the frontiers of science, which may have a material effect on licensing hazard.

Privately funded intellectual property. We used an indicator variable to determine whether the IP for an invention was funded by a private organization. Funded projects are likely to be of greater commercial interest to a sponsoring firm and, hence, are likely to get licensed sooner.

Intellectual property not protected. Given that our sample includes nonpatented intellectual property such as biological materials, tools, and software that can also be licensed, we used a binary variable (1 = "not patented") to control for the absence of patent protection at the time of licensing.

Collaboration intensity. In our theory development, we argued that completeness of prior joint work experience among a team's members is important for achieving coordinated outcomes. We also controlled for prior collaboration intensity among team members, measured as the average of the count of the number of prior collaborations between each dyad in a team until the time of licensing or censoring.

TTO capabilities. A TTO's degree of experience licensing different technologies may impact the likelihood of licensing for a given invention. We controlled for TTO capabilities by counting the number of prior inventions a TTO had handled in the technological domain of the focal invention.

Year effects and time since sample start date. We included a year indicator variable to control for unobserved year fixed effects. In addition, we added a control for the number of days since January 1, 1981, and a disclosure date. This variable captures any time trends that may lead to changes in the dependent variable. Furthermore, this variable accounts for the possibility that disclosures in recent periods may be treated differently from the disclosures in prior periods. Omitting the time since start of sample variable did not change the results for the theory variables.

RESULTS

We report descriptive statistics and the correlations between variables in Table 1. All correlations above .02 are significant at the .05 level. In Table 2, we report the results of survival models with robust standard errors, clustered for multiple disclosures by the same inventor team. The dependent variable is the survival odds of an invention—that is, the odds that an invention survives in the observation period without a licensing event. Consequently, positive values of the coefficient imply a negative relationship between the variable and licensing hazard. In model 1, we report the baseline model containing only the control variables. In model 2, we included the main effects of theory variables: science distance, science distance squared, prior licensing experience, and prior collaboration experience. In model 3, we add the moderations between science distance and the experience variables.

Hypothesis 1 predicts a curvilinear relationship between science distance and survival odds that is

TABLE 1
Descriptive Statistics and Correlations of the Variables in the Study[a]

Variables	Mean	s.d.	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Time (years)	8.0	5.4													
2. Government funded	0.2	0.4	−.07												
3. Privately funded	0.6	0.5	−.08	−.51											
4. Quality of invention	4.7	12.5	.04	.05	−.06										
5. Stage of development	1.9	5.3	−.01	.03	.01	.48									
6. Inventor academic prestige	6.7	1.7	−.15	−.05	.03	−.04	.00								
7. Intellectual property not protected	0.7	0.5	−.06	.00	.00	−.58	−.56	−.04							
8. Time from start	8.6	5.9	−.62	.09	.13	−.34	−.12	.03	.33						
9. TTO capabilities	6.3	1.6	−.41	.02	.15	−.14	−.01	.33	.06	.45					
10. Collaboration intensity	1.2	1.5	.16	−.01	−.15	.25	.09	.32	−.25	−.55	−.02				
11. Science distance	0.3	0.4	.18	.04	−.12	.09	−.02	−.12	.01	−.18	−.24	−.07			
12. Science distance squared	0.2	0.4	.17	.05	−.10	.08	−.02	−.17	.03	−.12	−.25	−.13	.96		
13. Licensing experience	14.5	27.9	.05	−.02	−.08	.06	.05	.55	−.15	−.36	.11	.61	−.06	−.11	
14. Prior collaboration experience	0.6	0.4	.05	−.06	−.02	.15	.11	.28	−.18	−.22	.09	.51	−.12	−.13	.34

[a] n = 3,776 disclosures.

such that moderate distance inventions should have the lowest survival odds. In line with this prediction, in model 2 the main effect for science distance is negative and significant ($\beta = -1.54$, $p <$ .05) and the squared term is positive and significant ($\beta = 1.86$, $p < .01$). To test if moderate distance inventions have the lowest survival odds, we plotted the estimated licensing odds across the observed range of science distance in our sample. See Figure 1 for this plot. Note that the model predicts survival odds; we calculated the licensing odds as one minus predicted survival odds. As hypothesized, we find that moderate distance inventions have the highest licensing odds. The highest value licensing odds reaches is 0.30 when science distance is 0.42. Whereas when science distance is at the mean minus one standard deviation, the licensing odds are 0.23; and when science distance is at the mean plus one standard deviation, the licensing odds are 0.26. Hypothesis 1 is supported. Hypothesis 2a predicts that licensing odds will be higher as licensing experience increases. In model 2, there is a negative and significant relationship between licensing experience and survival odds ($\beta = -0.009$, $p < .01$), supporting our prediction in Hypothesis 2a. Hypothesis 3a predicts a positive relationship between prior collaboration experience and licensing odds for an invention. The coefficient for prior collaboration experience ($\beta = -0.0149$) is not significant in model 2. Hypothesis 3a is not supported.

We tested the moderation effects using the results from model 3 in Table 1. Hypothesis 2b predicts positive moderation by licensing experience of the relationship between science distance and licensing odds that is such that the curvilinear relationship is neutralized as prior licensing experience increases. The interaction term between science distance and licensing experience is negative and significant ($\beta = -0.081$, $p < .01$), and the interaction term between science distance squared and licensing experience is positive and significant ($\beta = 0.095$, $p < .01$). To facilitate interpretation, we plotted the licensing odds at different levels of science distance and different levels of licensing experience, as shown in Figure 2. We plotted these figures at the median time it takes to license an invention in our sample (approximately eight years).[5]

When prior experience is low (i.e., one standard deviation below mean prior licensing experience), the hazard of licensing an invention is 0.24, 0.40, and 0.23 at low, moderate, and high science distance, respectively. When prior experience is at the mean, the hazard of licensing an invention is 0.27, 0.50, and 0.28 at low, moderate, and high science distance, respectively. When prior experience is high (i.e., one standard deviation above the mean), the hazard of licensing and invention is 0.29, 0.69, and 0.29 at low, moderate, and high science distance, respectively (Figure 2). This suggests that curvilinearity is more pronounced as experience increases, contrary to Hypothesis 2b. Though not

[5] We checked for robustness using different years: 3, 5, 10, and 12 years, as well as at the mean (7.8 years) and mode (4 years). Our results are similar to those presented in the text.

