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WHEN DO STRATEGIC ALLIANCES INHIBIT INNOVATION BY FIRMS? EVIDENCE FROM PATENT POOLS IN THE GLOBAL OPTICAL DISC INDUSTRY

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Research and development (R&D) consortia are specialized strategic alliances that shape the direction and scope of firm innovation activities. Little research exists on the performance consequences of participating in R&D consortia. We study the effect of patent pools, a unique form of R&D consortia, on firm performance in innovation. While prior research on alliances generally implies that patent pools enhance firm innovation, our study finds the opposite. Analyzing data on systemic innovation in the global optical disc industry, we find that patent pool formation substantially and significantly decreases both the quantity and quality of patents subsequently generated by licensors and licensees relative to the patenting activity of nonparticipants. Our empirical findings suggest that patent pools actually inhibit, rather than enhance, systemic innovation by participating firms. Copyright © 2011 John Wiley & Sons, Ltd.

INTRODUCTION

In recent years, strategic management scholars have increased their examination of the role that patents and other forms of intellectual property (IP) protection plays with respect to firm performance (Reitzig and Puranam, 2009; Somaya, 2003; Ziedonis, 2004). While this research sheds light on an important aspect of what is now called the IP strategy of firms, the impact of research and development (R&D) consortia on innovation remains relatively unexplored. Specifically, little research exists on the phenomena of patent pools and their effect on firm performance. 'A 'patent pool' is an agreement between two or more patent owners to license one or more of their patents to one another or third parties' (Clark *et al*., 2000: 4). At its most fundamental level, a patent pool represents a formal knowledge sharing arrangement that aggregates IP rights among multiple entities for the purpose of developing and commercializing new technology-based products. This contractual relationship requires explicit approval from regulatory authorities over anticompetitive concerns and constitutes a legally recognized R&D consortium, which is a specialized form of strategic alliance. Patent pools are composed of two types of *participant* firms: *licensors* and *licensees. Licensors* are firms that own the essential patents, which are the core intellectual assets of the patent pool. *Licensees* are firms that purchase the right to use these patents in the design of various products. *Nonparticipants* are firms within the same industry that are not part of the patent pool.

Until recently, patent pools were a rare occurrence and typically failed to obtain regulatory approval because of concerns about active collusion among licensors. Of the 24 patent pools

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examined by U.S. courts from 1902 to 2001, only nine pools were legally approved; in each of the other 15 cases, the pool was deemed illegal and rejected as a result of 'competitive hazards identified by the courts' (Gilbert, 2001 : 4). While patent pools are infrequent, we believe they are important from both a strategic and an economic perspective. Patent pools may act as catalysts for the creation of significant new tradable markets for technology worldwide (Arora, Fosfuri, and Gambardella, 2001), and the perceived economic benefits of these markets have made governments increasingly willing to sanction their formation (De Laat, 1999).

During the span of the last 100 years, the establishment of U.S. government-authorized patent pools has facilitated the development of a few, but major, global industries (Carlson, 1999). These industries include aircraft manufacturing, terrestrial radio and television broadcasting, wireless communications, optical discs (Digital Versatile Discs, or DVDs) (Merges, 2001), and more recently, radio frequency identification (RFID) and selected areas of biotechnology. Despite the critical role they have played in the emergence and growth of these knowledge-intensive industries, R&D consortia, in general, and patent pools, in particular, remain underexplored phenomena within the realm of strategy research (for a notable exception, see the studies by Sakakibara [1997; 2001; 2002] and Aldrich and Sasaki [1995a; 1995b]).

Few empirical studies have been conducted on the question of how a firm's participation in an R&D consortium, such as a patent pool, impacts the firm's subsequent patenting activities (Lampe and Moser, 2009). Specifically, the literature has not directly addressed the unique nature of patent pools, which may influence the direction of incentives for future innovation for participating firms differently from that of nonparticipants (Heller and Eisenberg, 1998). In this study, we explore the degree to which R&D consortia have a positive or negative effect on both the *quality* and *quantity* of innovation by firms in an industry, and we examine empirically the following two main research questions:

(1) *Does the formation of patent pools enhance or inhibit firm-level innovation?*
(2) *Are the effects on innovation the same for licensor and licensee firms?*

From an economic perspective, governing authorities allow patent pools ultimately to benefit consumers by reducing transaction costs for licensees while providing financial incentives for licensors to continue to commercialize and invent new technologies. Prior streams of research have examined the process of patent pool formation (Shapiro, 2000; 2001) and the optimal design of such pools (Merges, 2001; Lerner and Tirole, 2004; Lerner, Strojwas, and Tirole, 2007). However, the central focus of these research streams has been on the economic antecedents rather than the innovation consequences of different licensing and royalty schemes. A related set of studies has explored the process of technology evolution (Rosenkopf and Nerkar, 1999; 2001) and autonomous versus systemic innovation (De Laat, 1999; Teece, 1986; Chesbrough and Teece, 2002) in high-tech industries in which patent pools have emerged. Some innovations are autonomous, meaning that they can be pursued independently of other innovations, while others are systemic, meaning that their benefits can only be realized in conjunction with complementary innovations (Teece, 1986). These findings suggest that, given the highly collaborative nature of such R&D alliances, patent pools are typically formed in industries in which systemic innovation is more prevalent than autonomous innovation.

Earlier work stems from the concept that strategic alliances typically provide expanded access beyond firm boundaries to resources and knowledge (Dyer and Singh, 1998), which may be potential sources of competitive advantage for alliance participants (Oliver, 1997; Gulati, Nohria, and Zaheer, 2000). In this context, R&D consortia are a means for firms to share complementary knowledge assets in order to pursue technological advances and improve innovation at the firm level and overall competitiveness at the industry level (Sakakibara, 2001; 2002). Previous research streams generally conclude that alliances help firms achieve superior performance, albeit under specific conditions (Dutta and Weiss, 1997; Mowery, Oxley, and Silverman, 1996; 1998). Alliances are fundamentally 'access relationships' and serve as 'both pathways for the exchange of resources and signals that convey social status and recognition' (Stuart, 2000: 791). Both direct and indirect network ties among firms have a positive effect on innovation (Ahuja, 2000). Interfirm alliance networks enable firms to gain access to valuable technologies that may increase the chances of firm survival in environments with sustained radical change (Gay and Dousset, 2005). While, on the whole, these studies suggest that alliances have a positive effect on innovation and overall firm performance, the empirical evidence for this effect is far from conclusive. For example, in some industries, such as semiconductor manufacturing, many innovations developed internally have higher cooperative competencies and higher success rates than those developed through alliances (Sivadas and Dwyer, 2000). Furthermore, in some countries, such as Japan, firms 'do not perceive R&D consortia to be critical to the establishment of their competitive position' (Sakakibara, 1997: 447). In addition, R&D consortia are likely to have a stronger positive impact on innovation when they are focused on more basic, rather than more applied, research initiatives (Sakakibara and Branstetter, 2003). More recent studies further indicate that 'alliance organizational form likely influences partner ability and incentives to share information, which affects performance' (Sampson, 2007: 364).

In this study, we develop a theoretical framework with testable hypotheses for examining the question of how patent pools, as a form of R&D consortia, impact innovation. We assemble a historical dataset spanning a period of 30 years (1976 to 2006) of patenting activity by participants in three patent pools within the global optical disc industry. Counter to the predictions of prior studies, we find that patent pool formation leads to substantial and significant *decreases* in both the *quantity* and *quality* of patents subsequently generated by licensors *and* licensees. Our findings suggest that *patent pools actually inhibit, rather than enhance, systemic innovation at the firm level*. We explore the deeper implications of these findings on firm-level R&D alliance and innovation strategy. We also highlight potential contributions, address possible limitations, and outline proposed directions for further research. Patent pools may be much more commonplace in the future. Strategy researchers, policy makers, regulators, and managers may all benefit from a careful understanding of both the intended and unintended consequences of patent pool formation, which are empirically examined in this study.

