Paper to be presented at

DRUID15, Rome, June 15-17, 2015

(Coorganized with LUISS)

Collaborative promotion of fragmented technology standards and the impact on follow-on innovation: Evidence from modern patent pools

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Jelcodes:O32,O33

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Introduction

A technology standard, once adopted by a critical mass of users, can generate long-term competitive advantage and substantial financial returns for its owner (David & Greenstein 1990; Hill 1997; Schilling 2002; Suarez & Utterback 1995). It is no surprise, therefore, to see firms investing heavily in boosting the adoption of their developed standards (Hill 1997). Previous studies broadly emphasize the importance of strategic factors such as timing of entry (Khazam & Mowery 1994, Schilling 2002), pricing (Hill 1997, Khazam & Mowery 1994, Rosenbloom & Cusumano 1987), and forming alliances with users and complementors (Hill 1997, Langlois 1992, Schilling 1999, Soh 2010, Suarez 2005) in shaping the user base of a firm's standard. However, these studies are largely agnostic about the nature of the standard or technology itself. More particularly, they generally rely on the implicit assumption that standard developers have full ownership control over their developed standards and hence can directly strategize on particular pricing, timing, and networking strategies.

Yet, recent technology standards are increasingly developed through collaboration among a large number of market players (Chiao, Lerner & Tirole 2007, Farrell & Simcoe 2012, Rysman and Simcoe 2008) which leads to considerable fragmentation in their ownerships (Shapiro 2001). The ownership fragmentation, in turn, creates particular hurdles for any individual partial owner to promote the fragmented standard. The threat of free-riding of other owners can discourage each firm from investing in any promotional strategies. Moreover, any pricing, marketing or networking tactics would be rendered ineffective if not coordinated among 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 & Shapiro 2007, Shapiro 2001). These issues together can result in underutilization of fragmented standards in subsequent technologies and products and highlight the importance of effective collaborative mechanisms that would facilitate coordinated promotion of the standard among the partial owners (Merges 1999, Shapiro 2001).

While a growing body of research has studied standard setting organizations (SSOs) as a collaborative platform that allows firms to coordinate their actions during the development phase of fragmented standards (Besen & Farrell 1991, Chiao et al. 2007, Farrell & Simcoe 2012, Rysman & Simcoe 2008), much less attention is given to studying collaborative arrangements that firms use to promote fragmented standards post-development. This paper attempts to address this gap by studying a particular collaborative arrangement that has been increasingly used by firms to address the fragmentation problem: modern patent pools.

A patent pool is an agreement between two or more parties to license their patents on a particular technology to other parties based on some fixed terms. Majority of modern patent pools have been formed around fragmented technology standards that had been previously developed within standard setting organizations (SSOs). Department of Justice requires pooling agreements to promote both competition and innovation (U.S. Department of Justice & Federal Trade Commission 2007).

However, due to anti-trust concerns associated with collaborative arrangements involving competing parties, much of extant research on patent pools has focused on their competitive effects and antitrust aspects (Gilbert 2004, Lerner, Strojwas & Tirole 2007, Lerner and Tirole 2004, Layne-Farrar and Lerner 2011, Shapiro 2001). These studies, however, only indirectly hint at whether and how patent pools influence follow-on innovation based on fragmented standards. The recent studies that have examined the impact of patent pools on innovation have mainly focused on traditional patent pools – of which many were already deemed as anti-competitive and anti-innovative and got dismantled eventually (ex: Lampe & Moser 2010, Lampe & Moser forthcoming). The very few studies on the impact of modern pools on innovation are either limited to case studies (ex: Flamm 2013) or has focused on a particular group of firms such as pool members or licensees (ex: Joshi & Nerkar 2011). Hence, whether or not these arrangements promote or hinder subsequent technological development based on the pooled standards remains relatively unexplored.

Predicting the impact of these arrangements on innovation is not theoretically straightforward. In principle there are several mechanisms through which modern patent pools influence further innovation based on pooled standards. On the one hand, modern patent pools can lower the cost of access to the pooled standard by reducing the search, negotiation and licensing costs associated with licensing the standard. Moreover, they can build a "bandwagon" momentum (Suarez and Utterback 1995) behind the pooled standards by showing commitment to their adoption by the industry leaders participating in forming the pools. 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 which require licensees to transfer the rights to any improvements to the standard back to the pool at a low cost. Also, the risk of cannibalizing the pooled standard can in principle disincentive pool members and licensees to invest in follow-on generations of the standard (Joshi & Nerkar 2011). The presence of these offsetting effects makes it difficult to make a straightforward prediction regarding the net impact of modern pools on subsequent innovations.