TABLE 2
Predicting the Survival Odds of an Invention[a]

Dependent Variable: Survival Odds	Model 1	Model 2	Model 3
Government funded	−0.214	−0.252	−0.227
	(0.169)	(0.169)	(0.167)
Privately funded	−0.393**	−0.408**	−0.421**
	(0.144)	(0.143)	(0.142)
Quality of invention	−0.0333**	−0.0354**	−0.0364**
	(0.005)	(0.005)	(0.005)
Stage of development	0.0213*	0.0217*	0.0221*
	(0.010)	(0.010)	(0.010)
Inventor academic prestige	−0.0544	0.0420	0.0408
	(0.038)	(0.044)	(0.044)
Intellectual property not protected	0.505**	0.471**	0.499**
	(0.144)	(0.143)	(0.141)
Time from start	−0.000302**	−0.000318**	−0.000336**
	(0.000)	(0.000)	(0.000)
TTO capabilities	−0.261**	−0.214**	−0.216**
	(0.049)	(0.047)	(0.047)
Collaboration intensity	−0.269**	−0.196**	−0.181**
	(0.043)	(0.058)	(0.057)
Theory Variables			
Science distance		−1.542**	−1.404*
		(0.551)	(0.555)
Science distance squared		1.858**	1.788**
		(0.559)	(0.560)
Licensing experience		−0.00882**	−0.00907**
		(0.003)	(0.003)
Prior collaboration experience		−0.0149	0.0501
		(0.170)	(0.168)
Licensing × science distance			−0.0809**
			(0.017)
Licensing × science distance squared			0.0950**
			(0.017)
Collaboration × science distance			4.329**
			(1.317)
Collaboration × science distance squared			−4.497**
			(1.336)
Constant	8.866**	5.960**	6.063**
	(1.001)	(0.854)	(0.854)
Year fixed effects	Yes	Yes	Yes
Chi-square	507.8	546.8	545.6
Log-likelihood	−4,374.3	−4,336.0	−4,297.1
Observations	5,010	5,010	5,010

[a] Survival means an invention was not licensed in a given observation period. Hence negative and significant coefficients mean that the hazard of licensing increases with an increase in the explanatory variable.

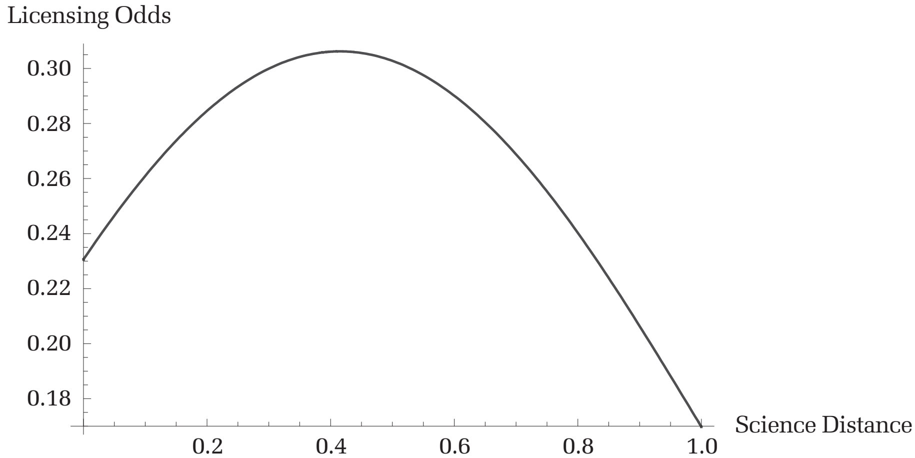
* $p < .05$

** $p < .01$

Robust clustered standard errors are in parentheses.

presented here, a plot of the entire data range shows that at extreme values of prior licensing experience, in line with our hypothesis, the relationship between science distance and hazard of licensing is essentially flat except at the ends, very low and very high science distance. However, within the two standard deviation range, Hypothesis 2b is not supported. Hypothesis 3b predicts that the curvilinear relationship between science distance and licensing hazard is more pronounced at low values of prior collaboration and is neutralized at high values of prior collaboration. We tested the moderation effects using the results from model 3 of Table 1. The interaction term between science

FIGURE 1
Hazard of Licensing at Different Levels of Science Distance



distance and collaboration experience is positive and significant ($\beta = 4.329$, $p < .01$), and the interaction between science distance squared and licensing experience is negative and significant ($\beta = -4.497$, $p < .01$). To interpret the moderation hypotheses, we plotted Figure 3, which shows the relationship between science distance and licensing hazard at various levels of prior collaboration experience. When prior collaboration experience is at the mean, the hazard of licensing an invention is 0.29, 0.33, and 0.24 at low, moderate, and high science distance, respectively. When prior collaboration experience is low (mean – 1 s.d.), the value of the hazard of licensing and invention is 0.25, 0.34, and 0.20 at low, moderate, and mean science distance, respectively. This suggests that the curvilinear relationship of science distance and licensing hazard is more curvilinear (inverted U-shaped) at low than at moderate distance, as per Hypothesis 3b. When prior collaboration is high (mean + 1 s.d.), the hazard of licensing an invention is 0.32, 0.30, and 0.28 at low, moderate, and high science distance, indicating that the curvilinear relationship is now flatter, supporting Hypothesis 3b.

Robustness Checks

We conducted several robustness checks to test the sensitivity of our results to alternative specifications, different measures, and the influence of

FIGURE 2
Science Distance and Hazard of Licensing Moderated by Licensing Experience