THEORETICAL FRAMEWORK

The phenomena of interest for us are the innovation related consequences of patent pool formation. In this section, we develop a theoretical framework based on the literature on the economics of IP and antitrust law. We first briefly describe the critical role that incentives play for encouraging the pursuit of innovation by competing firms. We then examine the motivation for firms to collaborate through R&D consortia, in general, and patent pools, in particular, and how this motivation helps firms overcome some of the limitations of patents and strategically enhance their innovation activities. Finally, based on this description, we explore how the formation of a patent pool in an industry affects the incentives for patenting[1] by firms within that industry. We generate testable hypotheses that reflect the potential impact of these innovation incentives on the subsequent quantity and quality of patents produced by licensor and licensee firms relative to the patenting activity of nonparticipants in a patent pool.

Incentives for the pursuit of innovation

Strategy research has considered the pursuit of supranormal rents or profits to be a fundamental objective of firms (Amit and Schoemaker, 1993). By definition, achieving supranormal profits or rents involves managing firm resources and making strategic decisions that decrease costs and/or increase revenues (McGrath *et al*., 1996). In perfectly competitive environments, absent strong IP regimes, firms have difficulty sustaining competitive advantage even if they are innovative (Liebeskind, 1996). Patents and strong IP rights are a primary means for firms to simultaneously reduce possible competition and increase potential profits through the process of innovation (Mazzoleni and Nelson, 1998). Patents are an exclusionary form of government granted monopoly rights (Lerner, 2002). From the perspective of the resource-based view of the firm, patents are implicitly valuable and rare; to the extent to which they are also inimitable and non-substitutable, patents are significantly related to firm profitability and new product introductions (Markman, Espina, and Phan, 2004). Patents may enable firms to earn

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[1] Note that, throughout this study, we use the terms 'innovation' and 'patenting' interchangeably.

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entrepreneurial (Schumpeterian) rents (Amit and Schoemaker, 1993; Baumol, 1996) and generate excess returns from their inventions for the time that the patent protection is in effect and enforced by the grantor (Helpman, 1993).

As Kitch (1977: 266) explains, 'The patent is a reward that enables the inventor to capture the returns from his investment in the invention, returns that would otherwise (absent secrecy) be subject to appropriation by others.' Empirical studies suggest that firms in many nonmanufacturing industries prefer to rely on patent protection rather than the use of trade secrets, and in some major industrial sectors, such as chemicals and pharmaceuticals, over 80 percent of the patentable inventions are eventually patented by the inventors (Mansfield, 1986; Levin *et al*., 1987). Thus, patents appear to provide meaningful economic incentives for firms to engage in R&D. Furthermore, for firms that lack the complementary knowledge assets required to fully commercialize technologies on their own, stronger patent protection increases the propensity to license out patented technologies to other firms (Arora and Ceccagnoli, 2006).

A firm's managerial logic for determining whether to act as a licensor involves weighing the 'revenue effect' against the 'rent dissipation effect' when licensing out (Arora and Fosfuri, 2003: 278; Fosfuri, 2006). Normally, firms that find this tradeoff unattractive will choose to take alternative actions to enhance revenue (through higher unit pricing) and reduce profit dissipation (via exclusivity in licensing uses) or produce an integrated product themselves (Motohashi, 2008). However, in many industries that involve systemic innovations, the potential to engage in licensing and similar alternative actions is severely limited by the holdup problem caused by fragmented IP rights (Arora, 1997). Participation in an R&D consortium such as a patent pool represents an economically attractive choice for both licensors and licensees. Although profit motives are extremely important, firms may also patent for reasons that 'extend beyond directly profiting from a patented innovation through either its commercialization or licensing. In addition to the prevention of copying, the most prominent motives for patenting include the prevention of rivals from patenting related inventions (i.e., 'patent blocking'), the use of patents in negotiations and the prevention of suits' (Cohen, Nelson, and Walsh, 2000: 1).

Motivations for firm participation in R&D consortia and patent pools

Generalized forms of R&D consortia, such as research joint ventures (RJVs), and specialized forms, such as patent pools, enable firms to address issues related to the aforementioned use of patents in deliberate strategies for blocking, negotiating, and litigating IP rights. To understand why, note that patents, although useful to inventors, are only an imperfect mechanism for protecting IP rights (Takalo, 1998). This is because in most cases imitation is costly but not prohibitively expensive, and competitors are often able to 'invent around' (Chang, 1995: 34; Gallini, 1992: 52) the technologies represented by a patent and reverse engineer a substitute (Gallini, 1992). In fact, the longer the period of time for which patent protection is granted, the greater the incentive for rivals to attempt to bypass or circumvent the patent through their own inventions (Scotchmer, 1996; Samuelson and Scotchmer, 2002).

Patents only partially help to resolve Arrow's (1962) information paradox by enabling parties engaged in a technology licensing transaction to assess the potential value and usefulness of the knowledge asset that a patent represents without risking the unauthorized appropriation of the asset itself (Dasgupta and David, 1994; Jaffe and Trajtenberg, 2002). Patents do not always prevent unintended knowledge spillovers to competitors (Hall, Jaffe, and Trajtenberg, 2005), and 'knowledge once produced has the attributes of a *public good*; the use of information by one party does not exclude simultaneous use by others at no further cost' (Grossman and Shapiro, 1986: 317–318, italics in original). R&D consortia such as RJVs offer a means for reducing the previously described problem of appropriability (Arrow, 1984) by enabling participating firms to share research costs and research outcomes (Grossman and Shapiro, 1986; Gilbert and Tom, 2001). However, because of anticompetitive concerns, RJVs and patent pools among firms with demonstrable market power typically require formal approval from government regulators (Dunford, 1987).[2]

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[2] Dunford (1987) provides several examples of active collusion by patent pool participants, including the deliberate suppression of radio-tuning technology by electronics firms (see *United States v. General Instrument Corp., 1953*), the intentional prevention of the spread of pollution control-technology by carmakers (see *United States v. Automobile Manufacturers Association,*

It is important to note that patent pools differ from RJVs in the three critical ways described below. First, RJVs tend to be organized to *jointly and collaboratively conduct basic research* in a new technological area. In contrast, patent pools are typically formed *after basic research has already been independently and competitively conducted* by multiple firms in a new technological area and each of these firms already owns one or more patents that are critical for commercializing the new technology. Second, RJVs and patent pools encounter different levels of regulatory scrutiny. Unlike RJVs, where the stage of research is typically early and exploratory and the outcome is highly uncertain, patent pools are usually formed when the stage of development is close to commercialization, and the market value of the technology is much more clearly ascertainable. Thus, regulators are concerned about the possible adverse effects of patent pools, especially for consumer welfare. Third, RJVs and patent pools differ in terms of the selection mechanism for participation by firms. In RJVs, the prospective partner firms submit their plans to the regulatory authorities for approval. In patent pools, this process is much more extensive as a result of the anticompetitive concerns mentioned earlier. For example, in the United States, the Department of Justice (DOJ) requires that all of the essential patents included in a pool must, by law, be evaluated by an independent examiner (Gilbert, 2004) who selects or rejects patents for inclusion based solely on their scientific and commercial importance. To alleviate anticompetitive concerns,[3] the government-mandated objective of the examiner is to ensure to the extent possible that the patents that represent complementary knowledge assets are included in the pool, while those patents that represent potential substitute knowledge assets are excluded from the pool (Merges, 2001). Furthermore, the essential patents selected for inclusion in the pool by the examiner must be made available to any and all prospective licensees on a reasonable and nondiscriminatory basis after the pool is formed (Shapiro, 2000).

