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Collaborative Promotion of Technology Standards and the Impact on Innovation, Industry Structure, and Organizational Capabilities: Evidence from Modern Patent Pools

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Abstract

This study explores the impact of modern patent pools—inter-organizational collaborative arrangements for promoting the adoption of technology standards—on the rate of follow-on innovations based on pooled technologies, the vertical structure of associated industries, and organizational capabilities of non-collaborating firms. On one hand, the formation of modern pools can boost follow-on innovation by lowering the search, negotiation, and licensing costs associated with pooled standards. On the other hand, they may decrease the incentives to invest in follow-on innovations due to cannibalization risks and grant-back provisions. To the extent that modern pools succeed in establishing a dominant standard, their collaborative nature and their reliance on markets for technology can reduce technological uncertainty and appropriation hazards, hence triggering vertical disintegration in related industries. Moreover, by establishing a dominant standard, modern pools can effectively diminish the relative importance of integrative capabilities inside firms. Employing a combination of empirical strategies, I show that the formation of seven major modern patent pools has, on average, increased the rate of follow-on innovations based on the pooled standards by about 14%. Moreover, the results suggest that the establishment of modern pools can facilitate a shift towards vertical disintegration in associated industries where upstream technology-focused organizations would disproportionally contribute to the development of follow-on complementary technologies. The results also suggest that modern pools reduce the relative importance of integrative capabilities and provide a more advantageous position for specialized startups vis-à-vis diversifying entrants. I discuss the implications for literatures on organizational economics, organizational capabilities, business ecosystems, standards, and nascent industries.

Introduction

Technology standards are increasingly developed and promoted through collaboration between a large number of potentially competing market players (Chiao et al. 2007, Farrell and Simcoe 2012, Rysman and Simcoe 2008), leading to considerable fragmentation in their IP ownership where different parties hold patents over different components of a standard (Shapiro 2001). While a growing body of research has studied standard-setting organizations as collaborative platforms that allow firms to coordinate their actions during the development phase of standards with fragmented ownership (Besen and Farrell 1994, Chiao et al. 2007, Farrell and Simcoe 2012, Rysman and Simcoe 2008), far fewer studies have addressed collaborative arrangements that firms use to promote fragmented standards after development. Building on the organizational economics, organizational capabilities, and ecosystems literatures, I propose that collaborative promotion of technology standards not only can influence their adoption in follow-on innovations and products, but can also cause substantial changes in the structure of related industries and the relative importance of different firm capabilities.

The ownership fragmentation of a standard creates particular hurdles for any individual partial owner to promote the standard. The threat of free-riding by other owners can discourage each firm from investing in any promotional strategies. Moreover, any pricing, marketing, or networking tactics (Suarez 2005, Schilling 2002, Hill 1997, Soh 2010) would be rendered ineffective if not coordinated between all partial owners of the standard. The fragmented ownership can further lead to excessive searching, negotiation, and licensing costs associated with adopting the standard (Lemley and Shapiro 2007, Shapiro 2001). These issues together can result in underuse of fragmented standards in subsequent technologies and products, and they highlight the importance of collaborative organizational forms that could facilitate coordinated promotion of standards by all the partial owners (Merges 1999, Shapiro 2001). This study examines one such collaborative arrangement that has been increasingly used by firms to promote fragmented technology standards: modern patent pools.

A patent pool is an agreement between two or more parties to license their patents on a particular technology to one another and to third parties based on some fixed terms. A patent pool essentially acts as a one-stop shop for the pooled technology standard where those interested in using the standard can acquire a single license to all the patents included in the pool. Patent pools can be categorized into traditional and modern pools. Traditional patent pools in the United States date back to 1856 and were quite common until the end of World War II. They were not well regulated and many of them turned out to be shelters for collusive behavior among competing firms (Carlson 1999). Hence, many traditional pools were eventually deemed anti-competitive and dismantled under the stronger enforcement of antitrust laws (Carlson 1999). In 1995, the US Department of Justice (DOJ) and the US Federal Trade Commission (FTC) introduced new guidelines governing the pooling and licensing of intellectual property (IP) rights, which facilitated the formation of modern patent pools. The new guidelines require modern pooling agreements to include only essential and non-substitutable patents and promote both competition and innovation (US DOJ & FTC 2007). The first modern pool, the MPEG-2 pool, was subsequently formed in 1997, and the number of modern patent pools and their economic impact has been growing substantially since then (World Intellectual Property Organization 2011).

Modern patent pools are similar to other collaborative arrangements such as cross-licensing agreements and technology alliances in that they usually involve collaboration among competitors and complementors to facilitate access to particular technologies. However, patent pools usually involve a much larger number of firms. For example, a typical modern pool in my sample brings patents from more than 10 parties together. More importantly, whereas cross-licensing agreements grant each involved party access to agreed-upon IP rights owned by other involved parties, patent pools are especially formed to extend similar access to external, third parties as well. The price that third parties pay to access the pooled patents is also exactly the same as what pool members would need to pay. This outward-facing nature of modern pools and the larger number of firms that are usually involved in their formation mean that modern pools can potentially have a much larger impact on their external environment. Studying modern patent pools, hence, provides a unique opportunity to look beyond the impact of inter-organizational collaborations on the performance of collaborating parties and to instead investigate how large-scale collaborations among potentially competing firms can influence the broader evolution of technologies, industry structure, and other firms' innovation and capabilities.

Predicting the impact of modern pools on innovation is not theoretically straightforward.[1] In principle, there are several channels through which modern patent pools influence subsequent organizational choices to innovate based on pooled standards. On one hand, modern patent pools can lower the cost of access to the pooled standards by reducing the search, negotiation, and licensing costs associated with using them. Moreover, modern patent pools can build "bandwagon" momentum (Suarez and Utterback 1995) behind the pooled standards by showing commitment by the industry leaders forming the pools to their adoption. On the other hand, modern patent pools can potentially reduce the incentives to develop follow-on innovations due to regular grant-back provisions usually included in the licensing terms of pooled standards that require licensees to transfer the rights to any improvements to the standard back to the pool at a low cost (Joshi and Nerkar 2011). Also, the risk of cannibalizing the pooled standard can in principle discourage pool members and licensees from investing in follow-on generations of the standard (Joshi and Nerkar 2011). In the presence of these

[1] For an empirical assessment of the impact of traditional patent pools on innovation, see Lampe and Moser (2010, 2016)

offsetting effects, whether modern pools increase or decrease subsequent innovations remains as an empirical question.

While estimating the net effect of modern pools on innovation has important policy implications and provides strategic insights for pool owners on the effectiveness of patent pools as promotional instruments, it tells us little about their broader impact on industry structure and the strategic behavior of firms in response to the formation of these arrangements. To predict the impact of modern patent pools on industry structure and firms' boundary decisions, I draw on the recent set of studies that attempt to integrate the research in organizational economics, organizational capabilities, and business ecosystems and view them as complementary approaches to understand the firms' boundary decision making and industry evolution (Argyres and Zenger 2012, Qian et al. 2012, Jacobides and Winter 2005, Leiblein and Miller 2003, Madhok 2002). From an organizational economics point of view, patent pools can alter various transient transactional hazards associated with developing products and technologies based on a technology standard. By delineating the boundaries of a technology standard and creating convergence around it, modern patent pools reduce technological uncertainty with respect to using the pooled standards. At the same time, these arrangements can reduce appropriation hazards and litigation risks associated with using a pooled standard by providing a reliable platform supported by the IP system to acquire a single license to the various essential components necessary to comply with the standard. Furthermore, modern patent pools can facilitate the development of complementary technologies based on pooled standards by ensuring the successful integration of these complementary technologies with downstream products. From an ecosystem point of view (Adner and Kapoor 2010), modern patent pools can thus offset bottlenecks associated with accessing standard's essential components as well as those associated with a lack of complementary technologies. In all, by driving down the transaction costs, modern patent pools can trigger vertical disintegration within the industry value chain where technology-focused upstream firms would focus on developing complementary technologies and downstream firms would focus on manufacturing downstream applications based on the pooled standards (Argyres and Bigelow 2010, Arora et al. 2001, Williamson 1975, 1991).

The formation of modern pools also has important implications for the relative importance of integrative capabilities of firms. Whereas activity-specific capabilities determine the competency of firms in performing a particular activity, integrative capabilities relate to effective communication and coordination between different parts of a firm's internal value chain (Helfat and Campo-Rembado 2016, Chen et al. 2012, Helfat and Raubitschek 2000). Here I propose that the establishment of modern pools reduces the relative importance of integrative capabilities. At the core of a pooled technology standard are the rules that ensure inter- and intra-standard compatibility across standard components as well as between standard components and external complementary technologies. The establishment of pooled technology standards as intermediary integrative and coordinative platforms can substitute for the internalized integrative capabilities of firms. Prior research suggests that diversifying entrants generally have higher levels of integrative capabilities than startups do (Helfat and Campo-Rembado 2016, Chen et al. 2012). As modern patent pools substitute the need for integrative capabilities within firms with compatibility rules that ensure vertical and horizontal integration between the outputs of specialized entities, they erode the potential competitive advantage of diversifying entrants stemming from their integrative capabilities. Meanwhile, the extra cost of maintaining the integrative capabilities (or pursuing disintegration) gives additional advantage to startups that do not need to incur such costs. Therefore, I expect the entrance into upstream technology markets after the formation of modern pools to be largely dominated by startup entrants rather than diversifying ones.

Similarly, the formation of modern pools has further implications for the competitive advantage and positioning of incumbents with prior investments in technologies related to the pooled standards. The disintegration of the industries and the devaluation of integrative capabilities puts upstream specialized incumbents in a more advantageous position where they can use their prior stock of knowledge to develop the early set of complementary technologies based on the pooled standards and easily license them to downstream players in the market for technologies. In contrast, integrated firms are more likely to avoid competition with upstream specialized players and to instead use their manufacturing capabilities to focus on developing downstream products based on the standard.

I test these predictions using detailed data on seven major modern pools formed between 1997 and 2004. While this analysis does not allow me to observe the counterfactual—that is, what would have happened to subsequent innovations based on the pooled standard if these pools had not been formed in the first place—I use a series of matching and difference-in-difference empirical strategies to estimate the causal impact of modern pools on follow-on innovation and industry structure.

The findings reveal that the establishment of the seven modern patent pools I studied lead to an economically and statistically significant increase in follow-on innovations based on the pooled standards. Consistent with theoretical predictions, I also find that there has been a disproportionate increase in follow-on innovations by upstream technology-focused entities and a decrease in innovations by vertically integrated firms. I also find evidence that the increase in upstream entrance is largely dominated by startups rather than diversifying entrants. The results further suggest that, relative to upstream non-integrated incumbents, vertically integrated incumbents with prior investments in technologies related to a pooled standard are more likely to focus on downstream application development after the pool formation.