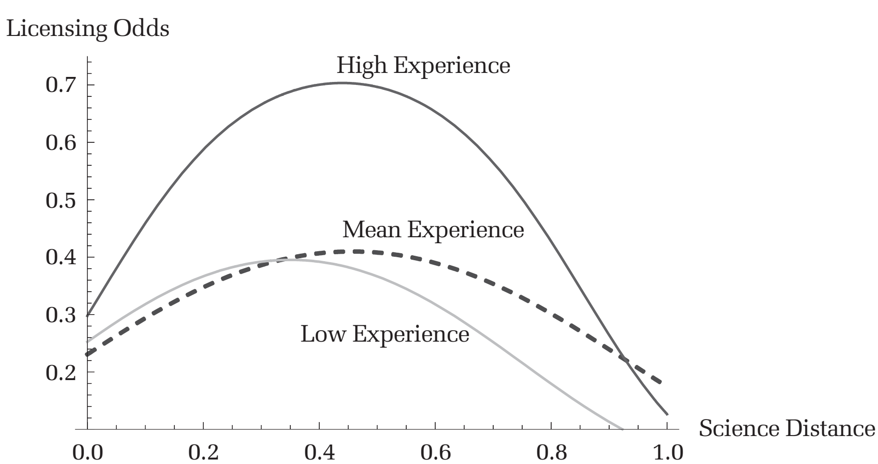
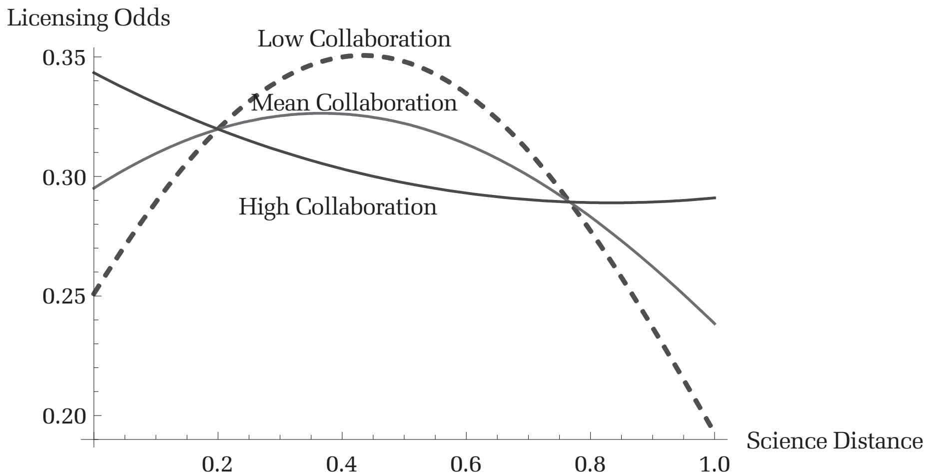


FIGURE 3
Science Distance and Hazard of Licensing Moderated by Collaboration Experience



outliers. First, our sample combines disclosures that are patented and those that are not patented. We checked to see if our theory holds across these subsamples. We report the estimations by patented (model 3) and not patented (model 2) subsamples in Table 3. The results for the theory variables are broadly similar in these two subsamples. The main difference is that the moderation terms for prior licensing experience are not significant in the patented subsample. One explanation for this result is that the patenting process potentially codifies a large part of the tacit knowledge that underlies an invention, which may reduce firm-team coordination costs.

We ran several other estimations that are not reported in this article. We tested results' sensitivity to our assumption of the parametric form in the survival models. Our results were qualitatively unchanged for several different parametric assumptions as well as in nonparametric estimations. We tested the robustness of our results to multiple licensing events of the same disclosure. We ran survival models with only a single failure event (licensing or censoring) per disclosure and compared it to survival models with multiple failure events (multiple licenses for the same disclosure), clustered by disclosure and inventor team. Our results were qualitatively identical for these estimations. Some licensee firms may have licensed more than one invention from a TTO and had routines in place that reduced the coordination cost in licensing. Since we could not explicitly use a control variable capturing the history of licensing between a licensee firm and TTO, as this record is not defined for inventions not licensed, we reran our estimations clustering for the repeated licensing by some firms. Similar results were obtained.

In addition to controls for demand conditions, we included variables from the Yale Survey on industrial research and development, on the relationship between sciences and industry, that may influence certain types of science to be commercialized faster (Klevorick, Levin, Nelson, & Winter, 1995). These variables are not significant in the hazard of licensing and hence are not included in our estimations. Furthermore, we ran estimations dropping outliers, and our results remain unchanged. We also tried to check if unobserved factors regarding team formation impacted licensing. We followed a two-stage method to predict the likelihood that a given team would form and then used the hazard ratio from this prediction as an additional control in predicting licensing. Our results remain robust.

DISCUSSION

We examined the coordination problems that stem from lack of mutual knowledge when innovative teams attempt joint action. By contrasting the coordination of experts from distant versus proximate scientific domains, we were able to highlight the different coordination challenges in commercializing inventions, specifically, the challenges of taking university research to industry application. Our findings suggest that mutual knowledge among

TABLE 3
Robustness Subsample Estimation of the Survival Odds of Inventions[a]

Dependent Variable: Survival Odds	Full Sample	Not Patented	Patented
Government funded	−0.227	−0.204	−0.259
	(0.167)	(0.291)	(0.243)
Privately funded	−0.421**	−0.845**	−0.0625
	(0.142)	(0.231)	(0.202)
Quality of invention	−0.0364**		−0.0298**
	(0.005)		(0.005)
Stage of development	0.0221*		0.0179†
	(0.010)		(0.010)
Inventor academic prestige	0.0408	0.0328	0.0489
	(0.044)	(0.067)	(0.063)
Intellectual property not protected	0.499**		
	(0.141)		
Time from start	−0.000336**	−0.000277*	−0.000452**
	(0.000)	(0.000)	(0.000)
TTO capabilities	−0.216**	−0.216**	−0.254**
	(0.047)	(0.066)	(0.087)
Collaboration intensity	−0.181**	−0.230*	−0.140†
	(0.057)	(0.093)	(0.082)
Theory Variables			
Science distance	−1.404*	−1.460†	−2.218**
	(0.555)	(0.900)	(0.773)
Science distance squared	1.788**	2.390**	1.835*
	(0.560)	(0.926)	(0.786)
Licensing experience	−0.00907**	−0.0148**	−0.0064†
	(0.003)	(0.004)	(0.0038)
Prior collaboration experience	0.0501	0.0838	0.241
	(0.168)	(0.257)	(0.214)
Licensing × science distance	−0.0809**	−0.118**	−0.0307
	(0.017)	(0.024)	(0.023)
Licensing × science distance squared	0.0950**	0.140**	0.0304
	(0.017)	(0.025)	(0.028)
Collaboration × science distance	4.329**	5.879**	3.667†
	(1.317)	(2.005)	(2.000)
Collaboration × science distance squared	−4.497**	−5.433**	−4.317*
	(1.336)	(2.046)	(1.995)
Constant	6.063**	3.814**	6.587**
	(0.854)	(0.761)	(0.772)
Year fixed effects	Yes	Yes	Yes
Chi-square	545.6	476.4	237.9
Log-likelihood	−4,297.1	−2,734.2	−1,430.2
Observations	5,010	3,510	1,500

[a] Robust clustered standard errors are in parentheses.
† $p < .10$
* $p < .05$
** $p < .01$

inventors and routines that transfers knowledge to licensee firms is important to overcome coordination challenges. We find that prior collaborative and prior licensing experience respectively help mitigate these two types of coordination costs. The implications for theories of coordination in organizational design and the production and commercialization of discoveries are discussed next.