HYPOTHESES DEVELOPMENT

How patent pool formation affects innovation incentives

Building on the preceding description of R&D consortia and the literature in transaction cost economics and property rights, patent pools are asset bundling mechanisms that facilitate the development of viable markets for technology within an industry. Markets for technology expand the feasible strategy space for firms (Arora, Fosfuri, and Gambardella, 2001) by giving firms the added strategic flexibility to buy and sell technologies on a stand-alone basis as intermediate products. For example, in a market with strong protection of IP rights, a firm may choose to act as (1) a licensee (technology buyer), purchasing an inbound license for technology from external suppliers instead of pursuing internal development; or as (2) a licensor (technology seller), offering outbound licensing of its own proprietary technology to other firms. Patent pools thus support the formation of an active market for technology within an industry because licensors have a legally approved means to bundle knowledge assets together for sale to prospective licensees, who in turn have the legal right to inbound license the assets on a reasonable and nondiscriminatory basis (Grindley and Teece, 1997; Arora, 1997). Previous studies have focused on cost minimization as the primary motivator for patent pool participation (Merges, 2001; Lerner and Tirole, 2004; Lerner, Strojwas, and Tirole, 2007). Government policy on patent pools assumes that firms acting to minimize their costs will ultimately benefit the consumer. Firms may also seek to minimize the costs of future legal action (patent infringement lawsuits) as a risk management strategy (Lampe and Moser, 2009).

Before the formation of a patent pool, all firms in the industry have strong incentives to increase both the quantity and quality of the patents they generate. The rationale for this is that the greater the *quantity* of patents (measured in terms of the number of patents related to the pool's technology areas) and/or the *quality* of the patents (measured in terms of the citation count of patents

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1969) and the secret discouragement of further research in fuel-cell technology by aerospace companies (see *United States v. United Aircraft Corp., 1973*).

[3] Note that becoming a licensor is not purely an endogenous choice of a patenting firm. The firm must first decide to submit its patents for evaluation, after which the independent examiner must determine the 'essentiality' of these patents. According to Shapiro (2000), essential patents are patents that are truly *complementary* knowledge assets, and their inclusion in the pool is pro-competitive; *substitute* or rival patents are excluded from the pool to avoid anticompetitive effects such as elevated licensing fees.

related to the pool's technology areas) a prospective licensor owns prior to patent pool formation, the more likely that one or more of its patents will be selected by the examiner for inclusion in the pool. Therefore, a firm that seeks to become a licensor in a possible future patent pool will increase its chances of actually becoming a licensor if it produces more patents and/or better quality patents in the technology areas related to the pool. This competition-induced incentive to increase the quantity and quality of patenting activity is described as 'portfolio racing' by Hall and Ziedonis (2001). Their findings suggest that the 'racing' effect for firms is driven 'not only by the (observable) scale of their investments but also by the (unobservable) likelihood of ex post licensing negotiations with outside patent owners' (Ziedonis, 2004: 805). Thus, owning more patents and/or higher quality patents strengthens a firm's bargaining position (Reitzig, 2003; Ziedonis, 2003) for negotiating its share of any royalties resulting from licensing out the technologies represented by a patent pool (Ziedonis, 2004; Barton, 1996; 2001). The empirically observed 'portfolio racing' effect (Hall and Ziedonis, 2001) reflects a strong incentive for all firms in industries with fragmented ownership of IP rights to increase the quantity and quality of their patenting activity prior to patent pool formation.

After the formation of a patent pool, a market for technology is established; the previously fragmented IP rights are conveniently packaged into one-stop shopping (Gilbert and Shapiro, 1990) for licensees; and the innovation incentives for all of the firms in the industry change substantially (Farrell and Katz, 2000). To understand the nature of this directional shift in incentives, first consider the impact that patent pool formation has on classifying firms by their respective strategies. By definition, the establishment of a patent pool within an industry acts as a sorting mechanism that classifies all firms into one of three groups: licensors, licensees, and nonparticipants. Licensors and licensees are both participants in the pool but have a different legal status regarding patent ownership and the permissible level of information sharing among firms. Licensors are firms that submitted patents for review by the independent examiner and had at least one patent deemed 'essential' and selected for inclusion in the pool. Licensors also have the right, but not the obligation, to utilize technology from the patent pool in exchange for payment. Licensees are firms that can only obtain the technology represented by the pool through the legal licensing and payment of fees associated with the use of the essential patents in the production of products for which the pool was intended. Nonparticipants are firms that either (1) decided not be a part of the pool in any form for strategic reasons, such as the ownership of substitute technologies (or the lack of a sufficient quantity or quality of complementary patents); or (2) had one or more of their patents evaluated by the examiner but were rejected because the patents were deemed nonessential to the pool.

Hypothesized impact of patent pool formation on licensors

After a patent pool is formed, we expect the quantity and quality of related patents generated by licensors to decrease relative to those of nonparticipants for three main reasons: (1) an increase in the expected revenues for licensors from licensing out essential patents through the pool; (2) a decrease in expected litigation costs resulting from fewer lawsuits from fellow licensors; and (3) expected enforcement by pool administrators of independent licensing and grant back provisions for all patent pool participants. All three of these reasons are consistent with different aspects of profit-maximizing behavior by licensors and are described in more detail below.

Increase in expected revenues

For licensors, after patent pool formation, the primary motivation is to ensure the continued state of cooperation among licensor firms, which reduces overall competition and enables previously fragmented IP to be collectively bundled for sale to any and all prospective licensees. Further attempts by individual licensors to increase the quantity and quality of patenting activity related to the pool may bring uncertain benefits to all licensors and threaten to disrupt the stability of their collaborative arrangement.

As Grossman and Shapiro (1986: 333) explain, 'Certainly, a consortium with widespread industry membership that makes its research results available freely to its members stimulates the diffusion of information. The only real danger in such cases is that the consortium's incentive to devote resources to research is diminished by the prospect of immediate competition among the members using the new technology.' From a licensor's perspective, not pursuing follow-on innovation based on the pool enables all licensors to maximize revenues by not introducing unwanted competition for the remaining period of time during which the patent pool is active.

Decrease in expected costs

For licensors, after patent pool formation, a major source of cost reduction is the lower likelihood of litigation initiated by fellow licensors for the infringement of essential patents (Gilbert, 2004; Lampe and Moser, 2009). Having carefully obtained approval from regulatory authorities to form the pool in the first place, and then having reached a complex multilateral revenue sharing agreement among all licensors, individual licensor firms are unlikely to engage in subsequent patenting activity related to the pool that might prompt a revaluation of the validity of the pool's essential patents (Chang, 1995). Further reductions in costs are also possible as a consequence of economies of scope in litigations (Choi, 2003); the licensors of a patent pool are collectively in a strong position to defend themselves against potential patent infringement suits made by non-licensors (licensees and nonparticipants). The threat of a countersuit by licensors as a group may in some cases serve as an effective deterrent to patent infringement suits initiated by non-licensors. From the viewpoint of a licensor, not continuing to generate innovation based on the pool may dramatically reduce the risks and costs associated with patent litigation and thereby enhance profits during the existence of the pool.

Expected enforcement of independent licensing and grant back provisions

Two common provisions of patent pools—independent licensing and grant backs—are driven by antitrust policy in a manner that may attenuate the innovation incentives for licensors post-patent pool formation. *Independent licensing* refers to the right of licensors to outbound license their own essential patents directly to firms that wish to apply these knowledge assets to potential uses outside of the intended scope of the patent pool (Carlson, 1999). *Grant backs* refer to the obligation under which licensees of patent pools agree to transfer ('grant back') to the pool any improvements to the patent that the licensees make (Lerner and Tirole, 2004). Independent licensing and grant backs are both commonly observed in patent pools that are pools of complements, while pools of substitutes are unlikely to allow either provision (Lerner *et al.*, 2007). Pools of complements allow independent licensing, providing an incentive to licensors to develop new applications of the technologies represented by the pool, but unrelated to its original purpose (Lerner and Tirole, 2007). Thus, independent licensing enables licensors to increase revenues by making their technologies available for innovations outside of the scope of the pool. For licensors, innovation outside the pool is potentially more attractive than innovation within the pool because the revenue generated from independent licensing of the essential patent is not subject to the revenue sharing arrangements of the pool.