This study makes several notable contributions. First, it contributes to the literature on industry dynamics (Helfat and Campo-Rembado 2016, Argyres and Bigelow 2010, Jacobides 2005, Agarwal and Gort 1996, Williamson 1975) by illustrating how collaboration among competitors and complementors can result in endogenous disintegration of industries and shifts in the competitive positioning of firms along the value chain. Moreover, the results provide new insight into the intertwined relationship between transactional hazards and organizational capabilities (Argyres and Zenger 2012, Qian et al. 2012, Jacobides and Winter 2005, Leiblein and Miller 2003, Madhok 2002) and into the way in which collaborative arrangements such as modern pools can alter the relative importance of integrative capabilities and hence the competitive balance between diversifying entrants and startups as well as between integrated and specialized incumbents.

The study also contributes to the business ecosystem literature (Adner and Kapoor 2016 2010; Kapoor and Adner 2012) by highlighting how collaborative arrangements such as modern patent pools can address both component and complementary challenges and enlarge the total market size and the total value created through the industry chain. Further, the results highlight how modern patent pools and similar collaborative arrangements can be used as strategic levers to foster the development of nascent technologies, particularly during their incubation period, where technological uncertainty is high and firms face considerable transactional hazards (Moeen and Agarwal 2016). Finally, the findings inform the current debates around the impact of modern pools on innovation and in particular emphasize the importance of understanding the heterogeneous impact of these arrangements on different market players.

Fragmented Standards and Modern Patent Pools

A technology standard is, by definition, a set of rules that determine how various pieces of a particular technology should communicate with one another and with external technologies (Tassey 2000). Technology standards are increasingly developed through collaborative arrangements such as standard-setting organizations (David and Greenstein 1990, Rysman and Simcoe 2008). Because the development process is collaborative, various pieces of the standard are usually patented by different parties, leading to what is known as ownership fragmentation (Heller and Eisenberg 1998). Several theoretical and empirical works suggest that the ownership fragmentation of a technology standard can lead to under-adoption of the standard as a result of higher litigation risks, excessive royalty rates, and soaring transaction costs that potential adopters face (Lerner 1995, Heller and Eisenberg 1998, Lemley and Shapiro 2007, Murray and Stern 2007). Meanwhile, any pricing, marketing, or networking strategy by a partial IP owner to boost the adoption of the standard faces the threat of free-riding by other owners and would turn out to be fruitless in the absence of effective coordination with other parties.

These issues together require the partial owners to collaborate in order to promote the fragmented standard. A solution increasingly used by the partial owners of fragmented standards is to put related patents into a common pool and consolidate all the associated rights into a central entity (pool organizer) for the purpose of joint licensing (Merges 1999, Shapiro 2001). Patent pools are private arrangements between multiple parties to license their interdependent patents on a particular technology to one another and to third parties, usually on defined fixed terms.

Patent pools have a long history in the United States, dating back to the formation of the Sewing Machine Combination pool in 1856. However, these arrangements raised serious antitrust concerns (Carlson 1999, Gilbert 2004); and with the stronger enforcement of antitrust laws in the early

20th century, traditional pools were increasingly recognized as anti-competitive arrangements, and many of them were eventually dismantled by antitrust authorities (Gilbert 2004). No major pool arrangements were established after the end of World War II until the introduction of the MPEG-2 pool. On June 26, 1997, the DOJ sent a letter to MPEG LA LLC, approving its request to pool the patents "essential" to compliance with the MPEG-2 standard. The DOJ business review for the MPEG-2 pool also provided a template for modern pooling arrangements that would not violate antitrust laws.[2]

The major difference between modern pools and their traditional counterparts is that the former are only allowed to include essential and complementary (i.e., non-substitutable) patents. Modern pools are also required to provide their licenses to any party interested, with no competitive discrimination. The licensing terms and fee structure are the same for the pool owners and any third party who is interested in acquiring a license. These policies are intended to prevent, to the extent possible, opportunistic, anti-competitive behavior by pool members (Shapiro 2001). The availability of all the pooled patents to any interested third party through a single license is also a major difference between modern patent pools and other forms of major cross-licensing agreements signed between multiple parties. Whereas in the case of cross-licensing agreements, only the involved parties acquire access to one another's agreed-upon IP rights, in the case of modern patent pools, any party has the right to acquire a license to the pooled patents.

Since the formation of the MPEG-2 pool in 1997, modern patent pools have consistently increased in number, economic significance, and the extent of the technological fields in which they are implemented (World Intellectual Property Organization 2011). Furthermore, as technology standards evolve over time, the pools associated with them also gradually change and grow. For example, there were originally 27 patents included in the MPEG-2 pool in 1997; by the end of 2011 the pool included more than 1,000 patents from 27 different entities and was licensed to 1,518 different licensees.

[2] For an extended discussion on fragmented technologies, modern patent pools, the incentives of firms to form modern pools, and the anticompetitive concerns surrounding them, see Shapiro (2001) and Carlson (1999). Also, see the discussion section for various benefits that firms can gain from forming and joining modern pools.

Theory

In the following sections, first I develop the arguments on the impact of modern patent pools on follow-on innovation. Next, I put forth the theoretical predictions on how modern patent pools can cause shifts in the vertical structure of industries and firms' innovation strategy and competitive positioning contingent on their capabilities. The discussion on the impact of modern pools on firms' innovation strategy and competitive positioning provides further insight into the sources of change in follow-on innovations based on modern pools.

Impact of Modern Pools on Innovation

Modern patent pools are required to be both pro-competition and pro-innovation (US DOJ & FTC 2007). However, because serious concerns about traditional pools rested on their anti-competitive effects, most of the literature on modern pools has focused on their impact on competition and total welfare (Shapiro 2001, Gilbert 2004, Lerner and Tirole 2004). The general prediction of these theoretical studies is that modern pools should be pro-competitive and welfare-enhancing based on the premise that they do not include substitute or weak patents. These studies, however, only hint at whether and how patent pools promote or hinder follow-on innovation based on pooled standards.

More recently, though, scholars have begun to explore the impact of patent pools on innovation. Most of their studies have focused on traditional patent pools, reporting evidence that they had negative effects on innovation, largely because of their anti-competitive aspects (e.g., Lampe and Moser 2010, 2016). In fact, Lampe and Moser (2016) note that their sample is "biased towards pools that became subject to antitrust investigations" and that "most of the 20 pools [in their sample] appear to have formed as a mechanism to weaken competition in product markets and potentially in R&D." The few conceptual works focusing on modern patent pools mainly predict that they are likely to encourage follow-on innovation by lowering the costs of adopting the pooled standards (Merges 1999, Shapiro 2001).

There are indeed various channels through which modern patent pools can boost follow-on innovation based on pooled standards. First, the current governing policies of modern pools mandate that any potential licensee be able to acquire a license to all the patents included in a modern pool at a fair price and with few negotiation hassles. This ensures that no potential licensee will be excluded intentionally by the pool members from accessing and adopting the technology standard.

Second, having all the patents in a common pool and having a single pool organizer to deal with can address the double-marginalization issue that arises when each partial IP owner wants to maximize its own profit (Merges 1999, Shapiro 2001). Modern pools can hence reduce both the negotiation and the licensing costs of acquiring the necessary rights to all the patented pieces of a fragmented standard within the pool.

Third, pooling the essential patents that compose a technology standard reduces the search cost for potential adopters. A common difficulty with adopting fragmented standards is that even if the potential adopters are willing to pay the excessive licensing fees for each component of the standard, they cannot be sure whether they have identified all the pieces essential to implementing the standard or whether there remain other pieces patented by unidentified parties who might later sue them for infringing on their IP. The inclusion of essential patents within the pool can greatly alleviate this issue and thus lower the probability of unforeseen infringement costs. One caveat here is that joining a pool is voluntary, and some essential patent holders might decide not to join a pool. Thus the set of patents inside a pool might not necessarily cover all the patents essential to implementing a particular standard. However, even if a pool does not contain all the essential patents, at a minimum it reduces the cost associated with identifying the patents that are included in the pool. In short, modern pools can reduce the search and potential infringement costs associated with adopting a fragmented standard.

Fourth, the formation of a pool can send a clear signal that the main developers of the pooled technology standard are committed to using the standard and to facilitating its future development. Such a commitment can indicate the presence of a sizable market for future complementary technologies and can therefore create a momentum behind the adoption of the pooled standard in complementary technologies. This initial momentum can further translate into higher adoption rates through positive network externalities (Katz and Shapiro 1994, 1986, Suarez and Utterback 1995). This mechanism is particularly relevant when the pool is formed in a technological environment with several competing standards and high uncertainty about which standard will dominate in the future.

These mechanisms together suggest that modern pools would increase the rate of technological development based on the pooled standards. However, there are also opposing mechanisms through which modern pools might negatively influence follow-on technological innovation. Formation of a pool can discourage pool members and potential licensees from investing in follow-on technological developments that might cannibalize the already-established pooled standard (Joshi and Nerkar 2011, Grossman and Shapiro 1988). Also, licensing deals of most modern pools include a grant-back provision that requires the licensees to transfer back to the pool any improvements they make to the licensed standards (Lerner et al. 2007). This prevents the pool members and licensees from independently marketing their own technological improvements, which can potentially reduce incentives for investing in such improvements. Both of these mechanisms apply only to investments in improving the pooled standard, and not to those in complementary technologies based on it. Nonetheless, they can negatively influence some of the investments in further technological developments based on the standard.

Given these contrasting forces, whether the net impact of modern pools on innovation is positive or negative remains as an empirical question. Therefore, I offer the following competing hypotheses:

> Hypothesis 1a (H1a): The formation of modern patent pools has a net positive impact on follow-on innovations based on the pooled technology standards.

> Hypothesis 1b (H1b): The formation of modern patent pools has a net negative impact on follow-on innovations based on the pooled technology standards.

Impact of Modern Pools on Industry Structure

In order to understand the heterogeneous response of firms to the formation of modern pools and the effect of these arrangements on industry structure, I draw from the literatures on organizational economics, organizational capabilities, and ecosystems.

Using the make-or-buy logic from transaction costs theory provides a first step towards understanding the changes in the industry structure due to the formation of modern patent pools (Williamson 1975). Modern patent pools can lower the transaction costs of using fragmented technologies through two mechanisms: (1) reducing technological uncertainty and asset specificity, and (2) mitigating litigation risks and appropriation hazards.

First, the formation of a pool around a technology standard can delineate the boundaries of the standard and cause convergence around it. Modern patent pools are required by law to include only the essential and complementary components that are necessary to comply with a technology standard. Hence, the formation of a modern pool demarks the boundary of the pooled standard and reduces the uncertainty around its core components. Moreover, technology standards generally emerge where there are many different ways to deliver the same functionality. The existence of multiple competing technological solutions can negatively affect the investment in the development of complementary technologies and products based on each individual solution, because of high uncertainties about which solution would prevail in the future. As a result, to the extent that modern patent pools establish consensus around a technology standard—through lowering the cost of access to it and/or creating a bandwagon momentum behind it—they can reduce uncertainty about the future nature of the technology in the market. The resolution of technological uncertainty could also reduce asset specificity (Gort and Klepper 1982, Williamson 1975), as outputs of the upstream players are no longer required to be tailored to specific needs of downstream buyers as long as they comply with the compatibility rules of the pooled standards.