Theories of Organizational Design and Coordination

Recent approaches to organization design drawing on the knowledge-based view have emphasized the role of achieving coordination in joint production tasks and the role of organizations as vehicles for generating adequate mutual knowledge or common ground that enables interdependent agents to coordinate their activities (Grant, 1996; Kogut & Zander, 1992, 1996; Puranam et al., 2012). These approaches articulate a view of organizations as coordination systems, as opposed to the traditional view of organizations as incentive systems (Holmstrom & Milgrom, 1994; Williamson, 1991). We explicitly adopted a coordination lens to study the joint production problem, specifically by focusing on the variation in the level of mutual knowledge in an inventor team, holding other factors constant. We found support for our arguments that anticipated coordination costs help explain licensing patterns of university technology.

The main effect of prior collaboration experience on licensing was not significant; instead, prior collaborative experience became pertinent only as a moderator of science distance. We found that low-experience teams perform much more poorly at high science distance that is due to lack of mutual knowledge and its attendant coordination costs. Joint work experience is likely to reduce coordination costs under all conditions; however, our finding suggests that in the invention commercialization process, such efficiencies gain importance only under some conditions. Specifically, within-team coordination costs become important only when the cost of coordination is expected to be large relative to the expected value of an invention. Further, theoretically, we differentiate firm-team coordination costs from within-team coordination costs and argue that these costs are respectively mitigated by different kinds of experience—that is, licensing experience and collaboration experience, respectively. Though we do not empirically distinguish between these two kinds of coordination costs, our moderation results strongly suggest that these different costs do drive the invention commercialization process.

It is intuitive that prior joint working experience is helpful in collaboration efforts by specialists from multiple domains. Specifically, we contribute to the literature on the impact of prior experience on coordination in specialist teams in two ways. First, prior research on joint work has typically used dichotomous measures for knowledge distance, conceptualizing distance as within-domain or across-domains. By measuring knowledge distance as a continuous variable, we contribute to understanding how prior experience likely impacts coordination costs depending on variation in the level of mutual knowledge available in a team. It is interesting to note that though levels of mutual knowledge likely vary monotonically with knowledge distance, prior experience that bridges this mutual knowledge gap has a nonmonotonic impact on the likelihood of commercialization. Second, studies have typically measured prior collaboration experience by intensity of joint work, using metrics such as the amount of time partners teams have worked together (e.g., Latour, 1986; Vural et al., 2013). However, intensity in addition to mutual knowledge creation can capture other effects, such as socialization. This confound prevents pinpointing whether observed effects are indeed a function of generating mutual knowledge. For instance, in our data, though collaboration intensity has a positive main effect on licensing odds, the interactions with science distance are not significant. This finding would be in line with our theory if collaboration intensity were actually capturing socialization effects rather than mutual knowledge effects. In contrast, we argue that the density or the closure of prior experience (i.e., the proportion of team members that have worked together before) is also an important consideration in reducing coordination costs. This is a more accurate measure of the existence of mutual knowledge, especially in large innovative teams, which are becoming more common. We show that the density of prior experience has an impact on coordination costs (and the likelihood of forming technology commercialization relationships) even after the intensity of prior experience is controlled for.

Our findings reinforce the crucial role played by mutual knowledge and coordination costs in organizational design and joint action. Future extensions of this study could take a more dynamic approach to the distances between science fields and consider how incentives and coordination costs jointly and independently influence outcomes of team action. Nevertheless, this is among the first large-scale longitudinal settings for a test of coordination when mutual knowledge is low in joint team production of inventions.

The Commercialization of Scientific Discoveries

Our study proffers evidence for the coordination costs perspective in technology commercialization. In so doing, this study speaks to the heart of commercialization of scientific discoveries and to the core challenges in integrating knowledge from disparate technical niches. The trend toward team production of scientific discoveries (Paruchuri, 2010; Wuchty et al., 2007) and the shift toward interdisciplinary science that recombines distant rather than insular domains push forward the frontiers of human knowledge (Basalla, 1988; George et al., 2008). In that context, our empirical finding of licensing likelihood at moderate science distance presents an interesting pattern. Figures 2 and 3 show that at moderate science distance, teams with a high level of collaboration experience do not perform better than teams with moderate experience. Though average experience seems to be beneficial when compared to low experience, the magnitude of the impact of experience seems to be lower than at the low or high ends of science distance. It is likely that moderate-distance inventions occupy a "sweet spot" in the commercialization process—they tend to be more valuable than inventions resulting from adjacent or very distant combinations, and potential licensee firms are likely to recognize their value and partner with these inventions' academic inventors for commercialization. Therefore, potential licensees may be more willing to license such inventions and partner with teams that have some (rather than low) experience. Future research should explore these processes further. However, it is interesting to note that prior licensing experience is valued highly by potential licensee firms even at moderate science distance, and TTOs have higher success licensing inventions by teams with high prior licensing experience.

An explanation complementary to our coordination costs logic is that inventor teams with high licensing experience are working in more applied areas that are more readily commercialized, and teams with prior collaboration experience may be working on more incremental improvements to their prior work that could also have commercial applications. We attempted to control for these effects. First, we controlled for the academic publication record of inventors; presumably, more academic publications point to more basic research. Second, in the patented subsample, we controlled for the relative weight of academic citations to other (patent) citations. Arguably, the more academic work cited by a patent, the more basic it is; and the more applied work cited by the patent, the more incremental the invention. Our results for our coordination cost variables were unchanged in these robustness tests. Future work should more carefully delineate the impact of these different mechanisms.

The findings also add to the substantial repository of empirical work on the value of patents. The citations that a patent receives have been used as a proxy for the quality of the patent. In our study, the results suggest that the likelihood of licensing increases by 2 percent with every additional patent citation. The innovation literature has predominantly relied on patents as an indicator to explain both the process of creating knowledge and the performance of firms, which has drawn some criticism as scholars have questioned the value of patents, given the explosion of patenting activity by firms (Jaffe & Lerner, 2004). Furthermore, others have questioned the link between empirical measures and the reality of the patenting process, wherein some critical variables such as citations to prior art are frequently added by patent examiners; this suggests that either inventors may have not used the prior art cited or may have been unaware of it (e.g., Alcácer & Gittelman, 2004). There is a paucity of empirical work that examines commercialization beyond patenting.

In this study, we include all inventions disclosed at a university that could potentially be licensed. Of the 3,776 disclosures, only 23 percent were patented. Of the 2,902 disclosures that were not patented, 416 were licensed. The number of licenses from nonpatented inventions is 1.23 times greater than the number of licenses from patented inventions. This suggests that it is important to go beyond patenting to understand discovery and commercialization processes. For example, Shane (2002) found that nearly 60 percent of inventions at MIT were patented, out of which 52 percent were licensed. In that study and most others in this literature, inventions that could be licensed but were not patented are ignored. By including all inventions whether patented or not, we provide the first large-sample investigation of licensing of nonpatented inventions.