In addition, grant backs further reduce the incentives for licensors to innovate within the pool because grant back rules require that follow-on innovations related to the intended scope of the pool be transferred to the pool at no additional cost (Lerner *et al.*, 2007). Grant backs, therefore, are a strong disincentive for licensors to innovate within the pool because they effectively render a firm's subsequent pool-related innovation into a public good available to all pool participants (Choi, 2003). Regulators are eager to mandate both independent licensing and grant backs because of their perceived pro-competitive benefits: independent licensing reduces uncertainty about the complementarity of the essential patents in the pool, while grant backs reduce uncertainty about the future rights of licensors to use subsequent technical advances arising from these same essential patents. Based on the preceding description of the changes in innovation incentives (related to expected revenues, costs, and licensing mechanisms), which occur after a patent pool is formed, we propose the following hypotheses for licensors in comparison to nonparticipants in the pool:

> *Hypothesis 1a: Patent pool formation leads to a* decrease *in the* quantity *of related patents generated by* licensors, *relative to that for nonparticipants in the pool.*

> *Hypothesis 1b: Patent pool formation leads to a* decrease *in the* quality *of related patents generated by* licensors, *relative to that for nonparticipants in the pool.*

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Hypothesized impact of patent pool formation on licensees

For three critical reasons, we expect a decline in the quantity and quality of related patents generated by licensees relative to those of nonparticipants after a patent pool is formed. We expect this decline to result from: (1) a decrease in the expected costs of buying key technologies through inbound licensing from the patent pool; (2) an increase in the expected information asymmetry between licensors and licensees; and (3) expected enforcement of grant back provisions for licensees. As with the rationale for licensors presented earlier, all three of these reasons are consistent with the profit-maximizing behavior by licensees; they are described in more detail below.

Decrease in expected costs

For licensees, profit maximization involves the cost-minimizing decision to 'buy,' rather than 'make' the technology available through the patent pool (Teece, 1986; Walker and Weber, 1987). Inbound licensing of the technology is especially attractive to licensees, as the government-approved legal framework of the patent pool mandates reasonable and nondiscriminatory licensing terms. In addition, licensing the technology from the patent pool reduces the likelihood of engaging in costly litigation with licensors, as long as the licensees comply with the terms and conditions of the licensing agreement. Thus, after patent pool formation, we would expect the quantity and quality of related patents generated by licensees to decrease.

Increase in expected information asymmetry

After patent pool formation, licensors appear to obtain an informational advantage relative to licensees. Recall that licensors are able to engage in a breadth and depth of technological information sharing as part of the process of formation of the patent pool that would normally constitute a form of collusion (Shapiro, 2000; Gilbert, 2004), without the special legal exemption status conferred by regulatory authorities. In contrast, licensees have access only to a limited subset of technical information related to the knowledge assets represented by the patents in the pool. This unequal information access impairs the ability of licensees to innovate further within the scope of the patent pool. Note that nonparticipants may not have the same information disadvantage as licensees, especially if their nonparticipation in the pool is a strategic choice driven by their ownership of substitute or rival technologies that independent examiners would attempt to exclude from the pool even if offered for evaluation. In addition, for licensees that attempted originally to join the patent pool as licensors, pool formation can trigger a possible decertification effect that impacts the market perception of the respective technology base of each licensee (Albert *et al*., 1991; Harhoff *et al*., 1999). Any subsequent innovation by a licensee is perceived as less scientifically and commercially valuable than the corresponding innovations generated by licensors. Overall, this information asymmetry (coupled with the decertification effect for some licensees) is a further disincentive for licensees to innovate within the technological bounds of the patent pool.

Expected enforcement of grant back provisions

Grant backs negatively impact the incentives for licensees to produce innovations related to the patent pool because grant back provisions require that licensees of patent pools agree to transfer at no cost back to the pool any technical improvements to the patent that the licensees make (Lerner and Tirole, 2004). Furthermore, the specification of a grant back clause for the licensees of a patent pool signals that the future value of the patent pool will not be adversely affected by potential litigation from licensees on blocking patents, as licensees are precluded from withholding from licensors technical advances based on essential patents from the pool.[4] Hence, both the quantity and quality of the licensee patents related to the technological areas of the patent pool are expected to decrease after the pool is formed. Based on the preceding theoretical framework, hypotheses for the expected impact of patent pool formation on the subsequent quantity and quality of innovation generated by licensees are presented below.

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[4] Independent licensing by definition only applies to licensors, who are the owners of the essential patents in the pool. Most licensors typically act as licensees as well to obtain full access to the technologies represented by the patent pool. Grant backs apply to all patent pool participants (licensors and licensees) in order to prevent the holdup problem in which firms intentionally avoid offering a patent for evaluation by the examiner prior to pool formation in hopes of blocking the subsequent utility of the pool after formation (Lerner *et al*., 2007).

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> *Hypothesis 2a: Patent pool formation leads to a* decrease *in the* quantity *of related patents generated by* licensees, *relative to that for nonparticipants in the pool.*

> *Hypothesis 2b: Patent pool formation leads to a* decrease *in the* quality *of related patents generated by* licensees, *relative to that for nonparticipants in the pool.*

METHODS AND SAMPLE

Industry context

Our theory and hypotheses presented earlier are connected with the performance effects of R&D consortia, specifically patent pools. In the history of the legal system in the United States, few industries exist in which patent pools have been granted regulatory approval (Gilbert, 2004). A notable exception, and the subject of this empirical study, is the modern optical disc industry, a market segment within the global consumer electronics sector, in which multiple legally approved patent pools have been formed by competing firms for the intended benefit of consumers. The optical disc industry is unique in that it comprises a diverse and active population of firms that engage in high levels of patenting activity and are at the forefront of designing and implementing patent pools. During a two-year period, from June 1997 to June 1999, the DOJ approved the formation of three patent pools closely related to systemic innovation in digital video technology.[5] These events marked a fundamental shift in U.S. government policy and became a precedent for approving similar patent pools in other industries and other countries.

In June 1997, the Moving Picture Experts Group 2 (MPEG-2) pool became the first patent pool to receive approval. Part of a larger family of MPEG standards used for coding audio-visual information, the MPEG-2 pool represents the most widely implemented consumer electronics standard in the world.[6] The main benefit of the MPEG-2 standard is the efficient coding of images, video, and audio into a compressed digital format that enables storage in a small file size with high quality. In December 1998, the DOJ approved the second patent pool, the DVD3C (Digital Versatile Disc 3 Companies) pool, followed in June 1999 by the approval of the third patent pool, the DVD6C (Digital Versatile Disc 6 Companies) pool. Both the DVD3C and DVD6C bundle essential patents required for the manufacture of DVD players and discs.

In order to legally produce a DVD player without infringing on established IP rights, a firm must license technology embodied in the essential patents of all three patent pools. Correspondingly, the licensor members of the patent pool are legally bound to license out this technology on a reasonable and nondiscriminatory basis to prospective licensees, upon payment of licensing fees by licensees. Thus, a DVD player and disc may be conceptualized as a systemic innovation that is based on critical technology components or fundamental building blocks from all three patent pools, MPEG-2, DVD3C, and DVD6C. Table 1 presents a summary of the key characteristics of each patent pool within the optical disc industry.

Sample construction

Our theory suggests that patent pool formation has a differential impact on the quantity and quality of innovation subsequent to the formation of the pool. To test our hypotheses, we first collected all of the patents that were contributed to the patent pool by the various licensors, using data provided by pool administrators. Following prior studies that use patents to study innovation (Jaffe and Trajtenberg, 2002; Lahiri, 2010), we concentrated only on the patents granted in the United States, although the patent pools also have patents that were granted under the IP regimes of other nations. We first identified the patents that were part of the three pools mentioned above—MPEG-2, DVD3C, and DVD6C. A total of 874 patents were contributed to the three standards by 18 licensors. In the second step, we collected the unique three-digit U.S. Patent and Trademark Office (USPTO) technology classes in which each of these 874

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[5] See the following DOJ Business Review Letters for additional details on each patent pool:
MPEG-2: http://www.usdoj.gov/atr/public/busreview/215742.htm
DVD3C: http://www.usdoj.gov/atr/public/busreview/2121.htm
DVD6C: http://www.usdoj.gov/atr/public/busreview/2121.htm

[6] For more information on MPEG-2, see http://www.chiariglione.org/mpeg/standards/mpeg-2/mpeg-2.htm