Beyond providing an easy and relatively cheap access to the pooled technology standards and facilitating their smooth integration in downstream products, modern patent pools can also increase investment in complementary technologies within the broader business ecosystem surrounding the pooled standards. Using an ecosystem lens, Adner and Kapoor (2010) identify two broad sets of challenges facing the successful adoption of a firm's technology or innovation: upstream component challenges and downstream complement challenges. Component challenges refer to the difficulties that the focal firm faces in developing, obtaining, and integrating all the components necessary to implement its technology/innovation in its final product. Complement challenges, on the other hand, limit the ability of the focal firm's buyers to benefit fully from consuming the focal firm's product due to lack of sufficient complementary technologies and products.

Modern patent pools are particularly unique in being able to address both component and complementary challenges. As noted before, the formation of a modern pool enables each partial owner of the pooled technology standard to access all the other pieces at once and at a reasonable price. In other words, the formation of a modern pool enables partial owners of the pooled standard to bundle their components and offer them in one package to interested users. The bundling of all necessary components into one package essentially addresses the major component challenge that downstream players interested in the pooled standard face. At the same time, by establishing a set of compatibility rules, modern patent pools reduce uncertainty around investments in complementary technologies and products by guaranteeing future compatibility and integration. The simultaneous addressing of component and complementary challenges can further reinforce the convergence around the pooled standards and drive technological uncertainty and asset specificity further down. The collective commitment of pool members active in the downstream market also provides the necessary demand for early complementors to justify their investments in the pooled technology and thus reinforces the adoption of the pooled standard in the future.

Second, modern pools reduce the risk of opportunistic behavior by both pool members and potential adopters by centralizing the licensing process and relying on the markets for technology (Arora and Gambardella 2010, Arora et al. 2001). Pool members are required by law to license all the pooled patents at a reasonable price to any party who wants to license them. The terms of licensing are similar for pool members and all external parties. Hence, the formation of a modern pool prevents pool members from strategically upholding any essential pieces of the pooled standard or engaging in discriminatory license pricing against non-members. Therefore, potential pool licensees are protected against opportunistic behavior by pool members. At the same time, the reliance of the pooled standards on the patent system protects the IP rights of pool members through the licensing process and afterwards. Modern pools, thus, can potentially facilitate a synergic relationship between standard owners, standard users, and complementors (Arora and Merges 2004, Gans and Stern 2003, 2010).

These mechanisms suggest that modern patent pools can lower the value of internalizing both upstream and downstream activities and instead increase the efficiency of market mechanisms in industries associated with the pooled standards. The formation of modern pools can thus trigger a process of vertical disintegration along the value chain of related industries, creating a more efficient division of labor between upstream technology-focused organizations and downstream application developers. With such a division of labor, upstream organizations can take advantage of their knowledge assets and more agile organizational structures to produce the complementary technologies, while relying on the presence of downstream product manufacturers as potential buyers of the developed technologies. At the same time firms with manufacturing capabilities can focus on application development to establish their position in the downstream market, while relying on upstream organizations to provide the required technologies. The latent gains from trade can further reinforce the specialization process within the industry value chain. Hence, in short, I expect the follow-on innovations based on newly formed pools to be disproportionally developed by upstream technology-focused organizations.

> Hypothesis 2 (H2): Following the formation of modern pools, there will be a higher share of follow-on innovations developed by specialized entities relative to vertically integrated firms.

The formation of modern pools and the resulting vertical disintegration of industries can further change the competitive landscape for different types of new entrants and incumbents. Several recent studies have highlighted the intertwined relationship between organizational economics and organizational capabilities that shape industry evolution. Scholars have particularly focused on unpacking different types of capabilities that influence the performance and value chain configuration of firms, either upon entry into a new industry (Qian et al. 2012, Chen et al. 2012, Helfat and Lieberman 2002) or through various stages of the industry life cycle (Helfat and Campo-Rembado 2016, Helfat and Peteraf 2003, Henderson 1994). Prior research particularly highlights the role of integrative capability in shaping firms' vertical-integration decisions and their competitive advantage (Helfat and Campo-Rembado 2016, Qian et al. 2012).

An integrative capability consists of various routines for communication and coordination between the units along the internal value chain of a firm in order to ensure a smooth downward and upward transfer and integration of knowledge and material (Helfat and Raubitschek 2000, Iansiti and Clark 1994, Henderson 1994). At its core, an integrative capability has a set of rules, principles, codes of communication, and routines that are shared among all the units in the organization and that are usually governed by various overarching organizational mechanisms and governance structures (Helfat and Campo-Rembado 2016).

The benefits of integrative capabilities come at a cost (Helfat and Campo-Rembado 2016). Development of shared organization-wide disciplines, rules, and routines requires long-term investments and commitments. Their successful development usually occurs through learning by doing and entails not only the direct costs of time and effort, but also the costs of failures (Nelson and Winter 1982, Lieberman 1987). Maintaining integrative capabilities further requires various supporting organizational mechanisms such as employee rotation and cross-functional teams, and demands continuous support from management, which could in turn increase the overhead costs (Leiblein and Miller 2003, Mayer and Salomon 2006). Overall, developing and maintaining integrative capabilities entails substantial sunk costs.

In many respects, modern pools incorporate the various functions of integrative capabilities inside a collaborative inter-organizational entity. They essentially promote a set of common compatibility rules that enable organizations at different stages of the value chain to coordinate their flow of inputs and outputs with little cost and active communication. They also create a common interface language that facilitates complementary technological development and integration. Meanwhile, as noted above, their reliance on the market for technologies provides a legal governing structure for the embodied compatibility rules, protecting both developers and users against opportunistic behavior and litigation hazards. Importantly, pool members are legally mandated to provide the pooled standards to any interested party at fair and reasonable prices. Hence, for potential buyers of the technology, relying on a pooled standard can be much cheaper than developing an alternative technology along with the integrative capabilities that are necessary to ensure the smooth integration of the new technology with the internal chain of activities. Hence, the formation of modern pools can diminish the relative importance of internal integrative capabilities, raising instead the importance of activity-specific capabilities—that is, capabilities that support functions needed for a specific stage of the value chain such as technology development or manufacturing.

For new entrants in the industry, the change in the relative importance of integrative versus activity-specific capabilities translates into a change in the relative competitive advantage of diversifying firms versus startups upon entrance. Prior research has shown that diversifying entrants have higher levels of integrative capabilities than startups do (Helfat and Campo-Rembado 2016, Qian et al. 2012). The diminishing value of integrative capabilities after the formation of modern pools, along with the additional costs of maintaining integrative capabilities, puts diversifying entrants into a disadvantageous position relative to startups that do not need to incur such costs. The long-term benefits of integrative capabilities and the high costs of disposing of them means that diversifying entrants cannot easily circumvent their disadvantageous cost structure by shedding their integrative capabilities. Hence, I expect follow-on innovations by new entrants after the formation of modern pools to be disproportionally introduced by startups rather than diversifying firms.

> Hypothesis 3 (H3): Following the formation of modern pools, ceteris paribus, the follow-on innovations by new entrants are disproportionally developed by startups rather than diversifying firms.

The same line of reasoning suggests that among the incumbents with previous investments in technologies related to the pooled standards, the increase in the relative importance of activity-specific capabilities vis-à-vis integrative capabilities puts specialized upstream incumbents in a more advantageous position in the upstream technology market than integrated incumbents. Therefore, upstream specialized incumbents are likely to continue investing in complementary technologies to take advantage of their previously accumulated knowledge on the pooled standards. In contrast, vertically integrated firms are relatively more likely to shift their attention to downstream application development to take advantage of their manufacturing capabilities and to establish their early position in the downstream markets based on the pooled standards. By doing so, they can avoid fierce completion in the upstream market against more agile and better prepared specialized firms. Moreover, the relatively larger costs of entering into the downstream market mean that they would face lower competition there. Take 8X8 Inc. and Pioneer Corp. for example: 8X8 Inc. is a specialized communication company with a focus on VoIP technology services. In 1997, 8X8 was an upstream company largely focused on producing semiconductor chips and software technologies for the videoconferencing market. Pioneer Corp., on the other hand, is a vertically integrated company specializing in digital entertainment products. In 1997, Pioneer Corp. was an integrated company focused on producing various consumer products including set-top boxes, DVD recorders, and navigation systems. Both companies were developing video- and audio-encoding technologies in the years before the formation of the MPEG-2 pool. After the pool's formation, 8X8 used its prior stock of knowledge to develop a new generation of semiconductor chips that would implement the emerging audio- and video-compression standards such as MPEG-2. 8X8 Inc. later licensed its technology to Apple, Compaq, Dell, and various other companies in the personal computers and electronics industries. In contrast, in order to avoid tough competition in the upstream technology market of audio/video compression, instead of developing its own proprietary audio/video encoding technology, Pioneer Corp. acquired a license to the MPEG-2 standard in 1999, and invested in developing the first generations of audio/video entertainment systems, set-top boxes, and navigation systems that use MPEG-2 technology. Following this line of reasoning, I expect the following:

> Hypothesis 4 (H4): Following the formation of modern pools, ceteris paribus, there will be a decline in the technological innovation rate of vertically integrated firms relative to non-integrated entities that had invested in technologies related to the pooled standard before the formation of the pool.

Empirical Strategy and Data Sources

I use patent data to measure the impact of modern pools on follow-on innovation rate. In particular, following prior research (Hall et al. 2001, Rysman and Simcoe 2008, Trajtenberg 1990), I use the number of subsequent patent citations to a patent as a proxy for the total amount of follow-on innovation built upon that patent. I exclude citations by the owner of the focal patent in order to capture the adoption rate by other parties. Also, I use the total amount of patenting in a particular technology subclass as a proxy for the total amount of innovative activity in that technology subclass (Lampe and Moser 2016).

The key challenge of estimating the net causal impact of modern pools on follow-on-innovation rate is to distinguish their impact from that of other, unobservable factors. Ideally, I would like to observe and measure what would have happened to follow-on innovations based on pool patents if they had never been added to a pool. Since I cannot observe the counterfactual and there is no natural experiment to exploit, I rely on two different, complementary estimation strategies.

In the first set of estimations, following the method used by Rysman and Simcoe (2008) to study the effectiveness of standard-setting organizations, I identify the impact of these seven pools by measuring the changes in the number of citations received by each pool patent after its addition to a pool relative to a comparable set of control patents. In this set of estimations, I use two different sets of control patents: (1) a set of matched patents selected based on application year, main technology subclass, and citation impact; and (2) the set of patents that are already added or that will be added in the future to one of the seven pools in the sample. With the former control sample, I rely on the accuracy of the matching method to estimate the unobserved counterfactual for pooled patents. However, there is no guarantee that the selected matched patents would constitute the basis for a comparable set of fragmented standards. The latter control sample addresses this issue by using exclusively the pool patents in my sample. This method exploits the fact that these pool patents have been added to their respective pools at different points of time. Hence, for each patent that is added to a pool at any point in time, other patents that are already added or not yet added to a pool can serve as comparable controls. In both cases I use the following difference-in-difference equation to estimate the effect of addition to a pool on a patent's subsequent citations:

(1) $Ln(Citation_{it} + 1) = \beta Pool\_Patent_{it} + Patent_i + Year_t + age_{it}^n + \alpha + \varepsilon_{it}$

where $Ln(Citation_{it} + 1)$ is the log-transformed number of citations (plus 1) received by patent i in year t. I exclude any self-citations by the owner of patent i in order to capture the impact of the pool on technological development by other parties in the market. $Patent_i$ and $Year_t$ are patent and year fixed effects. Patent fixed effects capture the time-invariant characteristics of individual patents (including their application year, technology class, etc.), and year fixed effects capture the general macro time trends that affect the yearly citations of all patents in the sample similarly. The non-linear effect of patent age on yearly citation frequency is captured by age_{it}^n, a set of five dummies from a five-degree polynomial age function ($age_{it}^{n} = age_{it} + age_{it}^{2} + age_{it}^{3} + age_{it}^{4} + age_{it}^{5}$). Age of patent i in year t is equal to t minus the patent's grant year. $Pool\_Patent_{it}$ is equal to 1 if patent i is added to a pool in year t; 0 otherwise. Hence, coefficient β captures the net effect of inclusion in a pool on the subsequent average yearly citation rate of a typical patent. As noted above, I first estimate β using the sample of pool patents and their matched controls. Subsequently, I estimate β using only the sample of pool patents.