Our research also has implications for more traditional licensing of technology between firms and, more broadly, for interorganizational technology transfer or development. In the past decade, an increasing number of studies on technology-sourcing relationships, including buyer-supplier relationships (Becker & Zirpoli, 2011; Srikanth & Puranam, 2011), technology alliances, joint ventures (Gulati & Singh, 2009; Hoetker & Mellewigt, 2009), and acquisition integration–acquisition performance (Ahuja & Katila, 2001; Makri et al., 2010; Puranam & Srikanth, 2007) have begun to emphasize the role of knowledge integration in the success of interorganizational relationships. We extend this coordination costs logic to the formation of technology-licensing relationships characterized by need for close joint work between the licensee and licensor.

Our setting is particularly interesting because we observe the formation of technology licensing relationships where the traditional make-or-buy considerations do not apply. The university does not commercialize its own inventions. Therefore, any inventions that are not licensed essentially have zero net present value, which provides an opportunity to observe the role of coordination costs in the formation of a licensing relationship. We draw from theories of experience, especially theories of learning by doing at the individual and group levels of analysis, to inform our understanding of the influence of coordination problems on the formation of interorganizational licensing relationships. Considering the role of coordination costs in technology commercialization relationships is an interesting extension to prior research on role of coordination costs in make-or-buy decisions (Hoetker, 2005; Monteverde, 1995).

The literature on open innovation suggests that firms should take advantage of innovations produced by specialists outside their boundaries (Chesborough, Vanhaverbeke, & West, 2006). A significant and growing portion of these licenses are from universities and scientific research laboratories (Mowery & Rosenberg, 1998), where the respective partners have complementary capabilities: basic research and commercialization of innovations. Our study suggests that the licensing of interdisciplinary inventions could involve significant coordination costs that may not occur in licensing specialized inventions. Since managing these coordination costs is likely to hold the key to commercial success, firms should keep in mind such costs when making decisions regarding the external procurement versus internal development of innovations.

Incentives and Coordination

In this study, we focused on the anticipated coordination cost as an explanation of why some inventions are licensed and others are not. Presumably incentives offered to license intra- and interdisciplinary inventions could be heterogeneous. Whereas a wealth of theoretical work focuses on the optimal contract structure between licensee and licensor, there is little empirical work on this topic. Future work could consider the variations in incentive contracts with differences in types of inventions and how these contracts change with the experience of licensee and licensor capabilities. Such research efforts would throw light on the role of incentive structure on successful commercialization of a licensed invention as a product or service.

Future research could also be enriched by examining the role of a central coordinating agent in a team. It is plausible that, in lieu of dyadic ties between inventors working across distant scientific domains, one central coordinating agent, who has worked with all the inventors on a team and can interpret results of the work of all members, may be just as effective. Because this coordinating team member will expend more effort in orchestrating the actions of others, whether the central coordinator should be rewarded with a higher share of the income is an important question. More fundamentally, does the bearer of the coordination cost also commensurately benefit from its success? The limited empirical evidence on incentive sharing is seen in the literature on entrepreneurs distributing equity to their helpers. A substantial majority of founders of nascent ventures tend to share incentives equally with their helpers (Ruef, 2009), whereas some entrepreneurs with specific human capital are able to deviate away from the equal distribution of incentives (Kotha & George, 2012). Consequently, the effects of specific and general human capital of the inventors on incentive distribution and its implications for team performance become interesting and economically meaningful questions for future research.

Opportunity Recognition in Entrepreneurship

The central debate in the literature on entrepreneurship concerns the nature of opportunities (Alvarez & Barney, 2010; Dimov, 2011). Some scholars have taken the view that opportunities for bringing new products and services to market are objective and that entrepreneurs identify these opportunities drawing on their prior experience (Shane, 2012). Other scholars have viewed entrepreneurs as constructing opportunities where it is not possible to specify an opportunity ex ante unless it has been enacted (Venkataraman, Sarasvathy, Dew, & Forster, 2012). Our study considers inventions as potential opportunities that might be commercialized and that vary in value on the basis of science distance and anticipated coordination costs. We find support for the likelihood that moderately distant inventions have a higher probability of being successfully licensed. These results are consistent with the treatment of opportunities as objective and the view that inventor experience improves the odds of success, which is consistent with an opportunity-individual nexus view of entrepreneurship (Shane, 2012). By starting with all inventions that could potentially be licensed, we avoided the fallacy of defining opportunities on the basis of their successful outcome. On the issue of whether opportunities objective or subjective, we proffer evidence to support the view that the value of opportunities, on average, may be objectively assessed by the scientific distance between the inventors in a team. Individual factors further improve the likelihood of licensing in distant domains, in keeping with the notion of opportunities being objective, as is consistent with the literature's treatment of individual experience effects in entrepreneurship.

TTO Role and Managerial Implications

We argued that the variation in the level of mutual knowledge of inventors in a team influences the perceived value of a technology and its anticipated coordination cost, thereby influencing which inventions gets licensed. The central actors in our setting are inventors, TTOs, and licensing firms. TTOs are tasked with protecting and licensing inventions. It is TTOs that communicate with potential licensee firms, negotiate and monitor contracts, and protect the inventions assigned to them against infringements. Given the importance of TTOs, it is not surprising that they are able to license more inventions in domains in which they have high level of capabilities—that is, have handled a higher number of inventions. We found that TTO expertise is positively and significantly related to the hazard of licensing an invention. It would be interesting to consider the joint variation in TTO capabilities and mutual knowledge of inventors as further steps in future studies.

This study also holds implications for managing technology transfer organizations, especially in a university setting. From initial interviews, we found that TTO intellectual property managers and licensing managers realize how helpful and available specific inventors have been in prior deals. TTO managers use this information to assuage concerns from potential licensee firms regarding knowledge transfer and industry engagement issues—the effects of prior licensing experience underscore the importance of this strategy. The added implication is that TTO managers should consider the mutual knowledge in teams and how comfortable inventors are as a team, especially if they are from different scientific domains. The findings reveal that prior collaboration experience makes a substantive difference to inventions combining highly proximate and distant domains—highlighting that the "chemistry" between inventors and their ability to work together in commercialization is especially important.