Table 1. Overview of optical disc industry patent pools

Patent pool	MPEG-2	DVD3C	DVD6C
Date approved by US DOJ	26 June 1997	16 December 1998	10 June 1999
Licensors	**Original (9):** Columbia University, Fujitsu, General Instrument, Lucent Technologies, Matsushita, Mitsubishi, Philips, Scientific-Atlanta, Sony **Subsequent (1):** Thomson Licensing	**Original (3):** Philips, Sony, and Pioneer **Subsequent (2):** LG, Hewlett-Packard	**Original (6):** Hitachi, Matsushita, Mitsubishi, Time Warner, Toshiba, Victor Company of Japan **Subsequent (4):** IBM (patents later purchased by Mitsubishi), Samsung, Sanyo, Sharp
No. of licensors	10	5	10
No. of licensees	1455	551	467
No. of (US) essential patents	18	263	608
Technology area	Video and image compression and decompression technology	DVD technology for players and discs for read-only memory (ROM) and video	DVD technology for players and discs for read-only memory (ROM) and video
Player royalties	$4.00 per encoder or decoder unit before 2002, dropping to $2.50 per unit afterward	3.5% of net selling price of each unit sold, subject to a minimum of $7.00/unit before 2000, dropping to $5.00/unit afterward	4% of net selling price of each unit sold, subject to a minimum of $4.00/unit
Disc royalties	$0.03 for each video event or packaged medium (disc)	$0.05/disc	$0.075/disc
Independent licensing	Yes, 'The Portfolio license states that each Portfolio patent is also available for licensing independently from the MPEG-2 Licensor that had licensed it to MPEG LA and that the license may not convey rights to all Essential Patents.'	Yes, 'All three Licensors, however, remain free to license their 'essential' patents independently of the Portfolio Licenses, including for uses outside the DVD-ROM and DVD-Video formats.'	Yes, 'The Authorization Agreement preserves the Licensors' right to license their 'essential' patents independently for any application.'
Grantbacks imposed	Yes, 'The license's grantback provision requires the licensee to grant any of the Licensors and other Portfolio licensees a nonexclusive worldwide license or sublicense, on fair and reasonable terms and conditions, on any Essential Patent that it has the right to license or sublicense.'	Yes, 'The licensees' grant back obligation: Portfolio licensees must grant the Licensors and fellow licensees a license, 'on reasonable, nondiscriminatory conditions comparable to those set forth herein,' on any patents they own or control that are 'essential' to either disc or player manufacture in conformity with the Standard Specifications.'	Yes, 'The licensee's only grantback obligation covers any 'essential,' patents it may own or control during the term of the license. Each licensee agrees to grant non-exclusive licenses on such patents, on 'fair, reasonable and non-discriminatory terms,' to the Licensors, their affiliates, and all other licensees of the pool.'
Administrator	MPEG LA (independent licensing administrator)	Philips	DVD6C LA (independent licensing administrator)

Sources: US DOJ Antitrust Division Business Review Letters, and Administrators of the respective patent pools.

Table 2. USPTO technology classes for population of patents representing optical disc technology

Rank	Description	Technology class	Number of patents	Risk set of granted patents (1976–2006)
1	Dynamic information storage or retrieval	369	398	13,815
2	Television signal processing for dynamic recording or reproducing	386	256	2587
3	Error detection correction and fault detection/recovery	714	24	5777
4	Television	348	21	12,270
5	Cryptography	380	20	3607
6	Pulse or digital communications	375	18	14,858
7	Facsimile and static presentation processing	358	14	22,332
8	Image analysis	382	13	13,434
9	Error fault detection techniques	371	10	5027
10	Coded data generation or conversion	341	9	0
			783	93,707

patents were categorized to arrive at the defining set of technology classifications of optical disc related technologies. Each patent can fall in multiple classes with the first class being the original technology class while the others are known as secondary. Based on these technology classes, we find that the top 10 technology classes account for the bulk of the 874 patents, as shown in Table 2. We define this as the population of patents that potentially are part of the optical disc technology sector.

Next, we collected all of the patents granted in these top 10 technology classes from the years 1976 through 2006 from the patent dataset provided on the National Bureau of Economic Research (NBER) Web site[7] (Hall, Jaffe, and Trajtenberg, 2001). Our intention in collecting the data over this time frame was to develop control variables using the patenting activities of the firms in the initial years. This dataset was further refined by focusing on patent-generating firms of significance: we eliminated any assignee that did not have at least 10 patents in the optical disc area in the 30 years spanning 1976 to 2006. This led to a total of 679 companies that were actively patenting in the area of optical disc technology, for a total of 17,654 observations. Of these 679 patenting companies, 18 were licensors, 56 were licensees, and the remaining 605 were nonparticipants in the patent pool but did patent in the optical disc area. This represents the dataset that we analyzed to test our hypotheses on patent pools and their effects on innovation. The dataset is a panel dataset in which the unit of the analysis is the firm, while the level of analysis is the firm year. We track three types of firms in our data: (1) 18 licensors—firms that contributed to the patent pool; (2) 56 licensees—firms that patented in the optical disc area and that licensed patents from the pool; and (3) 605 nonparticipants—a control group of firms that patented in the optical disc area but were neither licensors nor licensees.

It is important to note that there are 18 unique firms among the 25 total licensors participating in the three patent pools. As a result primarily of the DOJ's anticompetitive concerns, none of the licensors are members of both the DVD3C and DVD6C pools; the overlapping membership is completely accounted for by firms that are members of MPEG-2 *and* DVD3C or MPEG-2 *and* DVD6C. While 1,866 unique licensees of technology derive from the three patent pools, most of these licensees do not have any patents in the area of optical disc technology, and only 56 licensees have more than 10 patents in the 30-year study timeframe. We exclude these 1,810 firms from our analysis, as these firms do not patent in the optical disc area, and their inclusion in the sample may bias our results. Many of these firms are assemblers and manufacturers of DVD players and recorders that have never filed any patents at all.

We track 679 firms in our dataset. The period from 1976 to 1981 was used to construct the presample control variables, as 1982 marks the year in which the compact disc format was approved for the first time by the entertainment industry.

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[7] http://www.nber.org/patents/

The year 1982 also marks the earliest possible grant date for a patent that could be submitted for evaluation by pool examiners. Earlier patents would have already expired before the formation of the first pool in 1998 and would, therefore, not be eligible for selection as essential patents. This serves as a starting point for our analysis. We track the patenting activities of these 679 firms every year from 1982 to 2006. All firms that participate in the patent pool are classified as either licensors or licensees. Nonparticipants are the remaining firms that continued to patent in the industry, but were not part of the pool. Our theory suggests that those firms that became part of the pool had incentives to be less productive and less innovative (in terms of patent quantity and quality) after pool formation. This group of nonparticipant firms that continued to patent but were not part of the patent pools serves as a control group. In essence, our model is analogous to a hazard model, in which we know the performance of each firm and whether it belongs to the control group or risk set for each year of the dataset (see Hoetker and Agarwal, 2007, for a similar approach). We test the impact of patent pool formation on the quality and quantity of innovation for different types of firms: licensors, licensees, and nonparticipants (the control group in this study).

Dependent variables

By means of our previously described data collection procedures, we captured the following dependent variables, which we incorporated into our analyses. Consistent with prior research that uses patents to represent innovation (Jaffe and Trajtenberg, 2002; Jaffe, Trajtenberg, and Henderson, 1993), we measure performance as follows:

Quantity of innovation is the number of related patents generated by a given firm in a given year. Related patents are those patents that have a technology classification corresponding to one of the 10 classes representing optical disc technology as shown in Table 2.

Quality of innovation is the citation count of related patents (Trajtenberg, 1990) generated by a given firm from its grant date to the end of our study period in 2006. Again, related patents are those patents that have a technology classification corresponding to one of the 10 classes representing optical disc technology, as shown in Table 2.

Independent variables

Through our previously described data collection procedures, we captured the following independent variables, which we incorporated into our analyses. (Note that only licensors and licensees are considered participants in or members of the patent pool. Firms that are neither licensors nor licensees are considered nonparticipants in the patent pool.)