The problem with using changes in citations to pool patents after their inclusion in a pool is that increases in patent citations might arise from factors other than those that reflect how effectively pooling arrangements promote the adoption of pooled standards. For example, once patents are added to a pool, their observability in searches for prior art might increase, and patent examiners might therefore add them more frequently as prior art for subsequent patents. Also, innovators might be more afraid of strategically ignoring prior art references to pool patents due to higher threat of litigation by a powerful pool organizer that is there to enforce the collective IP rights of pool members.

Given these issues, as a complementary robustness analysis, I use a second set of estimations based on a different empirical strategy that does not rely on patent citations. Following the approach introduced by Lampe and Moser (2016), I examine the change in the number of patents in technology subclasses that are assigned to pool patents. The USPTO assigns one primary technology subclass and potentially several other ones to each granted patent. Related technological subclasses are then grouped under a parent technology class. The core idea behind this empirical strategy is that if the formation of modern pools increases adoption of pooled patents, we should expect more innovative activity, and hence patenting, in technological subclasses that are associated with pooled standards. Similar to the previous empirical strategy, I need to compare the changes in patenting in a technology subclass after it receives its first pool patent to a comparable technology subclass that is not affected by any pool. To construct the control sample, again I exploit the fact that different patents were added to each pool at different points of time. In other words, different technology subclasses were affected by these seven pools at different points of time. Hence, at any point in time, each technology subclass with a pool patent can be compared with other technology subclasses that are not yet affected by any pool patents. More specifically, I use the following estimating equation on the full set of technology subclasses that were assigned to all the pool patents in my sample:

$$(2)\ Ln(Patent\_Subclass_{ct} + 1) = \beta Pool\_SubClass_{ct} + Top\_Class_{c} \times Year_{t} + \alpha + \varepsilon_{it}$$

where $Ln(Patent\_Subclass_{ct} + 1)$ is the log-transformed number of patents (plus 1) in the technology subclass c in year t. In robustness analyses, I repeat the estimations with the weighted count of patents in each technology subclass whereby I weight each patent by the total number of citations it has received in the five years following its grant date. $Top\_Class_{c} \times Year_{t}$ is a set of interaction dummies between the parent class of the focal technology subclass c and each year in the sample.[3] These interaction dummies capture any macro trends that would influence the level of inventive activity in a parent technology class and thus all of its subclasses similarly in a particular year. $Pool\_SubClass_{ct}$ is equal to 1 if in year t there exists at least one pool patent to which the technology subclass c is assigned as the primary technology subclass. To put it differently, $Pool\_SubClass_{ct}$ is the dummy that captures when a technology subclass is first affected by a pool. Coefficient β, thus, captures the impact of the seven modern pools on the total number of patents in technology subclasses associated with them.

In another set of robustness tests, rather than using the $Pool\_SubClass_{ct}$ dummy, I use the total number of pool patents in technology subclass c in year t. The idea here is that to the extent that the formation of modern pools would influence the total patenting activity in the associated technology subclasses, those subclasses with more pool patents should be affected more heavily.

An advantage of using these two different estimation strategies—one based on follow-on citations to the pool patents and one based on the total patenting in technology subclasses associated with pools—is that they are unlikely to suffer from the same set of biases and identification issues. For example, whereas citations added by examiners or strategic citations added by other firms due to litigation fears might lead to an upward bias under the first estimation strategy, they would not lead to

[3] For example, in the case of patent 5175618 (Title: Compression method for interlace moving image signals), which was added to the MPEG-2 pool in 1998, the assigned primary technology subclass is 375/240.13 and the parent class is 347.

such bias in the second set of estimations. Hence, while neither of these two empirical strategies is entirely free of bias, their results allow for complementary assessments.

In order to construct the sample for the analyses, I use detailed data on seven major pools that were formed between 1997 and 2004 around these technology standards: MPEG-2, IEEE 1394, AVC, MPEG-2 Systems, MPEG-4 Visuals, Audio MPEG, and DVD 6C. Table 1 provides a brief description for each technology standard, the formation year of each pool, and links to additional details on each pool. All standards except for IEEE 1394 contain different coding algorithms to compress and transfer digitalized video and audio signals. IEEE 1394 contains the interface algorithms for high-speed, real-time data transfer through a serial bus. For the first five pools in the list, I acquired the data on the list of patents and their dates of inclusion in each pool directly from the MPEG LA LLC, the company in charge of organizing these pools. For the two other pools (Audio MPEG and DVD 6C), I used the Internet Archive (accessible at https://archive.org) to extract the list of patents mentioned on each pool's website at each year since its inception. Using this method, I identify the approximate year in which each patent was added to its respective pool. To have at least five years of citation data for each patent after its inclusion in a pool, I excluded the patents that were added to each pool after 2005. In total, I identified 489 patents that were added to at least one of these pools between 1997 and 2005. In order to construct the matched control sample, I followed the approach used by Rysman and Simcoe (2008). In particular, for each pool patent, first I collected all the non-pool patents in the same primary technology class and application year from the NBER patent database. Next, I sorted the collected patents based on the total number of citations received from subsequent patents and selected only the top 40% cited patents. The 40% threshold ensured the highest similarity between the pool and control patents in terms of average citation rate. The final control sample includes 1,868 matched patents.

— Insert Table 1 about here —

In order to test H2, I examine whether there is a decline in the share of vertically integrated firms that have been citing a patent after its inclusion in a pool. To do this, I need to know whether a firm had been vertically integrated in any given year in the sample. In the absence of any public or private dataset that contains the vertical-integration status of firms, I used publicly available information from the Internet about each firm's activities and products. In particular, following the approach in Layne-Farrar and Lerner (2011), I searched for any indication that a firm manufactured any downstream products in any given year in the sample. Firms with downstream products are then marked as vertically integrated. Non-integrated entities include firms that do not manufacture any downstream products, and universities, non-private research labs, and independent inventors not associated with any institution. Given the large number of firms that have cited the selected pool patents and the intensive time required to identify the vertical-integration status of these firms in each year, I collected this data only for the entities that cited the MPEG-2 pool patents along with those that cited the set of the matched control patents for MPEG-2 patents. In total I could identify the vertical-integration status of 695 entities. Econometrically, I use an estimating equation similar to equation (1) above, with a different dependent variable:

(3) $VI\_Share_{it} = \beta Pool\_Patent_{it} + Patent_i + Year_t + age_{it}^n + \varepsilon_{it}$

where VI_Share_{it} is the share of vertically integrated firms that cite patent i in year t. All the other variables are similar to those explained in equation (1). Coefficient β here captures the differential impact of the inclusion of patent i in a pool on the total share of vertically integrated firms that would cite it in their patents subsequently. As discussed previously, I expect to see a decline in the share of vertically integrated firms following the inclusion of a patent into a pool (and hence a negative β). While the theory predicts an increase in the share of all types of non-integrated entities using pooled technologies after the formation of a modern pool, as a robustness analysis I also repeat the estimation including only for-profit companies.

Testing H3 requires estimating the change in the share of startups to diversifying entrants that develop follow-on innovations based on pooled patents after the formation of a pool. To distinguish between startups and diversifying entrants, I rely on the patenting history of each firm in the sample. First, I define new entrants in a particular upstream technology market as all the firms that patent for the first time in any given technology subclass. Subsequently, I define startups as new entrants that have never patented before, and diversifying entrants as those that have previously patented in other technology subclasses. This categorization is coarse and suffers from potential misidentification and sampling bias. A diversifying firm may decide to patent for the first time after the formation of a modern pool, which would lead to its misidentification as a startup. This particular misidentification, however, leads to more conservative estimates. Further, there may be diversifying entrants or startups that attempt to innovate based on pooled patents but fail and hence never show up in the sample. Hence, the estimates here apply only to the set of new entrants that succeeded in obtaining at least one patent. Moreover, I define upstream technology markets at the level of technological subclasses defined by the USPTO. In robustness tests, I repeat the estimations using parent technology classes as a broader definition of upstream markets, and the results remain the same. To estimate the change, again I use an estimating equation similar to equation (1), using the ratio of startups to diversifying entrants as the dependent variable.

(4) $Startup\_Share_{it} = \beta Pool\_Patent_{it} + Patent_i + Year_t + age_{it}^{n} + \varepsilon_{it}$

where $Startup\_Share_{it}$ is the ratio of startups to diversifying entrants citing patent i in year t. Other variables are the same as those in equation (1).

To test H4 I need to track the innovation rate of vertically integrated and specialized (i.e., non-integrated), upstream firms that had been developing technologies related to a pooled technology standard before the formation of the pool to assess whether there is a change in their innovation rates after pool formation. To do so, I use the set of 70 publicly listed firms that had cited the MPEG-2 pool patents prior to the formation of the MPEG-2 pool (40 vertically integrated firms and 30 non-integrated, upstream firms). The use of publicly listed firms enables me to identify changes in the patenting rate of these firms above and beyond what would be expected due to changes in their sales and R&D investments. Hence, what I would capture as the change in the patenting rate of these firms can be interpreted as a change in their R&D investment direction rather than a decrease or increase in their total R&D investment, sales, or size. I use Delphion, the NBER patent database, and other public sources to identify all the patents that are assigned to each firm and its subsidiaries. Within this sample of firms, I estimate the change in the patenting rate of vertically integrated firms relative to that of technology-focused upstream firms after the formation of the MPEG-2 pool, using the following estimating equation:

(5) $Ln(Firm\_Patenting\_Rate_{ft} + 1) = \beta Vertically\_Integrated_f \times After\_PoolFormation_t + Firm_f + X_{ft} + Year_t + \varepsilon_{it}$

where $Ln(Firm\_Patenting\_Rate_{ft} + 1)$ is the log-transformed total number of successful patents (plus 1) applied by firm f in year t. Firm fixed effects, $Firm_f$, control for the time-invariant characteristics of each firm, and year fixed effects, $Year_t$, control for the macro trends that influence all the firms in the sample similarly. X_{ft} is a set of time-varying, firm-specific characteristics including log-transformed total sales, R&D intensity (total R&D spending over sales), and capital intensity (total capital over sales). These data are collected from the Compustat database. The interaction term $Vertically\_Integrated_f \times After\_PoolFormation_t$ is equal to 1 for vertically integrated firms after the formation of the MPEG-2 pool in 1997, and 0 otherwise. The coefficient β then captures the differential impact of the MPEG-2 pool on the patenting rate of vertically integrated firms relative to specialized, technology-focused ones. Following H4, I expect a decline in the relative patenting rate of vertically integrated firms after the formation of the pool. One potential caveat is that any decline might be the result of a more focused investment in higher-quality inventions. To address this caveat, I repeat the estimation with the quality-weighted number of patents of each firm as the dependent variable as well. Again, I use the number of citations that a patent has received in the five years following its grant date as a measure of its quality.