Limitations

This study is not without its limitations. First, we relied on a single institution for data. There may be a risk of idiosyncratic institutional practices that influence our results. However, a single institution naturally controls for between-institution differences that can confound results, especially with regard to coordination costs that arise from differences in administrative bureaucracies. Furthermore, we follow the tradition of prior studies that have argued that with the advent of technology transfer associations and journals, best practices are widely spread (Clarysse et al., 2005; Nerkar & Shane, 2007; Shane, 2000; Siegel et al., 2003). Another issue that stems from our setting is that the relationship between academic inventors and licensee firms is mediated by universities' TTOs, organizations dedicated to pursuing commercialization opportunities stemming from academic settings. Findings from this context may not be directly applicable to commercialization of R&D from corporate labs. However, the rise of contract research organizations and the increasing establishment of units dedicated to licensing technologies arising from corporate labs that a firm chooses not to commercialize itself may be appropriate avenues for generalizing the insights from this study.

Second, we used a time-invariant measure of science distance, measuring it at the end of our sample period in 2006. Since sciences are growing closer, we are more likely to be understating, rather than overstating, science distance. If there is any bias, it is more likely to suggest that sciences are closer than they actually were at the time of the invention. Since our moderation hypotheses specify different effects at high science distance, this bias should work against our finding any results. Finally, scientists may elect to pursue projects taking into account their likelihood of commercialization, and plausibly, our study may suffer from an endogeneity problem. Theoretically, whereas endogeneity can confound the interpretation of main effects, it is hard to think of a compelling story that explains the moderator effects. It is possible that only inventors who believe their coordination costs are low engage in inventions combining distant sciences. If this were the case, then we should not find evidence for the moderation by prior collaboration experience. The fact that we still find significant results suggests that ours is a more conservative test for the impact of coordination costs on licensing.

Conclusion

This study adds to the literatures on coordination of experts from distant domains to commercialize new inventions. We capture disclosure and licensing data over a 26-year-long window that starts with the uniform change in legislation (Bayh Dole Act) for all US universities. Our sample includes both patented and nonpatented inventions, and our estimation is robust for single and multiple licensing events. We find support for our predictions that prior licensing and collaboration experience increases the hazard of licensing an invention. The pattern of our results suggests a nuanced mechanism of how prior collaboration within a team influences intrateam coordination costs and the hazard of licensing an invention. Specifically, we find that prior collaboration experience increases the hazard of licensing more for inventions that combine very proximate or very distant sciences than it does for inventions that combine moderately distant sciences. In doing so, this study expands empirical investigation to the practice of commercialization of innovation and to theories of coordination and organizational design.

REFERENCES

Ahuja, G., & Katila, R. 2001. Technological acquisitions and the innovation performance of acquiring firms: A longitudinal study. ***Strategic Management Journal,*** 22: 197–220.

Ahuja, G., & Lampert, C. M. 2001. Entrepreneurship in the large corporation: A longitudinal study of how established firms create breakthrough inventions. ***Strategic Management Journal,*** 22: 521–543.

Alcácer, M., & Gittelman, M. 2004. Patent citations as a measure of knowledge flows: The influence of examiner citations. ***Review of Economics and Statistics,*** 88: 774–779.

Alvarez, S., & Barney, J. 2010. Entrepreneurship and epistemology: The philosophical underpinnings of the study of entrepreneurial opportunities. In A. P. Brief & J. P. Walsh (Eds.), ***Academy of Management annals,*** vol. 4: 557–583. Essex, UK: Routledge.

Amabile, T. M. 1988. A model of creativity and innovation in organizations. In B. M. Staw & L. L. Cummings (Eds.), ***Research in organizational behavior,*** vol. 10. Greenwich, CT: JAI.

Basalla, G. 1988. ***The evolution of technology.*** Cambridge, UK: Cambridge University Press.

Bayus, B. L., & Agarwal, R. 2007. The role of pre-entry experience, entry timing, and product technology strategies in explaining firm survival. ***Management Science,*** 53: 1887–1902.

Becker, M. C., & Zirpoli, F. 2011. What happens when you outsource too much? ***MIT Sloan Management Review,*** 52(2): 59–67.

Camerer, C. 2003. ***Behavioral game theory: Experiments in strategic interaction.*** Princeton, NJ: Princeton University Press.

Chesborough, H., Vanhaverbeke, W., & West, J. 2006. ***Open innovation: Researching a new paradigm.*** Oxford, UK: Oxford University Press.

Clarysse, B., Wright, M., Lockett, A., Van de Velde, E., & Vohora, A. 2005. Spinning out new ventures: A typology of incubation strategies from European research institutions. ***Journal of Business Venturing,*** 20: 183–216.

Cleves, M., Gould, W., Gutierrez, R., & Marchenko, Y. 2010. ***An introduction to survival analysis using Stata.*** College Station, TX: Stata.

Cohen, W. M., & Levinthal, D. A. 1990. Absorptive-capacity: A new perspective on learning and innovation. ***Administrative Science Quarterly,*** 35: 128–152.

Cronin, M. A., & Weingart, L. R. 2007. Representation gaps, information processing and conflict in functionally diverse terms. ***Academy of Management Review,*** 32: 761–773.

Cummings, J. N., & Kiesler, S. 2005. Collaborative research across disciplinary and organizational boundaries. ***Social Studies of Science,*** 35: 703–722.

Dechenaux, E., Thursby, M. C., & Thursby, J. G. 2009. Shirking, sharing risk, and shelving: The role of university license contracts. ***International Journal of Industrial Organization,*** 27: 80–91.

Dimov, D. 2011. Grappling with the unbearable elusiveness of entrepreneurial opportunity. ***Entrepreneurship: Theory and Practice,*** 35: 57–81.

Dougherty, D. 1992. Interpretive barriers to successful product innovation in large firms. ***Organization Science,*** 3: 179–203.

Elfenbein, D. W. 2007. Publications, patents and the market for university inventions. ***Journal of Economic Behavior and Organization,*** 63: 688–715.

Faems, D., Janssens, M., Madhok, A., & Van Looy, B. 2008. Toward an integrative perspective on alliance governance: Connecting contract design, contract application, and trust dynamics. ***Academy of Management Journal,*** 51: 1053–1078.

Fleming, L. 2001. Recombinant uncertainty in technological search. ***Management Science,*** 47: 117–132.

Fleming, L. 2004. Perfecting cross-pollination. ***Harvard Business Review,*** 82(9): 22–24.

Fleming, L. 2007. Breakthroughs and the "long tail" of innovation. ***MIT Sloan Management Review,*** 49(1): 69–74.

Fleming, L., & Sorenson, O. 2001. Technology as a complex adaptive system: Evidence from patent data. ***Research Policy,*** 30: 1019–1039.

Fleming, L., & Sorenson, O. 2004. Science as a map in technological search. ***Strategic Management Journal,*** 25: 909–928.