Our first variable of interest is the formation of the patent pools in the optical disc area. Three patent pools were formed between the years 1997 to 1999 (as reported in Table 1). We used the year 1998 as the critical year to differentiate the time period before and after patent pool formation. *Pool formation* is a binary variable that takes a value of 0 for all observations before 1998 and a value of 1 for all observations after 1998.

Licensor is a binary variable that takes a value of 1 when a firm was a contributor of essential patents to one or more of the three optical disc industry patent pools, and 0 when it is a noncontributor of such patents. This variable takes a value of 1 or 0 independent of patent pool formation; that is, firms are tagged as 'licensors' in the time period before 1998.

Licensee is a binary variable that takes a value of 1 when a firm is engaged in the inbound licensing of essential patents from one or more of the three optical disc industry patent pools, and 0 when it is not engaged in such inbound licensing. Similarly to the *licensor* variable, the *licensee* variable takes a value of 1 or 0 independent of the formation of the patent pool. The omitted class is the group of firms classified as nonparticipants, that is, those that did not contribute essential patents to the pool and did not license from the pool.

Control variables

In order to determine the post-formation effect of patent pool participation on licensor and licensee patenting activity, we first obtain estimates of the historical average quantity and quality of innovation in a pre-sampling phase, encompassing the years 1976 to 1981. As mentioned earlier, we used the 1976 to 1981 period because the first optical disc standard was announced in 1982. Also, few patents granted before 1981 would be relevant for the patent pool, as most pre-1981 patents would have either expired or be close to expiration. Use of the pre-sample period enables us to estimate a baseline count for the quantity and quality of innovation for comparative purposes. We also need to control for the quantity and quality of innovation in other technology areas (technology classes other than those shown in Table 2).

We control for the pre-sample innovation performance of the firms in our dataset by developing a measure that represents the *historical average quality of innovation* in the optical disc area. This is measured as the citations received by the firm to its patents filed in the years 1976 to 1981 divided by the number of patents it filed in the same period. We also include a control for the size and the diversified technology base of the firms in our dataset. The construct *innovation in other areas* is measured as the number of patents filed by the firm in areas unrelated to optical disc technology.

In addition to these controls based on the pre-sample, we also include three firm-level time-varying controls that may influence the quantity and quality of patenting done by firms in the optical disc area. Our panel dataset uses the application year to measure the quantity of patenting. However, the time required for patents to be granted may vary across firms. This can influence both the citations received by the portfolio of patents held by firms as well as the actual quantity of patenting. To control for this effect, we include a measure *average time to grant,* which is the average time taken for patents in that filing year to be granted. Another factor that could influence the quantity and quality of patenting is the maturity of the technology. While our study does represent the entire population of patents in the optical disc technology, differences could exist across firms in the technologies for which they choose to file patents every year. To account for these differences, we include a measure called *technological maturity.* This is computed as the average backward citation lag of the patent portfolio of a firm in a particular filing year. In other words, we expect that firms that build on older knowledge will find it difficult to file patents. Also, such patents may have less impact in the future. Finally, firms may choose to specialize in a few or all of the technology classes (mentioned in Table 2) that represent the optical disc area. This may influence the quantity and quality of innovations they produce every year. To control for this effect, we include a variable, *technological focus,* which measures the number of optical disc technology classes in which a firm files patents during a particular year.

Model

Because our dependent variables—*quantity of innovation* and *quality of innovation*—are both nonnegative, integer count variables with overdispersion, the use of negative binomial models is indicated (Hausman, Hall, and Griliches, 1984; Hilbe, 2007). To address the problem of repeated observations on the same firm, we estimate the negative binomial model using the GEE (generalized estimating equations) approach (Zeger and Liang, 1986). Further, the inclusion of the pre-sample measure of performance helps us account for the problem of unobserved heterogeneity. Finally, we use robust standard errors clustered on firms, which ensure that potential misspecifications of the variance function are also accounted for. We then conduct two sets of negative binomial regression analyses of *quantity of innovation* and *quality of innovation* respectively on *pool formation, licensor*, and *licensee* with the appropriate controls.[8]

RESULTS

In Table 3, we summarize the descriptive statistics of the variables of interest. As shown in Table 3, the average firm in the dataset produced 5.78 patents per year, while being cited 8.38 times per year for these patents by year 2006. We also summarize the results of the correlation matrix of the variables of interest. As expected, size measured as *innovation in other areas* is strongly associated with the *quantity of innovation* (patents in the optical disc area). All of the other correlation coefficients are in the expected direction.

Figure 1 shows the *quantity of innovation* of the three different types of firms—licensors, licensees, and nonparticipants—that we track in our sample. The nonparticipants are tracked on the secondary axis. As shown in Figure 1, all of the firms filed patents at an increasing rate in the optical disc area until the late 1990s, at which point in time the

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[8] We conduct the analysis by using the GENMOD procedure in the statistical software SAS®. Its offset option enabled us to control for the differing citation times.

Table 3. Sample statistics and correlation matrix

	Variable	Mean	SD	Min	Max	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1)	Quality of innovation	8.38	14.75	0	564	1.00									
(2)	Quantity of innovation	5.78	22.26	0	748	0.00	1.00								
(3)	Pool formation	0.38	0.49	0	1	−0.01	−0.06	1.00							
(4)	Licensor	0.03	0.16	0	1	−0.01	0.39	0.01	1.00						
(5)	Licensee	0.11	0.32	0	1	−0.04	0.22	0.01	0.33	1.00					
(6)	Historical average quality of innovation in optical disc area	2.11	7.55	0	107	0.10	−0.02	0.01	0.00	−0.02	1.00				
(7)	Innovation in other areas	42.85	142.35	0	3721	−0.01	0.68	−0.08	0.39	0.21	0.01	1.00			
(8)	Average time to grant	0.76	1.08	0	6.62	0.00	0.52	−0.24	0.35	0.26	0.00	0.55	1.00		
(9)	Technological maturity	2.10	2.75	0	19	−0.02	0.12	−0.11	0.08	0.09	0.02	0.17	0.32	1.00	
(10)	Technological focus	0.97	1.51	0	9	0.00	0.52	−0.22	0.38	0.28	0.01	0.59	0.92	0.30	1.00

$N = 17{,}654$.
All correlation coefficients above |0.2| are significant at $p < 0.05$.

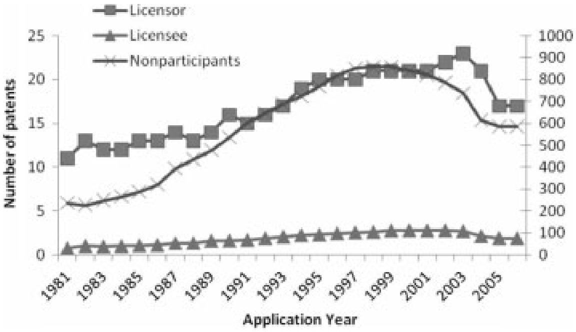

Figure 1. Quantity of innovation

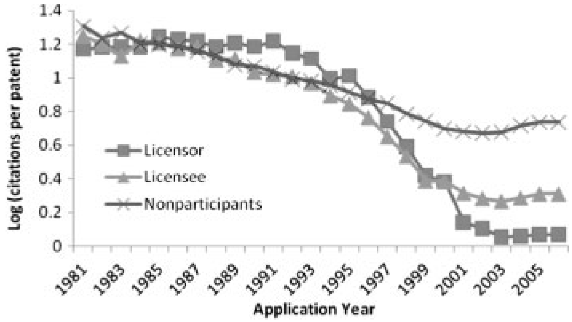

Figure 2. Quality of innovation

licensees and nonparticipants exhibit a downward shift. This observed increase in patenting activity is consistent with the 'patent race' theory suggested in prior research (Barton, 1996; Hall and Ziedonis, 2001; Reitzig, 2003), whereby all firms race to patent more and strengthen their potential bargaining positions until the patent pool is formed. The licensors also exhibit a decrease in the quantity of patenting, but only around 2001. In Figure 2, we show the effect of patent pool formation on the *quality of innovation* generated by the same set of firms. The variable plotted on the y axis is the natural log of the citations received by the patents of a firm every year. There is a steady drop in *quality of innovation* for all three types of firms from the mid-1990s onward. The quality of patenting does not appear to differ much early on in the evolution of the industry. However, differences begin to emerge across the three types of firms in the mid-1990s and are stabilized by the year 2000. More specifically, the quality of the patents filed by licensors and licensees are much lower than those filed by nonparticipants. The trends reflected in the figures are consistent with the theoretical