To better investigate the underlying theoretical mechanisms, I also explore the evidence for an intensified focus on downstream product development among vertically integrated firms after the formation of modern pools. I also examine the change in patenting behavior of pool members after the pool formation.

Results

Summary statistics are presented in Tables 2a, 2b, and 2c. Table 2a provides the relevant summary statistics for the set of patents included in the seven selected pools and their matched counterparts. Pool patents receive on average 0.589 citations per year during the sample period. In comparison, the matched control patents receive about 0.665 citations per year. The difference between the two is not significant. The summary statistics in Table 2a further suggest that about 27% of citations to MPEG-2 patents per year have been by vertically integrated firms. In comparison, the yearly share of citations by vertically integrated firms to the patents matched to MPEG-2 patents is 28%. Table 2b provides further pool-specific summary statistics for the main dependent variables at the patent level.

Table 2c presents the summary statistics for the technology subclasses assigned to pool patents. There are about 8 patents in each technology subclass in a typical year between 1985 and 2010. The average yearly weighted patent count in a typical pool subclass is about 51. Also, a typical technology subclass contains about 0.870 pool patents per year. The number of pool patents to which these technology subclasses are assigned range from 0 (for the period when the subclass has yet to be assigned to any pool patents) to 32. Each pool in the sample is associated with 39 technology subclasses on average (standard deviation: 32).

Finally, Table 2d shows the summary statistics for the set of publicly listed firms that had once cited at least one of the MPEG-2 patents before the formation of the MPEG-2 pool. Columns 1 and 2 show the summary statistics for the vertically integrated and non-integrated firms respectively. Both groups have relatively similar yearly rates of patenting (both weighted and non-weighted). As expected, the vertically integrated firms are larger (based on the total sales measure) and have lower levels of R&D intensity than the non-integrated, technology-focused firms. The sets of firms are comparable in terms of capital intensity level.

— Insert Table 2 about here —

Table 3 presents the estimation results for the impact of inclusion in a pool on the follow-on yearly citation rate of a patent (equation 1). Column 1 shows the results for the estimation with the set of matched control patents. The estimated β suggests that inclusion in a pool increases the subsequent average yearly citation rate of a patent by approximately 23%. The second column presents the results for the sample restricted to only pool patents in the sample. As explained in the methodology section, here the change in the yearly citation rate of a patent after its inclusion in a pool is compared with the yearly citation rate of other pool patents that were included in a pool or that would be included in the future. The estimated β suggests an approximately 14% increase in the yearly citation rate of patents once they are included in a pool. In column 3, I repeated the estimate in column 2 but excluded citations from universities, government labs, and other not-for-profit organizations to better estimate the standard adoption rate by for-profit firms. The results suggest an increase of 7% in the citations by for-profit firms to patents after their inclusion in a pool. I further tested the sensitivity of estimates to other functional forms such as negative binomial and Poisson. The estimates are essentially similar in terms of size and significance.

— Insert Table 3 about here —

One might be concerned that the increase in the yearly citation rate of pool patents had begun to grow before their inclusion in the pool. In other words, the increase in yearly citation rates of pool patents might have begun before their additions to the respective pools due to other factors such as their disclosure to the relevant standard-setting organizations. To address this concern, I repeated equation (1) and replaced the post-pool dummy with a flexible set of years-since-inclusion-into-pool dummies to capture the difference in the yearly citation rate of pool patents and control patents for the four years before the inclusion in a pool to nine years after the inclusion. Figure 1 shows the estimated yearly treatment effects using the sample of pool patents and the matched control patents. The graph shows no evidence of a pre-trend in yearly citation rates before the addition of patents to pools. Figure 2 shows the yearly treatment estimations excluding the control patents (i.e., using only pool patents). The yearly estimates are less precise and are not significant at the 5% level due to the more conservative estimation method. Nevertheless, the graph shows little sign of an upward trend in the yearly citation rates prior to the inclusion of the patents in a pool. Both figures suggest an increase in the yearly citation rate of pool patents starting about one year after their inclusion in a pool.

— Insert Figures 1 and 2 about here —

Table 4 reports the results for the impact of modern pools on the rate of innovation activity in technology subclasses assigned to the pool patents (equation 2). Column 1 shows the change in the patenting rate in technology subclasses with at least one pool patent relative to technology subclasses that have not yet been assigned to any pool patents (but would be in the future). The estimated β

shows an increase of about 40% in the average patenting rate in a technology subclass once it is assigned to at least one pool patent. In column 2, the 0/1 dummy indicating whether a technology subclass is assigned to a pool patent is replaced with the total number of pool patents to which the technology subclass is assigned in any given year. The results show that the assignment of a technology subclass to one extra pool patent is associated with an increase of about 9% in the patenting activity in that subclass. Columns 3 and 4 repeat the estimations in columns 1 and 2, with the weighted patenting rate as the dependent variable. The estimates are significant and relatively similar in size to those reported in columns 1 and 2. The results overall suggest that once a pool is formed, the total inventive activity in the technology subclasses associated with its patents increases subsequently.

— Insert Table 4 about here —

Similar to the previous set of estimations, one concern is that the increase in the patenting activity in each technology subclass might have begun before the assignment of the subclass to a pool patent and that the estimated β merely reflects an upward trend in these technology subclasses. To address this issue, I repeated the estimation in column 1 of Table 4, replacing the dummy variable ‘Has a pool patent’ with a set of year-since-first-pool-patent-assignment dummies to capture the average change in the total inventive activity in a technology subclass in the years before and after its first assignment to a pool patent. In order to further control for the specific time-varying innovation trend in each technology subclass, I also add the lagged dependent variable (by 1 year) as an additional control in the estimation. Figure 3 illustrates the estimated yearly treatment effects. Although the yearly estimates are less precise and not significant at the 5% level due to the conservative nature of the estimation method, the overall trend suggests an increase in the total patenting activity in a subclass in the years subsequent to the assignment of the subclass to the first pool patent. The figure shows little evidence of an upward trend before the first assignment. Overall, the results from this set of estimations along with the previous ones provide support for H1a, that the formation of modern patent pools increases the total amount of subsequent technological innovation based on the pooled patents.

— Insert Figure 3 about here —

Table 5 presents the estimated results for the change in the share of vertically integrated firms that cite one of the MPEG-2 pool patents after its inclusion in a pool. In column 1, I simply replicate the impact of the MPEG-2 pool formation on the yearly citation rate of MPEG-2 pool patents (equation 3) to show that the initial results for the seven patent pools reported in Table 3 also hold for the subset of MPEG-2 patents. The average increase in the yearly citation rate of MPEG-2 patents after their inclusion in the pool is about 23%, which is very close to previous estimations for the whole sample of pool patents. The second column reports the change in the share of vertically integrated firms that have cited MPEG-2 patents after their addition to the MPEG-2 pool relative to control patents matched to the MPEG-2 patents. The third column shows the estimates with only MPEG-2 patents used in the regression. In both cases, consistent with H2, the estimated β suggests a decline of about 10% in the total share of vertically integrated firms citing the MPEG-2 patents after they are added to the MPEG-2 pool. The results can be alternatively interpreted as a 10% increase in the share of non-integrated, technology-focused entities citing a MPEG-2 patent once it is added to the pool. In column 4, I repeat the estimates by calculating the share of vertically integrated for-profit firms after excluding individuals and other not-for-profit entities such as universities and government organizations. The estimates suggest a similar decline in the share of vertically integrated firms citing a patent after its inclusion in a pool.

— Insert Table 5 about here —

Performing the analysis on the sample of MPEG-2 patents raises some concerns regarding the generalizability of results to other modern patent pools. As explained in the previous section, because of data constraints I cannot replicate these results for all the pools in the sample. However, I can investigate the change in the share of citations to pool patents received from subsequent patents by independent inventors for all the pools in the sample. Independent inventors are an important subset of non-integrated entities (Nicholas 2010). Approximately 7% of the total patents granted in the United States in 2014 were filed by independent inventors. Patents by independent inventors can be easily identified since there are no assignees mentioned on their published documents by the USPTO. The estimates in column 1 of Table 6 suggest an increase of about 74% in the share of citations from patents by independent inventors to pool patents after their addition to a pool compared with matched patents. Column 2 reports a similar estimated increase in the share of citations to pool patents by independent inventors when only pool patents are included in the regression. This substantial increase is not surprising given that the high costs of adopting a fragmented technology standard create a significantly larger barrier for independent inventors than for non-integrated firms and government agencies that generally have access to more financial and legal resources. The results are overall consistent with those reported in Table 5 for the MPEG-2 patents and provide further support for H2.

— Insert Table 6 about here —

Table 7 reports the change in the share of startups vis-à-vis diversifying entrants in the upstream technology market after the formation of the modern pools using equation (4). Column 1 presents the estimates based on the full sample of pooled patents and their matches. The results suggest that the ratio of startups to diversifying entrants citing a patent increased by a factor of 4 after the patent is added to a pool. Column 2 reports the results based on the sample of only pooled patents. The estimated effect is again positive, significant, and close to that reported in column 1. Overall, the results support H3 and suggest that the formation of pools puts startups in the upstream market in a more advantageous position compared to diversifying entrants.[4]

— Insert Table 7 about here —

Table 8 reports the estimated change in the yearly patenting rate of vertically integrated firms that had been working on technologies related to the MPEG-2 standard, relative to non-integrated firms, after the formation of the MPEG-2 pool (equation 5). The dependent variables are the yearly patenting rate and the yearly weighted patenting rate in the first and second columns, respectively. Estimated βs in both columns suggest a significant decline in the patenting rate of vertically integrated firms compared with non-integrated firms after the formation of the MPEG-2 pool in 1997. In the

[4] My further analysis (available upon request from the author) suggests that startups indeed contribute the highest share to follow-on innovations based on pooled patents compared to diversifying entrants and incumbents who had previously patented in technology subclasses associated with these pools.

third column, I added two dummies to capture the change in the patenting rate of vertically integrated firms in the two years prior to the formation of the MPEG-2 pool. In both cases, the estimated coefficients are largely insignificant and much smaller than the estimated decline after the formation of the pool. The results overall confirm H4.

— Insert Table 8 about here —

One concern regarding the results reported in Table 8 is that the decline in the relative patenting rate of vertically integrated firms might be driven by a decline in their relative financial performance due to higher competitive pressure exerted on them by the pool members once the pool is formed. To test this idea, I compared the change in the financial performance of the identified vertically integrated firms with that of non-integrated ones after the formation of the MPEG-2 pool. Using three different measures of financial performance—ROA, net profit margin, and Tobin's Q—I find no evidence of any significant decline in the relative financial performance of integrated firms after pool formation (results are not reported here but are available upon request from the author).