Foster, R. 1986. ***Innovation: The attackers advantage.*** New York: Summit.

George, G. 2005. Learning to be capable: Patenting and licensing at the Wisconsin Alumni Research Foundation 1925–2002. ***Industrial and Corporate Change,*** 14: 119–151.

George, G., Kotha, R., & Zheng, Y. 2008. Entry into insular domains: A longitudinal study of knowledge structuration and innovation in biotechnology firms. ***Journal of Management Studies,*** 45: 1448–1474.

George, G., Zahra, S., & Wood, D. 2002. The effects of business-university alliances on innovative output and financial performance: A study of publicly traded biotechnology companies. ***Journal of Business Venturing,*** 17: 577–609.

Grant, R. M. 1996. Toward a knowledge-based theory of the firm. ***Strategic Management Journal,*** 17: 109–122.

Guimerà, R., Uzzi, B., Spiro, J., & Nunes Amaral, L. A. 2005. Team assembly mechanisms determine collaboration network structure and team performance. ***Science,*** 308: 697–702.

Gulati, R., Lavie, D., & Singh, H. 2009. The nature of partnering experience and the gains from alliances. ***Strategic Management Journal,*** 30: 1213–1233.

Gulati, R., Lawrence, P., & Puranam, P. 2005. Adaptation in vertical relationships: Beyond incentive conflict. ***Strategic Management Journal,*** 26: 415–440.

Heath, C., & Staudenmayer, N. 2000. Coordination neglect: How lay theories of organizing complicate coordination in organizations. In R. I. Sutton & B. M. Staw (Eds.), ***Research in organizational behavior,*** vol. 22: 153–191. Greenwich, CT: JAI.

Henderson, R., & Cockburn, I. 1996. Scale, scope and spillovers: The determinants of research productivity in drug discovery. ***RAND Journal of Economics,*** 27: 32–59.

Hoang, H., & Rothaermel, F. 2005. The effect of general and partner-specific alliance experience on joint R&D project performance. ***Academy of Management Journal,*** 48: 332–345.

Hoetker, G. 2005. How much you know vs. how well I know you: Selecting a supplier for a technically innovative component. ***Strategic Management Journal,*** 26: 75–96.

Hoetker, G., & Mellewigt, T. 2009. Choice and performance of governance mechanisms: Matching alliance governance to asset type. ***Strategic Management Journal,*** 30: 1025–1044.

Holmstrom, B. & Milgrom, P. 1994. The firm as an incentive system. ***American Economic Review,*** 84: 972–991.

Huber, G. P., & Lewis, K. 2010. Cross-understanding: Implications for group cognition and performance. ***Academy of Management Review,*** 35: 6–26.

Jaffe, A., & Lerner, J. 2004. ***Innovation and its discontents: How our broken patent system is endangering innovation and its progress, and what to do about it.*** Princeton, NJ: Princeton University Press.

Jain, S., & George, G. 2007. Technology transfer offices as institutional entrepreneurs: The case of Wisconsin Alumni Research Foundation and human embryonic stem cells. ***Industrial and Corporate Change,*** 16: 535–567.

Jain, S., George, G., & Maltarich, M. 2009. Academics or entrepreneurs? Investigating role identity modification of university scientists involved in commercialization activity. ***Research Policy,*** 38: 922–935.

Jensen, R., & Thursby, M. 2001. Proofs and prototypes for sale: The licensing of university inventions. ***American Economic Review,*** 91: 240–259.

Jones, B. F. 2009. The burden of knowledge and the "death of the renaissance man": Is innovation getting harder? ***Review of Economic Studies,*** 76: 283–317.

Kaplan, S., Murray, F., & Henderson, R. 2003. Discontinuities and senior management: Assessing the role of recognition in pharmaceutical firm response to biotechnology. ***Industrial and Corporate Change,*** 12: 185–233.

Kapoor, R., & Lim, K. 2007. The impact of acquisitions on the productivity of inventors at semiconductor firms: A synthesis of knowledge-based and incentive-based perspectives. ***Academy of Management Journal,*** 50: 1133–1155.

Katila, R., & Ahuja, G. 2002. Something old, something new: A longitudinal study of search behavior and new product introduction. ***Academy of Management Journal,*** 45: 1183–1194.

Kleinbaum, D., & Klein, M. 2012. ***Survival analysis a self learning text.*** New York: Springer Science and Media.

Klevorick, A. K., Levin, R. C., Nelson, R. R., & Winter, S. G. 1995. On the sources and significance of interindustry differences in technological opportunities. ***Research Policy,*** 24: 185–205.

Klimoski, R., & Mohammed, S. 1994. Team mental model: Construct or metaphor? ***Journal of Management,*** 20: 403–437.

Knez, M., & Camerer, C. 1994. Creating expectational assets in the laboratory: Coordination in "weakest-link" games. ***Strategic Management Journal,*** 15: 101–119.

Knorr-Cetina, K. 1999. ***Epistemic cultures: How the sciences make knowledge.*** Cambridge, MA: Harvard University Press.

Kogut, B., & Zander, U. 1992. Knowledge of the firm, combinative capabilities, and the replication of technology. ***Organization Science,*** 3: 383–397.

Kogut, B., & Zander, U. 1996. What firms do? Coordination, identity and learning. ***Organization Science,*** 7: 502–518.

Kotha, R., & George, G. 2012. Friends, family, or fools: Entrepreneur experience and its implications for equity distribution and resource mobilization. ***Journal of Business Venturing,*** 27: 525–543.

Kotha, R., Zheng, Y., & George, G. 2011. Entry into new niches: The effects of firm age and the expansion of technological capabilities on innovative output and impact. ***Strategic Management Journal,*** 32: 1011–1024.

Lane, P. J., & Lubatkin, M. H. 1998. Relative absorptive capacity and interorganizational learning. ***Strategic Management Journal,*** 19: 461–477.

Latour, B. 1986. ***Laboratory life: The construction of scientific facts.*** Princeton, NJ: Princeton University Press.

Lawrence, P. R., & Lorsch, J. W. 1967. ***Organization and environment: Managing differentiation and integration.*** Boston: Harvard University Press.

Lewis, K., Belliveau, M., Herndon, B., & Keller, J. 2007. Group cognition, membership change, and performance: Investigating the benefits and detriments of collective knowledge. ***Organization Behavior and Human Decision Processes,*** 103: 159–178.

Lewis, K., Lange, D., & Gillis, L. 2005. Transactive memory systems, learning, and learning transfer. ***Organization Science,*** 16: 581.