At the same time, while examining the aggregate net effect of modern pools on innovation would shed some light on their effectiveness as a promotional strategy, it nevertheless provides little insight into the strategic behavior of firms in response to the formation of these arrangements. This is particularly important given the potentially contrasting effects of modern pools on vertically integrated firms versus non-integrated technology-focused ones. 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 these compatibility rules facilitates the specialized production of individual components and complementary technologies which would, in turn, enlarge the strategy space of firms and potentially influence their future R&D trajectory based on their position in the market (Arora, Fosfuri & Gambardella 2001). Given their manufacturing and commercialization capabilities, vertically-integrated firms can choose to shift their investments towards downstream application development based on the standard. On the other hand, specialized technology firms which usually lack the manufacturing and commercialization capabilities can target the vacant upstream space and focus more narrowly on developing the complementary technologies. The existence of the pooled standards then ensures successful integration of upstream technologies and downstream products.

Given the gap in the literature, in this paper I explore both the aggregate effect of modern pools on follow-on innovation as well as their heterogeneous impact on the competitive position of vertically-integrated versus non-integrated, technology-focused firms. The analysis is performed using detailed data on six major modern pools that were formed between 1997 and 2004. The central empirical challenge is that I cannot observe the counterfactual, i.e. what would have happened to subsequent innovations based on the pooled standard if these pools had not been formed in the first place. In the absence of an ideal natural experiment, I use various matching and difference-in-difference empirical strategies to estimate the causal impact of modern pools on follow-on innovation.

The findings reveal that the establishment of modern patent pools can lead to an economically and statistically significant increase in follow-on innovations based on the pooled fragmented standards. Focusing on the MPEG-2 pool – the first modern patent pool – 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. In an unreported complementary analysis, using detailed data from the annual 10-K reports of publicly-listed firms that were affected by the formation of the MPEG-2 pool, I further find evidence of a shift in the investment direction of vertically-integrated firms from upstream technological development towards downstream application development post-pool formation. The findings suggest that the establishment of modern pools boosts further technological innovation based on pooled standards and at the same time causes a shift towards vertical disintegration in the associated industries.

The results have both managerial and policy implications. Can modern patent pools be used by firms as a collaborative platform to promote the adoption of fragmented technology standards that otherwise face the threat of under-adoption due to their excessive adoption costs? The results in this study suggest that the answer is yes. Moreover, the findings also explain why it might be in the benefit of firms to join a pool and charge a lower licensing fee for their pieces of a particular standard relative to what they could potentially charge outside the pool. The findings suggest that modern patent pools can considerably increase the total size of the market for the pooled technology standards by reducing the uncertainty and cost associated with their adoption. Thus, while the fee on each license might be lower when a firm joins a pool, the pool members can nevertheless enjoy a substantially larger market for their technology standard.

Moreover, this study provides a more nuanced picture of the impact of modern pools on the industry structure and the competitive position of firms along the value chain. Consistent with previous conceptual and qualitative works on industry standards, the findings suggest that modern patent pools can indeed trigger vertical disintegration across a wide range of industries and enable vertically-focused market players to enter and participate in the disintegrated value creation chain.

The results can also inform the current policy discussions around the potential negative impact of modern patent pools on innovation. The results here suggest that modern pools can indeed boost the development of subsequent complementary technologies based on the fragmented standards. These results, along with prior theoretical works suggesting their pro-competitive effects, provide stronger evidence in support of these arrangements form a policy point of view. Moreover, the findings 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 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.

Fragmented standards and modern patent pools

Technology standards are increasingly developed through collaborative arrangements such as standard setting organizations (David & Greenstein 1990, Rysman & Simcoe 2008). The collaborative nature of the development process means that various pieces of the standard are usually patented by several parties. Moreover, several theoretical and empirical works suggest that the ownership fragmentation of a technology standard can lead to under-adoption of the standard due to higher litigation risks, excessive royalty rates and soaring transaction costs faced by potential adopters (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 free-riding threat 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 engage in a collaborative strategy to promote the fragmented standard. A growingly used solution 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 each other and to third parties usually on defined fixed terms.