While the results in Table 8 provide evidence of a decline in the patenting rate of vertically integrated firms relative to specialized firms after the formation of modern pools, they do not directly show a shift towards more downstream application development among the integrated firms post pool formation. In the following supplementary analysis, I provide some evidence of this shift. A direct examination of such shifts in the investment direction of firms requires detailed data on how firms spend their investment money. In the absence of such detailed data, I rely on the information that public firms disclose in their annual 10-K reports to investors. Each report describes activities during the past year and plans for the future. These reports typically have comprehensive sections on business and product strategies of firms and their current and future products. Given that the MPEG-2 standard was an increasingly important technology in industries such as broadcasting, software, and semiconductors around the time of the formation of the MPEG-2 pool, mentioning any efforts towards implementing it in current or future products could potentially give firms a positive edge in investors' evaluations. This lets me identify any investment towards implementing the MPEG-2 technology in the annual reports of collected firms.

To perform the analysis, I first create a matched control sample for the 40 integrated firms that had investments in technologies related to the MPEG-2 standard before the formation of the MPEG-2 pool. I use 4-digit SIC code, and patenting rate over each of the three years prior to the formation of the pool to find a close match for each integrated firm in the sample. I could find satisfactory matches for 10 firms in my sample. Next, I collect the annual reports of the integrated firms and their matched counterparts for the years 1993 through 2003. I then identify the first report in which each firm mentions a product compatible with the MPEG-2 technology or a plan to implement it in current or new products. In doing so, I am able to identify all the firms that have reported their efforts towards implementing the MPEG-2 technology between 1993 and 2002. Finally, I compare the rate at which the integrated firms affected by the MPEG-2 pool mentioned a new product based on the MPEG-2 standard relative to their matched counterparts. I use an estimation model similar to that in equation (5), only changing the dependent variable to a dummy equal to 1 if firm f has mentioned MPEG-2 implementation in any of its annual reports in years t or before.

The results are presented in Table 9, suggesting that integrated firms in technological proximity to the MPEG-2 pool were 13% more likely to mention MPEG-2 implementation in their annual reports in the four years following the formation of the pool relative to the firms in the matched sample. The results are robust to using the full sample of vertically integrated firms as the treated sample and the full sample of public firms in the same industries as the control sample.

— Insert Table 9 about here —

I further performed additional analyses (available from the author upon request) to explore the change in the innovation rate of pool members after they join a pool. Note that while the formation of a pool is largely exogenous to firms outside the pool, it is a strategic action taken by the pool members and completely endogenous to them. Hence, the impact of the pool formation on pool members cannot be interpreted as a causal effect. Since most of the pool members in my sample are vertically integrated firms, following the line of argument behind H4, I expect a decline in their patenting rate and a stronger focus on downstream application development once they join a pool. The results from this supplementary analysis confirm both observations.

Discussion and Conclusion

This study draws upon prior research in organizational economics, organizational capabilities, and business ecosystems literatures to examine the impact of modern patent pools on innovation, firm capabilities, and industry structure. Using detailed data on seven major modern patent pools formed between 1997 and 2004, I find substantial evidence for the positive net impact of these modern pools on subsequent innovation based on the pooled standards. The estimates suggest that the addition of a patent to a modern pool increases the subsequent average yearly citation rate to that patent by about 14%. Also, assignment of a technology class to an extra pool patent raises the total patenting activity in that technology class by about 9%. The findings further suggest that follow-on innovations based on the pooled standards are disproportionally developed by non-integrated, technology-focused entities, whereas vertically integrated firms seem to be shifting their focus towards downstream application development after the formation of these pools.

The findings further build upon and contribute to prior work on standardization and modularity (Baldwin and Clark 2000, Schilling 1999, 2000). At the core of most modern pools are technology standards that were developed through extensive inter-organizational collaborations and negotiations with the aim that the resulting standard would enable the recombination of a diverse set of inputs and address heterogeneous demands downstream (Schilling 2000). Prior research shows how the emergence of modular product design and standardized technologies can change firm boundaries and support more disintegrated industry architectures (Schilling 2015, Schilling and Steensma 2001, Jacobides 2005). However, while prior research largely assumes that the designer of a standard or modular technology has full control over the design and promotion strategies, this study argues that the ownership structure of the technology, and in particular its fragmentation across multiple agents, can play a critical role in its eventual adoption in the market. While interfirm collaborations through the development process of most modern technology standards can facilitate industry-level congruence among various interested parties, it can also lead to fragmentation of ownership rights over different components of the developed standard, leading to excessive adoption costs. In settings where IP ownership over a standard or dominant design is fragmented, post-development collaborative arrangements such as modern patent pools can play a crucial rule in coordinating the strategic efforts of owners to promote the adoption of fragmented standards.

The results also provide valuable insight into the relationship between transactional hazards and organizational capabilities (Argyres and Zenger 2012, Qian et al. 2012, Jacobides and Winter 2005, Leiblein and Miller 2003, Madhok 2002), showing how the resolution of technological hazards can reduce the importance of integrative capabilities. The change in the relative importance of integrative capabilities can further change the competitive balance between startups and diversifying entrants as well as between integrated and non-integrated incumbents. The findings also shed new light on the relationship between technology life cycles and organizational capabilities. In particular, prior research suggests that as technologies mature, technological challenges may gradually dissipate while contractual challenges may remain or even increase. Adner and Kapoor (2010), for example, make the case that the maturity of technology can gradually increase co-specialization and transaction-specific assets. The shifting balance of technological and contractual challenges can thus increase the relative importance of integrative capabilities (Adner and Kapoor 2010). My findings suggest that modern pools and similar collaborative arrangements can simultaneously address both technological and contractual challenges, and hence lower the relative importance of integrative capabilities while fostering the emergence of a dominant technology. More broadly, the results suggest that the evolution of technological and contractual challenges through the technology life cycle depend, at least in part, on the means through which the technology is developed, promoted, and established.

Moreover, the findings suggest that modern pools and similar collaborative arrangements can particularly play a significant role in shaping the industry structure and the competitive positioning of firms during the incubation phase of nascent technologies where both technological uncertainty and contractual uncertainty are very high (Abernathy and Utterback 1978, Tushman and Anderson 1986). Moeen and Agarwal (2016) point out the importance of inter-organizational synergies in capabilities in shaping the progress and shakeout of technologies during the incubation stage. The results here confirm their observations and further illustrate the role of early collaboration among technology developers and a functioning market for technologies as essential elements for advancing new technologies from the incubation stage to the commercialization stage. The results further highlight the difference between the capabilities needed in established markets and those required during the incubation stage of nascent industries (Moeen 2016). In particular, the results suggest that the ability to form and sustain collaborative relationships with potential competitors can help firms overcome bottlenecks in the successful commercialization of nascent, fragmented technologies (Hannah and Eisenhardt, 2016). The findings also suggest that nascent industries do not necessarily start as integrated and gradually disintegrate through their life cycle. In contrast, early disintegration of nascent industries triggered by collaborative arrangements such as modern pools may help with joint value creation across the industry value chain and the movement of industry into the commercialization stage.

Further, the results contribute to the growing literature on business ecosystems (Adner and Kapoor 2010, Kapoor and Adner 2012). The results highlight how collaborative arrangements such as modern pools can simultaneously address both the component challenges (by bundling the necessary components together) and the complementor challenges (by establishing a common standard that would ensure ecosystem-wide integration). The findings respond to the call for better understanding of the value creation dynamics as an antecedent to value capture analysis (Adner and Zemsky 2006, Brandenburger and Stuart 1996). Joining a pool effectively lowers the licensing fee that each pool member can charge for its patented components to below what it could potentially charge outside the pool. However, the formation of a pool can considerably enlarge the overall market size for the pooled technology standard by addressing the value creation challenges faced by technology developers and downstream buyers. In other words, although the fee on each license might be lower when a firm joins a pool, the pool members can enjoy a substantially larger market for their technology standard. The findings thus illustrate a case where potential competitors can collaboratively increase their profits by increasing the total value created on each transaction at the expense of capturing lower value on each transaction.

The findings also contribute to the research on industry evolution, and in particular industry disintegration. Several conceptual and qualitative studies have pointed out the role of industry standards as a necessary force behind industry-level vertical disintegration (e.g., Argyres and Bigelow 2010, Jacobides and Winter 2005, Jacobides 2005, Steinmueller 2003). This study provides further large-sample empirical support for this claim and underscores the role of collaboration among competing parties in fostering vertical disintegration along the industry value chain. Moreover, while prior research provides a largely evolutionary account of industry disintegration, where firms passively change their vertical scope due to exogenous technological changes and the gradual emergence of industry standards, the results here highlight how firms can play an agentic role in triggering industry disintegration and growing industry-wide value creation through inter-organizational collaborations.

The findings also inform the literature on patent pools and current policy discussions on whether modern pools would stifle or foster innovation. Prior empirical studies on patent pools have largely focused on traditional pools, for which historical data are more abundant. The empirical literature on modern patent pools is comparatively sparse, despite the substantial growth in their use and economic significance over the past two decades (World Intellectual Property Organization 2011). The results are particularly of interest, as they provide the first robust empirical evidence of the positive impact of modern pools on follow-on innovation. The findings stand in contrast to those reported previously by Lampe and Moser (2010, 2016) on the negative effect of traditional patent pools on innovation due to their anti-competitive nature. Whereas many traditional pools could incorporate any patents related to a technology, modern pools are legally required to include only complementary and essential components of a technology standard. Moreover, modern pools are legally obliged to offer their licenses at a fair price to any interested party. The results suggest that these requirements have so far managed to curb the potential anti-innovative effects of patent pooling arrangements and instead help with materializing their pro-innovation goals.

The results expand prior literature on patent pools beyond examining the net effect of these arrangements on innovation or competition to exploring their broader impact on industry structure and firm capabilities. They also highlight the importance of understanding the heterogeneous impact of these arrangements on different market players and the risk of generalizing the impact on a particular group of firms to the whole population of affected entities. In the case of the MPEG-2 pool, for example, focusing on vertically integrated firms and the decline in their patenting rate after the formation of the pool might result in a short-sighted impression that the pool is anti-innovative. However, a more comprehensive analysis would show that the increase in technological innovations by non-integrated entities more than compensates for the decline in the patenting rate of vertically integrated players.

An important feature of my context is that all the pools in my sample are legally formed in the United States. Hence, one should be cautious about generalizing the results to settings outside the United States. That being said, all the pools in my sample (and almost all the major modern pools) incorporate patents from global companies around the world. The licenses of these pools are also acquired internationally. Anecdotal evidence suggests that the legal framework that oversees pooling agreements in Europe is quite similar to that in the United States. Nevertheless, in the absence of a detailed and informed comparison between various institutional settings governing pooling arrangements around the world, I cannot make any strong predictions about the effects of modern pools formed outside the United States on innovation and competition. Moreover, due to regional differences, pools formed in the United States may also have different effects on innovation and competition locally versus internationally. In supplementary analysis (available upon request), I find that the seven modern pools in my sample have positive and significant effects on both local and global follow-on innovations. However, the effect on innovation inside the United States is significantly larger, which may be because follow-on innovations are identified using the USPTO patent data and hence may not capture all the patented innovations granted outside the United States. Given the global impact of these arrangements and their growing prevalence outside the United States, future research may examine the role of national institutional differences in moderating the effects of modern pools.