Leydesdorff, L., & Rafols, I. 2009. A global map of science based on the ISI subject categories. ***Journal of the American Society for Information Science and Technology,*** 60: 348–362.

Liang, D. W., Moreland, R., & Argote, L. 1995. Group versus individual training and group performance: The mediating role of transactive memory. ***Personality and Social Psychology Bulletin,*** 21: 384–393.

Lockett, A., Siegel, D., Wright, M., & Ensley, M. 2005. The creation of university spin-off firms at public research institutions: Managerial and policy implications. ***Research Policy,*** 34: 981–993.

Makri, M., Hitt, M. A, Lane, P. J. 2010. Complementary technologies, knowledge relatedness, and invention outcomes in high technology mergers and acquisitions. ***Strategic Management Journal,*** 31: 602–628.

March, J. G. & Simon, H. A. 1958. ***Organizations.*** New York: Wiley.

Mathieu, J. E., Heffner, T. S., Goodwin, G. F., Salas, E., & Cannon-Bowers, J. A. 2000. The influence of shared mental models on team process and performance. ***Journal of Applied Psychology,*** 85: 273–283.

Mohammed, S., & Dumville, B. C. 2001. Team mental models in a team knowledge framework: Expanding theory and measurement across disciplinary boundaries. ***Journal of Organization Behavior,*** 22: 89–106.

Monteverde, K. 1995. Technical dialog as an incentive for vertical integration in the semi-conductor industry. ***Management Science,*** 41: 1624–1638.

Mowery, D. C., Nelson, R. R., Sampat, B. N., & Ziedonis, A. A. 2004. ***Ivory tower and industrial innovation: University-industry technology transfer before and after the Bayh-Dole Act.*** Palo Alto, CA: Stanford University Press.

Mowery, D., & Rosenberg, N. 1998. ***Paths to innovation.*** Cambridge, UK: Cambridge University Press.

Nerkar, A., & Shane, S. 2007. Determinants of invention commercialization: An empirical examination of academically sourced inventions. ***Strategic Management Journal*** 28: 1155–1166.

Owen-Smith, J., & Powell, W. 2003. The expanding role of university patenting in the life-sciences: Assessing the importance of experience and connectivity. ***Research Policy,*** 32: 1695–1711.

Paruchuri, S. 2010. Intraorganizational networks, interorganizational networks, and the impact of central inventors: A longitudinal study of pharmaceutical firms. ***Organization Science,*** 21: 63–80.

Phelps, C. C. 2010. A longitudinal study of the influence of alliance network structure and composition on firm exploratory innovation. ***Academy of Management Journal,*** 53: 890–913.

Postrel, S. 2009. Multitasking teams with variable complementarity: Challenges for capability management. ***Academy of Management Review,*** 34: 273–296.

Puranam, P., Raveendran, M., & Knudsen, T. 2012. Organization design: The epistemic interdependence perspective. ***Academy of Management Review,*** 37: 419–440.

Puranam, P., & Srikanth, K. 2007. What they know vs. what they do: How acquirers leverage technology acquisitions. ***Strategic Management Journal,*** 28: 805–825.

Rafols, I., Porter, A. L., & Leydesdorff, L. 2010. Science overlay maps: A new tool for research policy and library management. ***Journal of the American Society for Information Science and Technology,*** 61: 1871–1887.

Rosenkopf, L., & Almeida, P. 2003. Overcoming local search through alliances and mobility. ***Management Science,*** 49: 751–766.

Rosenkopf, L., & Nerkar, A. 2001. Beyond local search: Boundary spanning, exploration and impact in the optical-disk industry. ***Strategic Management Journal,*** 22: 287–306.

Schilling, M., & Phelps, C. 2007. Interfirm collaboration networks: The impact of large-scale network structure on firm innovation performance. ***Management Science,*** 53: 1113–1126.

Schumpeter, J. A. 1934. ***The theory of economic development.*** New York: Springer.

Shane, S. 2000. Prior knowledge and the discovery of entrepreneurial opportunities. ***Organization Science,*** 11: 448–469.

Shane, S. 2002. Selling university technology: Patterns from MIT. ***Management Science,*** 48: 122–137.

Shane, S. 2012. Delivering on the promise of entrepreneurship as a field of research. ***Academy of Management Review,*** 37: 10–20.

Siegel, D., Waldman, D., Atwater, L., & Link, A. 2003. Commercial knowledge transfers from universities to firms: Improving the effectiveness of university-industry collaboration. ***Journal of High Technology Management Research,*** 14: 111–133.

Singh, J., & Fleming, L. 2010. Lone inventors as sources of breakthroughs: Myth or reality? ***Management Science,*** 56: 41–56.

Srikanth, K., & Puranam, P. 2011. Integrating distributed work: Comparing task design, communication and tacit coordination mechanisms. ***Strategic Management Journal,*** 32: 849–875.

Thursby, J. G., & Thursby, M. C. 2002. Who is selling the ivory tower? Sources of growth in university licensing. ***Management Science,*** 48: 90–104.

Tzabbar, D. 2009. When does scientist recruitment affect technology reposition? ***Academy of Management Journal,*** 52: 873–896.

Utterback, J. M. 1994. ***Mastering the dynamics of innovation.*** Boston: Harvard Business School Press.

Van Knippenberg, D., & Schippers, M. C. 2007. Work group diversity. In M. I. Posner & M. K. Rothbart (Eds.), ***Annual review of psychology,*** vol. 58: 515–541. Palo Alto, CA: Annual Reviews.

Venkataraman, S., Sarasvathy, S. D., Dew, N., & Forster, W. R. 2012. Reflections on the 2010 AMR decade award: Whither the promise? Moving forward with entrepreneurship as a science of the artificial. ***Academy of Management Review,*** 37: 21–33.

Vural, O., Dahlander, L., & George, G. 2013. Collaborative benefits and coordination costs: Learning and capability development in science. ***Strategic Entrepreneurship Journal,*** 7: In press.

Weitzman, M. L. 1998. Recombinant growth. ***Quarterly Journal of Economics,*** 113: 331–360.

Williamson, O. 1991. Comparative economic organization: The analysis of discrete structural alternatives. ***Administrative Science Quarterly,*** 36: 269–296.

Wuchty, S., Jones, B. F., & Uzzi, B. 2007. The increasing dominance of teams in production of knowledge. ***Science,*** 316: 1036–1039.

Zahra, S. A., & George, G. 2002. Absorptive capacity: A review, reconceptualization and extension. ***Academy of Management Review,*** 27: 185–203.

Ziedonis, A. A. 2007. Real options in technology licensing. ***Management Science,*** 53: 1618–1633.

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