Table 4. Negative binomial regression of quantity of innovation on patent pool formation

Variable	Model 1	Model 2	Model 3	Model 4	Model 5
Constant	0.7398***	0.7536***	0.6731***	0.6804***	0.6876***
	(0.0443)	(0.0689)	(0.0611)	(0.0610)	(0.0612)
Pool formation		−0.0193	−0.0206	−0.0117	0.0148
		(0.0565)	(0.0576)	(0.0572)	(0.0574)
Licensor			0.8338***	0.9201***	0.8765***
			(0.1517)	(0.1703)	(0.1600)
Licensee			0.4045***	0.4012***	0.4246***
			(0.1029)	(0.1033)	(0.1167)
Licensor × pool formation				−0.4103**	
				(0.1929)	
Licensee × pool formation					−0.3514***
					(0.1405)
Historical average quality of innovation in optical disc area	−0.0048	−0.0048	−0.0036	−0.0036	−0.0034
	(0.0047)	(0.0048)	(0.0051)	(0.0051)	(0.0051)
Innovation in other areas	0.0014***	0.0014***	0.0015***	0.0015***	0.0015***
	(0.0002)	(0.0002)	(0.0001)	(0.0001)	(0.0001)
Average time to grant	0.3395***	0.3388***	0.3369***	0.3362***	0.336***
	(0.0465)	(0.0482)	(0.0467)	(0.0466)	(0.0469)
Technological maturity	−0.013***	−0.013***	−0.0111***	−0.0109***	−0.0109***
	(0.0044)	(0.0044)	(0.0042)	(0.0041)	(0.0040)
Technological focus	0.0363	0.036	0.0166	0.0145	0.0122
	(0.0300)	(0.0301)	(0.0245)	(0.0245)	(0.0249)
Fixed year Effects	Sig.	Sig.	Sig.	Sig.	Sig.
Quasi likelihood (QIC)	−185,089	−183,782	−202,936	−204,125	−204,951
Improvement in fit		−1306.5	19154.4	1188.02	2014.35
Comparison model	1	1	2	3	3

N = 17,654, $^{***}p < 0.001$, $^{**}p < 0.05$, $^{*}p < 0.1$, values in parentheses are robust standard errors clustered on firms. All tests for main effects are one-tailed, while those for controls are two tailed.

framework and hypotheses that we presented earlier in this study.

In Table 4 below, we summarize the results of the negative binomial regression of *quantity of innovation* on our independent variables of interest: *pool formation, licensor*, and *licensee*.

In Model 1, the coefficient of the control variable for *innovation in other areas* is positive and significant, while the coefficient on the control variable for the *historical average quality of innovation* in the optical disc area is negative, though not significant. This suggests that the amount of innovation in the pre-sample years is positively associated with innovation in later years, though high-performing firms in the pre-sample years may exhibit a decrease in quantity during the sampled years. The control variables *average time to grant* and *technological maturity* are significant but have opposite effects on q*uantity of innovation.* Increases in the *average time to grant* lead to more patenting activity, while greater t*echnological maturity* reduces the *quantity of innovation*. The control variable *technological focus* does not have a significant effect on *quantity of innovation.*

In Model 2, the addition of the independent variable *pool formation,* leads to a negative but not significant coefficient. Thus, the formation of the patent pool appears to have a negative effect on all innovation, but this effect is not statistically significant. In Model 3, we include the variables *licensor* and *licensee*. The parameter estimates for both of these variables are positive and significant, suggesting that licensors and licensees generally are in more of a race to patent than nonparticipants. Overall, licensors have an 83 percent higher patenting rate than nonparticipants, while licensees have a 40 percent higher patenting rate than nonparticipants. Model 4 tests Hypothesis 1a (H1a) by including the variable that represents the interaction effect of *pool formation* and *licensor*. The coefficient of the interaction term is negative and significant, suggesting that the formation of the

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pool more negatively impacts the *quantity of innovation* of licensors than it does the *quantity of innovation* of nonparticipants. As a result of the formation of the patent pool, the patenting activity of licensors decreases by 55 percent over that of nonparticipants. Model 5 tests Hypothesis 2a (H2a) by including the variable that represents the interaction effect of *pool formation* and *licensee*. The coefficient of the interaction term is negative and significant, suggesting that the formation of the pool more negatively impacts the *quantity of innovation* of licensees than it does the *quantity of innovation* of nonparticipants. As a result of the formation of the patent pool, the patenting activity of licensees decreases by 60 percent over that of nonparticipants. Table 4 also reports the fitness criteria, that is, quasi-likelihood for each model. As shown in the last row of Table 4, all of the models except for Model 2 are better than the null model that comprises only control variables.

In Table 5, we summarize the results of the negative binomial regression of *quality of innovation* on *pool formation, licensor and licensee.*

In Model 6, the coefficient of the control variable *innovation in other areas* is negative but not significant, while the coefficient of the control variable *historical average quality of innovation* is positive and significant. Of the other three firm-level time-varying controls, only *technological maturity* is significant and negatively associated with *quality of innovation*. Model 7 adds the independent variable *pool formation* and results in a negative and significant coefficient. This suggests that pool formation leads to a consistent industrywide drop in the *quality of innovation* (33% as compared to the period before pool formation). In Model 8, the addition of the independent variables *licensor* and *licensee* suggests that the difference in the quality of patents generated by licensors, licensees, and nonparticipants is significant though not in the same direction. Specifically, the *quality of innovation* of licensors is consistently better (18%) than that of nonparticipants, although the *quality of innovation* of licensees is lower than that of nonparticipants (17%).

In Models 9 and 10, the addition of variables that represent the interaction effect between *licensor* and *pool formation* and *licensee* and *pool formation* enables us to test Hypotheses 2a and 2b (H2a and H2b), respectively. The coefficient of the interaction term *licensor* × *pool formation* is negative and significant, suggesting that the formation of the pool negatively impacts the *quality of innovation* of licensors more than it does the *quality of innovation* of nonparticipants. The observed decrease in the *quality of innovation* resulting from the formation of the patent pool is five times greater for licensors than for nonparticipants. From Model 10, we observe that the coefficient of the interaction term is negative and significant, suggesting that the formation of the pool more negatively impacts licensees than it does nonparticipants. As is similar to the case with licensors, the decrease in the *quality of innovation* resulting from the formation of the patent pool is four times greater for licensees than for nonparticipants. Table 5 also reports the fitness criteria, that is, the quasi-likelihood, for each model. As shown in the last row of Table 5, all of the models are better than the null model (Model 6). Based on the preceding analyses, we find that patent pool formation leads to a significant decrease in *both the quantity and quality of related patents generated by both licensors and licensees as compared to those generated by nonparticipants in the pool.*

DISCUSSION

The results obtained through the two sets of negative binomial regression analyses we conducted appear to strongly indicate that overall, patent pool formation actually inhibits, rather than enhances, systemic innovation. Our results support our hypotheses. In the global optical industry dataset examined, after the 1997–1999 period in which the formation of three patent pools was approved by regulatory authorities, the related patenting activities of both licensors and licensees appear to decrease significantly more than those of nonparticipants in terms of patent quantity and patent quality. We believe that the positive effects of alliance activity (from knowledge sharing) on innovation efforts generally observed in prior studies are not visible in the context of patent pools because of the incentive structure imposed on the members of the pool and the nonparticipants in the pool. Patent pools change the direction of the incentives for firms to continue innovation within the intended scope of the pool. Prior to patent pool

Table 5. Negative binomial regression of quality of innovation on patent pool formation