Finally, like any other collaborative arrangement that involves competing parties, modern pools also provide an opportunity for anti-competitive and/or anti-innovative behavior. Modern patent pools are not only growing in number, they are also growing in size, from what used to be tens or hundreds to thousands of patents in some recent cases. This substantial growth in the size of modern pools raises concerns about how accurately experts can evaluate the quality of patents included in them and determine whether all the included patents are essential and complementary as required by law. The reported evidence here on the substantial impact of modern pools on the technology market and the industry structure, hence, calls for continuous, careful scrutiny of modern pools by antitrust authorities to ensure that these arrangements fulfill their purpose as pro-competition and pro-innovation platforms.

There is vast opportunity for future research. This paper attempts to explore the impact of modern patent pools on multiple related issues including innovation, industry structure, and firm positioning. The wide range of outcomes considered here naturally comes at the cost of analyzing each issue in lesser detail. Hence, there is ample opportunity in studying each of these aspects more deeply. There are also many related questions left unexplored: How does the membership composition of modern pools moderate their effect on innovation, industry structure, and competitive positioning of firms? How can pool members collectively commit to promote the adoption of the pool standard while at the same time potentially compete in developing the next generation of technologies that may render the current standard obsolete? More broadly, how can firms prepare for technological disruptions in the presence of interlocked relationships with other firms and strong network effects? How does the prospect of formation of a patent pool in the future influence the decision of firms to invest in one or another technology? How does the membership of not-for-profit organizations such as universities influence their research direction and contribution to future technologies? Under what circumstances do pooling agreements fail and how can firms develop capabilities to balance the tradeoffs between value creation and value capture through interfirm collaborations? The answers to these questions can help us better understand the complex relationship between interfirm collaboration, competition, innovation, and industry structure.

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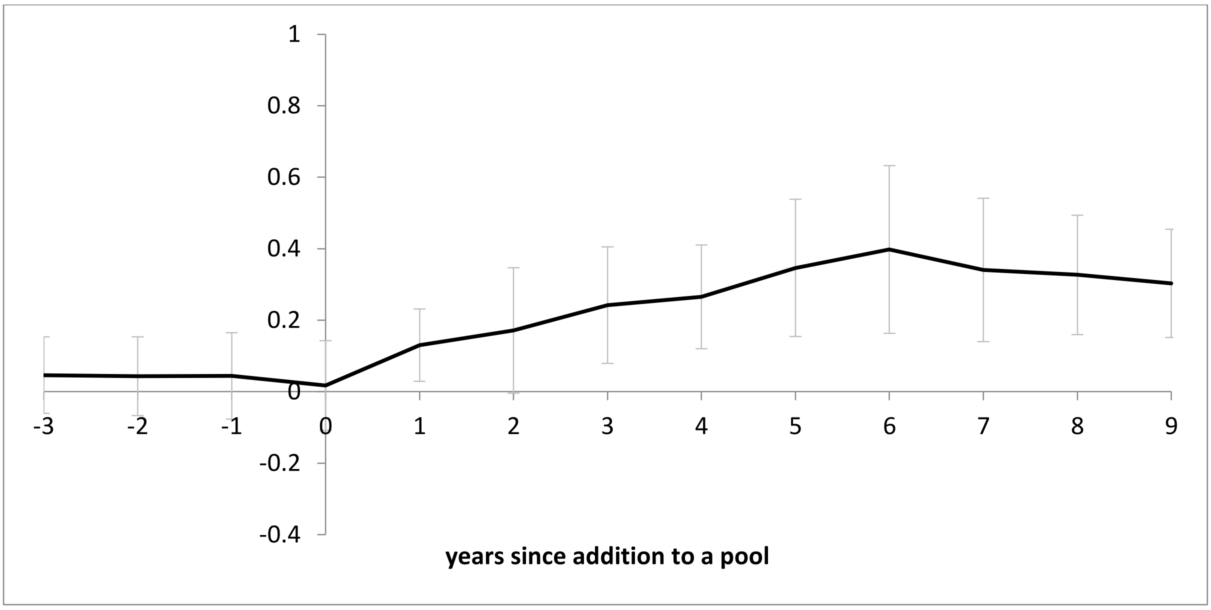
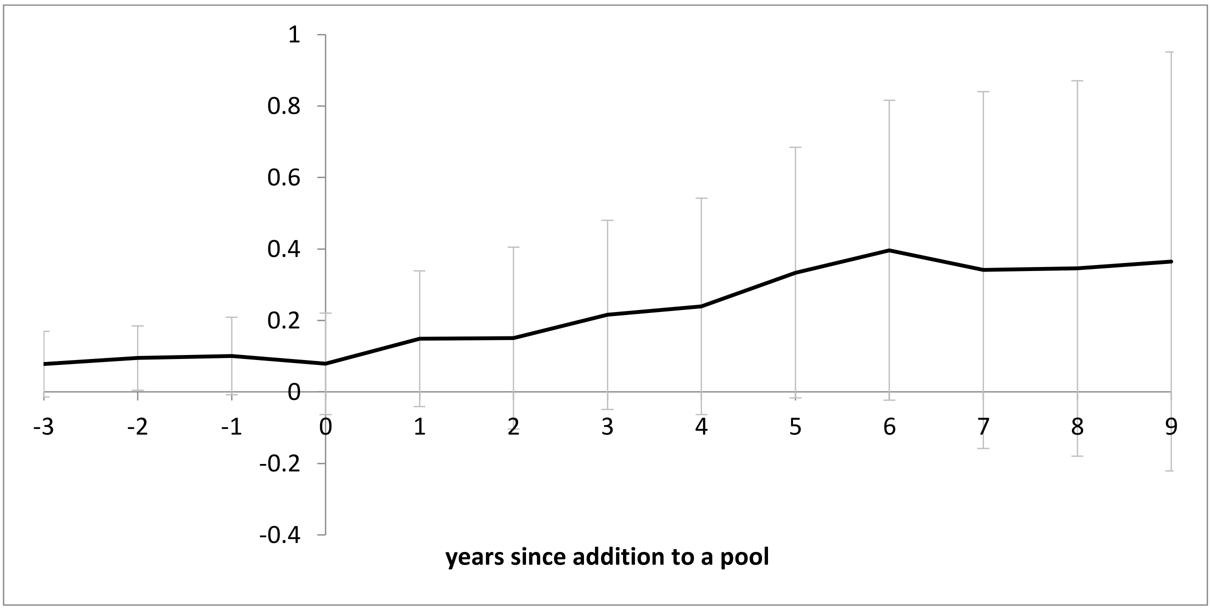
Figure 1- The estimated change in the logged yearly citation rate of patents before and after their addition to a pool (top 40% cited matched patents used as control)



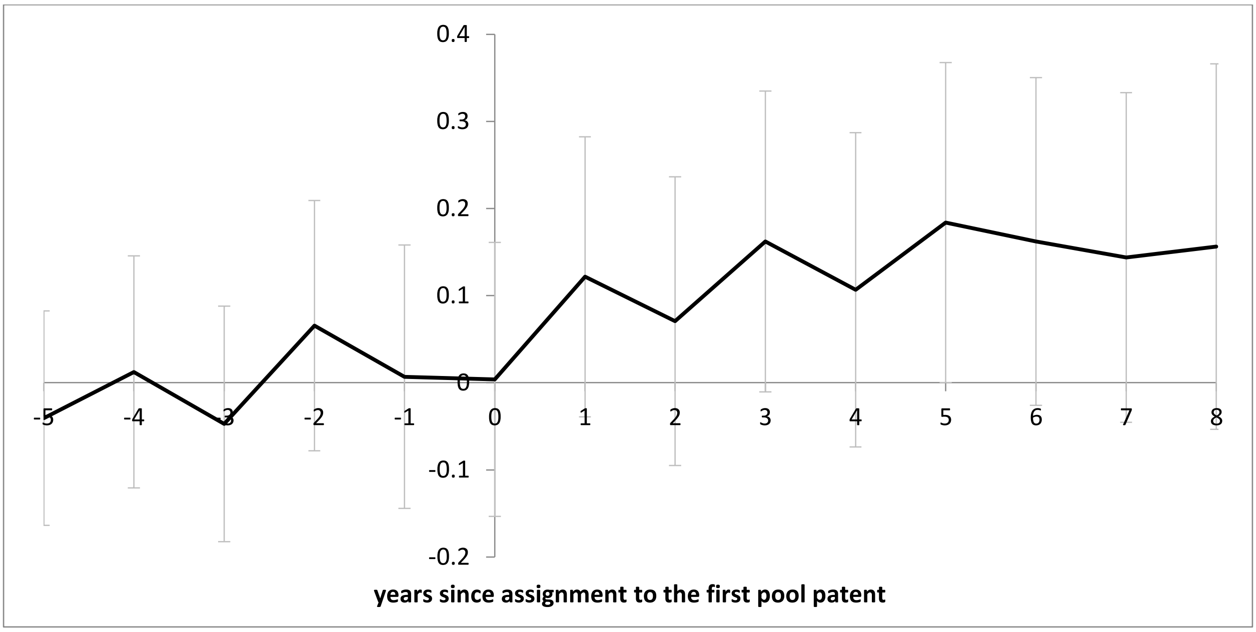
Note: the graph shows the impact of pooling agreements on a patent's yearly citation rate after inclusion in a modern pool. The estimated points are based on comparing yearly citation rates of patents added to a pool to yearly citation rates of a set of matched control patents. Error bars show the upper and lower bounds for the 95% confidence interval around each estimated point.

Figure 2- The estimated change in the yearly citation rate of patents (logged) before and after their addition to a pool (only pool patents included in the estimation)



Note: the graph shows the impact of pooling agreements on a patent's yearly citation rate after inclusion in a modern pool. The estimated points are based on comparing the yearly citation rate of patents added to a pool to that of patents that will be added to a pool in the future. Error bars show the upper and lower bounds for the 95% confidence interval around each estimated point.

Figure 3- The estimated change in the yearly patenting activity (logged) in technology subclasses assigned to pool patents before and after their first assignment



Note: The graph shows the impact of modern pools on technology subclasses associated with them. The estimated points are based on comparing the yearly patenting rates in technology subclasses associated with modern pools to technology subclasses that have yet to be associated with a pool but will be in the future. Error bars show the upper and lower bounds for the 95% confidence interval around each estimated point.

Table 1- Sample of modern pools

Name of the pool	Description of the technology standard	Year of pool formation	Initial pool member count	More information on the licensing structure
MPEG-2	MPEG-2 is an international standard developed by the Moving Picture Expert Group in the ’90s and defined as “the generic coding of moving pictures and associated audio information” (ISO/IEC 13818 MPEG2). The standard contains different coding algorithms to compress and transfer digitalized video and audio signals.	1997	9	http://bit.ly/1SYVnBl
MPEG-4 Systems	The MPEG-4 Systems Standard defines methods to format different components of multiplexer programs, merge them into a single program, and transfer the final program via digital streaming.	2002	5	http://bit.ly/1T1KYbs
MPEG-4 Visuals	MPEG-4 Visuals is a set of standards developed by the Moving Picture Expert Group and contains algorithms and methods for compressing and transmitting videos. Several popular codecs, including DivX, Xvid, and Nero Digital, implement this standard.	1997	5	http://bit.ly/1Uzpp0T
Audio MPEG	Audio MPEG contains a set of formats and coding algorithms to compress and transmit audio content, using lossy data-compression techniques.	2001	4	http://bit.ly/1rv6V6g
IEEE 1394	IEEE 1394 contains the interface algorithms for high-speed, real-time data transfer through a serial bus.	1999	8	http://bit.ly/1W9p4DU
AVC	AVC is a motion-compensation-based video-compression method. It is currently one of the most popular formats for recording, compressing, and transmitting video material.	2004	14	http://bit.ly/1LGdMzk
DVD 6C	DVD is an optical disc storage format that can store all types of digital data and is widely used for storing computer files as well as audio and video programs.	1999	6	http://bit.ly/1TmGlCy

Table 2a—Summary statistics for pool patents and matched control patents

	Stats
Pool Patents	
Logged yearly citation rate (excluding self-citations)	0.589 (0.780) Obs: 7140
Yearly share of vertically integrated firms citing the patent (MPEG-2 patents only)	.269 (0.335) Obs: 726
Matched control Patents	
Logged yearly citation rate (excluding self-citations)	0.665 (0.763) Obs: 25641
Yearly share of vertically integrated firms citing the patent (only patents matched to MPEG-2 patents)	0.281 (0.352) Obs: 2515

Table 2b—Summary statistics for each pool in the sample

	Number of Patents	Yearly citation rate of pool patents	Min/Max of yearly citation rate of pool patents	Ratio of startup to diversifying firms citing pool patents	Number of assigned technology subclasses to pool patents
MPEG-2	73	2.685 (4.324)	Min: 0 Max: 37	4.724 (26.406)	41
MPEG-4 Systems	9	0.704 (1.306)	Min: 0 Max: 6	1.861 (13.544)	8
MPEG-4 Visuals	69	1.488 (2.997)	Min: 0 Max: 19	2.549 (17.112)	41
Audio MPEG	16	1.167 (2.421)	Min: 0 Max: 20	2.823 (18.839)	11
IEEE 1394	56	1.785 (3.278)	Min: 0 Max: 29	2.588 (16.660)	38
AVC	27	1.912 (3.305)	Min: 0 Max: 19	1.268 (11.179)	23
DVD 6C	270	1.513 (3.612)	Min: 0 Max: 60	2.806 (18.108)	111

Note: some patents belong to multiple pools

Table 2c—Summary statistics for pool technology classes

	Stats
Yearly average patent count in a subclass (1985–2010)	7.633 (15.693) Obs: 5434
Yearly average weighted patent count in a subclass (1985–2010)	50.909 (127.031) Obs: 5434
Average yearly number of pool patents assigned to each subclass (1985–2010)	0.870 (2.179) Obs: 5434
Average number of technology subclasses associated with each pool (1985-2010)	39.000 (32.058) Obs: 7

Table 2d—Summary statistics for entities that had invested in technologies related to the MPEG-2 standard

	Vertically Integrated firms	Non-Integrated, technology-focused entities
Observations	505	341
Yearly patenting rate	3.756 (2.327)	3.056 (2.139)
Yearly weighted patenting rate	4.561 (2.842)	3.891 (2.706)
Logged sales	9.258 (1.907)	6.561 (2.310)
Logged R&D intensity	0.081 (0.048)	0.186 (0.391)
Logged capital intensity	0.777 (0.240)	0.835 (0.604)

Table 3—The impact of pool formation on follow-on innovation rate based on the pooled standard

	(1)	(2)	(3)
Sample:	**Pool patents + matched patents**	**Pool patents**	**Pool patents (excluding citations from universities, government labs, and other not-for-profit organizations)**
DV:	**Ln(citations$_{it}$+1)**	**Ln(citations$_{it}$+1)**	**Ln(citations$_{it}$+1)**
Model:	**Panel OLS with patent fixed effects**	**Panel OLS with patent fixed effects**	**Panel OLS with patent fixed effects**
Pool patent	0.236** (0.022)	0.137** (0.035)	0.070** (0.024)
Five-degree polynomial dummies for patent age	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes
Constant	0.361** (0.044)	0.255** (0.058)	0.286** (0.056)
Observations	32781	7140	7140
Number of patents	2357	489	489
F Statistics	307.43**	36.76**	36.76**
R-Squared	0.352	0.285	0.370

Note: All estimates are from panel ordinary-least-squares (OLS) models with patent fixed effects. Robust standard errors are clustered at the patent level and shown in parentheses. ** p<0.01, * p<0.05, + p<0.1

Table 4—The impact of pool formation on subsequent innovation rate in technology classes assigned to pool patents

	(1)	(2)	(3)	(4)
Sample:	**Pool technology subclasses**			
DV:	**Ln(patent count$_{it}$+1)**	**Ln(patent count$_{it}$+1)**	**Ln(weighted patent count$_{it}$+1)**	**Ln(weighted patent count$_{it}$+1)**
Model:	**OLS**	**OLS**	**OLS**	**OLS**
Has a pool patent	0.336* (0.140)		0.450* (0.221)	
Number of pool patents		0.089** (0.016)		0.071** (0.007)
Major tech class * year dummies	Yes	Yes	Yes	Yes
Constant	1.040** (0.000)	1.038** (0.000)	2.657** (0.000)	2.657** (0.000)
Observations	5434	5434	5434	5434
R-Squared	0.500	0.515	0.581	0.584

Note: All estimates are from ordinary-least-squares (OLS) models with year and technology class fixed effects. Robust standard errors are clustered at the technology subclass level and shown in parentheses. ** p<0.01, * p<0.05, + p<0.1

Table 5—The impact of pool formation on follow-on innovation rate based on the pooled standard by vertically integrated firms vs. non-integrated entities

	(1)	(2)	(3)	(3)
Sample:	**MPEG-2 pool patents + matched patents**	**MPEG 2 Pool patents + matched patents**	**MPEG-2 pool patents**	**MPEG-2 pool patents**
DV:	**Ln(citations$_{it}$+1)**	**Share of VI citers**	**Share of VI citers**	**Share of VI for-profit company citers**
Model:	**Panel OLS with patent fixed effects**	**Panel OLS with patent fixed effects**	**Panel OLS with patent fixed effects**	**Panel OLS with patent fixed effects**
Pool patent dummy	0.292** (0.087)	-0.082* (0.035)	-0.096* (0.048)	-0.072* (0.036)
Five-degree polynomial dummies for patent age	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Constant	0.629** (0.228)	0.271** (0.047)	0.405** (0.047)	0.851** (0.057)
Observations	3241	3241	726	726
Number of patents	386	386	73	73
R-Squared	0.149	0.071	0.222	0.170

Note: All estimates are from panel ordinary-least-squares (OLS) models with patent fixed effects. Robust standard errors are clustered at the patent level and shown in parentheses. ** p<0.01, * p<0.05, + p<0.1

Table 6—The impact of pool formation on follow-on innovation by independent inventors

	(1)	(2)
Sample:	**Pool patents + matched patents**	**Pool patents**
DV:	**Share of citations from patents by independent inventors**	**Share of citations from patents by independent inventors**
Model:	**Panel OLS with patent fixed effects**	**Panel OLS with patent fixed effects**
Pool patent dummy	0.738** (0.199)	0.790* (0.387)
Five-degree polynomial dummies for patent age	Yes	Yes
Year dummies	Yes	Yes
Constant	0.574* (0.274)	0.267** (0.050)
Observations	32781	7140
Number of patents	2357	489
R-Squared	0.009	0.015

Note: All estimates are from panel ordinary-least-squares (OLS) models with patent fixed effects. Robust standard errors are clustered at the patent level and shown in parentheses. ** p<0.01, * p<0.05, + p<0.1

Table 7—The impact of pool formation on follow-on innovation by integrated firms vs. non-integrated entities

	(1)	(2)
Sample:	**Pool patents + matched patents**	**Pool patents**
DV:	**Ratio of startups to diversifying entrants**	**Ratio of startups to diversifying entrants**
Model:	**Panel OLS with patent fixed effects**	**Panel OLS with patent fixed effects**
Pool patent dummy	4.357** (0.605)	3.826* (0.035)
Five-degree polynomial dummies for patent age	Yes	Yes
Year dummies	Yes	Yes
Constant	1.857 (1.286)	-2.285 (1.775)
Observations	32544	7110
Number of patents	2357	489
R-Squared	0.038	0.042

Note: All estimates are from panel ordinary-least-squares (OLS) models with patent fixed effects. Robust standard errors are clustered at the patent level and shown in parentheses. ** p<0.01, * p<0.05, + p<0.1

Table 8— The impact of pool formation on the total patenting rate of publicly listed, vertically integrated firms relative to publicly listed, non-integrated firms

	(1)	(2)	(3)
Sample:	**Publicly listed firms that had cited at least one MPEG-2 patent before 1997**		
DV:	**Ln(patent $count_{it}$+1)**	**Ln(citation weighted patent $count_{it}$+1)**	**Ln(patent $count_{it}$+1)**
Model:	**Panel OLS with firm fixed effects**	**Panel OLS with firm fixed effects**	**Panel OLS with firm fixed effects**
Vertically integrated × post-pool formation	-0.517* (0.242)	-0.545+ (0.287)	-0.409* (0.196)
Vertically integrated × After 95			-0.076 (0.171)
Vertically integrated × After 96			-0.095 (0.169)
Logged sales (1yr lagged)	0.467* (0.185)	0.302 (0.213)	0.462* (0.188)
Logged R&D intensity (1yr lagged)	0.066 (0.162)	0.050 (0.197)	0.059 (0.163)
Logged capital intensity (1yr lagged)	0.293+ (0.153)	0.199 (0.205)	0.280+ (0.161)
Constant	-0.190 (1.563)	2.788 (1.795)	-0.148 (1.596)
Observations	621	621	621
Number of firms	70	70	70
R-Squared	0.244	0.613	0.245

Note: All estimates are from panel ordinary-least-squares (OLS) models with firm fixed effects. Robust standard errors are clustered at the firm level and shown in parentheses. ** p<0.01, * p<0.05, + p<0.1

Table 9- The impact of the MPEG-2 pool on the tendency of firms towards mentioning MPEG-2 implementation in their annual 10-K reports after the pool formation

	(1)
DV:	**Mentioning MPEG-2 implementation in annual 10-K report (0/1)**
Model:	**Panel OLS with firm fixed effects**
Firms with investments in technologies related to the MPEG-2 technology standard * After Pool Formation	0.129** (0.052)
Constant	0.072 (0.126)
Firm fixed effects	Yes
Year fixed effects	Yes
Observations	186
Number of firms	20

Note: Estimates are from panel ordinary-least-squares (OLS) models with firm fixed effects. Robust standard errors are clustered at the firm level and shown in parentheses. ** p<0.01, * p<0.05, + p<0.1