Variable	Model 6	Model 7	Model 8	Model 9	Model 10
Constant	1.6763***	1.9316***	1.9437***	1.9442***	1.9347***
	(0.0676)	(0.0771)	(0.0784)	(0.0783)	(0.0782)
Pool formation		−0.3349***	−0.3359***	−0.3241***	−0.7116***
		(0.0453)	(0.0451)	(0.0456)	(0.1088)
Licensor			0.1815*	0.2812**	0.2736**
			(0.1355)	(0.1360)	(0.1422)
Licensee			−0.1718**	−0.1665**	−0.1076*
			(0.0784)	(0.0787)	(0.0834)
Licensor × pool formation				−1.1888***	
				(0.0911)	
Licensee × pool formation					−0.2814***
					(0.0473)
Historical average quality of innovation in optical disc area	0.0187***	0.0187***	0.0184***	0.0185***	0.0186***
	(0.0040)	(0.0040)	(0.0040)	(0.0040)	(0.0040)
Innovation in other areas	−0.0001	−0.0001	−0.0001	−0.0001	−0.0001
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Average time to grant	−0.0156	−0.0296	−0.0295	−0.0286	−0.0273
	(0.0398)	(0.0409)	(0.0405)	(0.0405)	(0.0408)
Technological maturity	−0.0445***	−0.0477***	−0.0476***	−0.0466***	−0.0454***
	(0.0061)	(0.0061)	(0.0060)	(0.0059)	(0.0059)
Technological focus	0.0289	0.0269	0.0269	0.019	0.0171
	(0.0199)	(0.0202)	(0.0201)	(0.0201)	(0.0202)
Fixed year effects	Sig.	Sig.	Sig.	Sig.	Sig.
Quasi likelihood (QIC)	−224,922	−228,475	−231,732	−232,774	−234,928
Improvement in fit		3552	3257	1042	3196
Comparison model	6	6	7	8	8

N = 17,654, *** $p < 0.001$, ** $p < 0.05$, * $p < 0.1$, values in parentheses are robust standard errors clustered on firms. All tests for main effects are one-tailed, while those for controls are two tailed.

formation, all firms have strong incentives to innovate and the 'portfolio racing' (Hall and Ziedonis, 2001) effect is evident for all patenting firms in the industry. After patent pool formation, firms are classified as licensors, licensees, or nonparticipants, and the innovation incentives change for each of these groups. For licensors, patent pools increase the expected revenues from both outbound licensing of essential patents through the pool and independent licensing of the essential patents for applications outside of the pool. Patent pools also substantially reduce litigation costs for licensors. For licensees, patent pools decrease the costs of purchasing technology externally, but increase the information asymmetry between licensors and licensees to the advantage of licensors. For both licensors and licensees, patent pools impose grant back provisions that discourage further innovation within the intended scope of the pool, as any subsequent technical improvements to essential patents must be transferred to the pool without compensation. Overall, these changes, brought about by the formation of a patent pool, strongly shift the economic incentives for licensors and licensees away from further innovation related to the pool. Profit maximization implies that both licensors and licensees will dramatically reduce their innovation related to the pool after the pool is formed.

In addition to the theoretical basis for the innovation-inhibiting effects of patent pools explored in this study, other factors may contribute to changes in the patenting activity of licensors and licensees after a patent pool is formed. For example, two main organizational concerns related to knowledge sharing and learning typically reduce the potential value of the incentive to participate in a patent pool and may offer some insight into the observed behavior of licensors and licensees. The first concern comes from inside the licensor firm, where managers fear a loss of competitive advantage when critical IP assets are externally licensed to downstream companies. The prospect of losing competitive advantage may motivate licensors to explore other technological areas while reducing their exploitation of related technological areas (such as optical disc). Thus, we would observe a decrease in both related patent quantity and quality for licensors. The second concern comes from outside the licensor firm, where prospective licensees fear that licensors will act opportunistically when competing as producers of a final product in the same market as the licensee (Grindley and Teece, 1997). Opportunistic actions by licensors may, in fact, inhibit the ability of licensees to increase the quality of their related patents and may also account for the significant decrease in both the related patent quantity and quality for licensees.

CONCLUSIONS

The primary contribution of this paper is the study of a hitherto unexplored phenomenon in the context of strategic alliances and R&D consortia, that is, patent pools. Our findings reveal that not all R&D consortia are helpful in terms of increasing the quantity and quality of innovation for the firms participating in the consortia. A second potential contribution of this study to literature is a systematic test of the arguments associated with incentives to innovate, patent, and license. In another potential contribution to the broader alliance literature, this study supplies one of the few empirical examinations of the impact of R&D consortia on firm-level innovation. Finally, a related contribution is the construction of a historical dataset spanning 30 years of systemic innovation in an industry that serves as a benchmark for the design of patent pools and as a legal precedent for proposed pools in other industry contexts worldwide.

Implications

At the firm level, our findings suggest that innovation in upstream markets for research may be inhibited by the formation of patent pools. Although patent pools catalyze the creation of new markets for technology that may be strategically and economically important, this market creation may come at a substantial cost—namely, producing dramatic reductions in subsequent innovation by both licensors and licensees within the intended scope of the patent pool. Patent pools may actually freeze, rather than foster, ongoing investments in critical technology areas. A deeper question, beyond the scope of this initial study but important for policy makers to consider, is whether the effect of decreases in related patent quantity and quality for both licensors and licensees in any way results in unanticipated costs or benefits to end-user consumers. A further implication of our study is that in industries in which patent pools have formed, patent citation counts may not serve as a reliable indicator of the value of the technologies represented by the essential patents in the pools. In fact, somewhat surprisingly, essential patents appear to be cited less rather than more frequently after the patent pool is formed. This finding constitutes an interesting phenomenon, which may merit further investigation, as the formation of a patent pool is an unambiguous signal of the scientific and commercial value of the essential patents in the pool. Though we would expect essential patents to be cited more often, this outcome—at least in the optical disc industry—does not appear to occur.

Limitations and future directions for research

Our findings suggest that firm-level innovation in a systemic technology industry such as optical disc may be reduced after the formation of a patent pool. We include three patent pools that represent different components in the optical disc technology area. Future research might investigate the differential impacts of the patent pools across these components. Based on our results, we speculate that there could be a more subtle and nuanced change in performance. For instance, is there a difference in the patenting activities across various components of the technology? Would licensors ignore certain aspects of the optical disc technology to focus, and consequently improve, performance in areas that are considered critical? Our present study, while controlling for some of the above variables, does not explore these questions and leaves them for future research. Most firms would like to maximize potential for revenue by adding an increasing number of firm-owned patents to the pool, while competitors and the administrator of the pool would resist such attempts. Among the related questions that emerge are: What are the factors underlying selection of patents and firms into a pool? Does the patent portfolio lead to selection into a pool or does the status of a firm in the market lead to the inclusion of its patents in a pool?

One limitation of this study has to do with the length of the time period available for data gathering after patent pool formation. Our sample included approximately 20 years of data from the period before patent pool formation and approximately 10 years of data from the period after formation. Another limitation relates to focusing the analysis on a single industry, even though this industry represents one of the few with multiple contemporaneous patent pools. Additional limitations may arise from the imprecise ability of patents to adequately capture interfirm knowledge flows.

In addition to addressing these limitations, further inquiries could examine several areas of promise, as briefly described here. A proposed extension of the current study involves incorporating data from multiple patent pools related to standards-based multimedia and communications technologies, such as Bluetooth, OpenCable, G.729 audio data compression, H.264 video data compression, and 3G wireless communications. The envisioned study would facilitate comparisons of multiple systemic innovations, which are themselves increasingly converging and becoming integrated into consumer products, such as mobile phones, video gaming systems, and personal computers. Another direction for future research would be to explore the possible differential impact that different types of R&D consortia, such as technology alliances, standards bodies, joint ventures, and patent pools, have on different types of participating firms. An additional research opportunity might involve examining the end-user impact of changes in patent quality and quantity in terms of product-level changes in pricing and performance.

The unique nature of patent pools as facilitators of markets for technology is still relatively unexplored in theoretical and empirical terms. Patent pools may become an increasingly common occurrence in knowledge-intensive industries. To better assess this phenomenon, researchers, managers, regulators, and policy makers may all need a more complete framework and tools with which to understand and analyze the antecedents and consequences of patent pools.

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