Patent pools do indeed have a long history in the U.S., 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 anticompetitive arrangements and many of them were eventually dismantled by antitrust authorities (Gilbert 2004). No major pool arrangements had been established since the end of World War II until the introduction of the MPEG-2 pool, the first modern pool. On June 26, 1997, the Department of Justice (DOJ) sent a letter to the 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 pooling arrangements that would not violate antitrust laws. The major difference between modern pools and their traditional counterparts is that the former is only allowed to include essential and complementary patents. This policy is intended to prevent opportunistic, anti-competitive behavior by pool members to the extent possible (Shapiro 2001).

Since the formation of the MPEG-2 pool in 1997, patent pools have consistently increased in number, economic significance and the extent of the technological fields in which they are implemented (World Intellectual Property Report 2011). It is also important to note that as technology standards evolve over time, the pools associated with them also change and grow gradually. For example, while there were originally 27 patents that were 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.

Impact of Modern Pools on Innovation

Modern patent pools are required to be both pro-competitive and pro-innovation (U.S. Department of Justice & Federal Trade Commission 2007). However, because serious concerns about traditional pools rested on their anticompetitive effects, most of the literature on modern pools has focused on their design and total welfare implications (Shapiro 2001, Gilbert 2004, Lerner & Tirole 2004). The general prediction of these theoretical studies is that modern pools should be welfare-enhancing based on the premise that they do not include substitute or weak patents.

More recently, though, scholars have started to explore the impact of patent pools on innovation. The few theoretical and conceptual works in this area mainly predict that modern pools are likely to encourage follow-on innovation by lowering the costs associated with adopting the pooled fragmented standard (Merges 1999, Shapiro 2001). First, the current governing policies of modern pools mandate that any potential licensee should be able to acquire a license to all the patents included in a modern pool at a fair price and with little 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 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 the licensing and negotiation costs of acquiring the necessary license to all the patented pieces of a fragmented standard within the pool.

Second, pooling the essential patents that compromise a technology standard reduces the search cost for the potential adopters. A common difficulty in front of adopting fragmented standards is that even if the potential adopters are willing to pay the excessive licensing fees for each essential piece of the standard, they cannot be sure whether they have identified all the essential pieces required for implementing the standard or whether there are still other pieces patented by unidentified parties that might later sue them for infringing on their intellectual property. The inclusion of essential patents within the pool can alleviate this issue to a great extent 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. It means that the set of patents inside a pool might not necessarily cover all the essential patents required for implementing a particular standard. However, even if a pool does not contain all the essential patents, at the minimum it reduces the cost associated with identifying the patents that are included in the pool. Thus, in short, modern pools can actually reduce the search and potential infringement costs associated with adopting a fragmented standard.

Third, the formation of a pool can send a clear signal that the main developers of the pooled technology standard are committed to use the standard and facilitate its subsequent development in the future. Such a commitment can indicate the presence of a sizable market for future complementary technologies and, therefore, can 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 & Shapiro 1994, 1986, Suarez & Utterback 1995). This mechanism is particularly relevant when the pool is formed in a technological environment with several competing standards and high uncertainty around which one 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 the pool can reduce the incentive of pool members and potential licensees to invest in follow-on technological developments that might cannibalize the already established pooled standard (Joshi and Nerkar 2010, Grossman and Shapiro 1986). Also, licensing deals of most modern pools include a grant-back provision which requires the licensees to transfer any improvements they make to the licensed standards back to the pool (Lerner, Strojwas & Tirole 2007). This prevents the pool members and licensees from independently market their own technological improvements which can potentially reduce incentives for investing in such improvements. Both of these mechanisms only apply to investments in improving the pooled standard, and not those in complimentary technologies based on it. Nonetheless they can negatively influence some of the investments in further technological developments based of 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 two following competing hypotheses:

H1a: the formation of modern patent pools has a positive impact on follow-on innovations based on the pooled technology standards.

H1a: the formation of modern patent pools has a negative impact on follow-on innovations based on the pooled technology standards.

While the sign of the net effect on innovation is not clear, it is nevertheless possible to make some inferences about the heterogeneous impact of these arrangements on innovations by vertically-integrated firms versus non-integrated, technology-focused ones.

A technology standard is a set of rules that determines how various pieces of a particular technology should communicate with each other as well as external technologies. Tassey (2000) defines a standard in technology-based markets as “a set of specifications to which all elements of products, processes, formats, or procedures under its jurisdiction must conform”. Technology standards generally emerge where there are many different ways of delivering the same functionality. The existence of multiple competing technological solutions can reduce the adoption of any one solution due to high uncertainties around which solution would become the dominant one in the future. Consensus around a particular technology standard can thus reduce uncertainty around future technological investments in complementary technologies and products by ensuring compatibility between them and the standard. As a result, establishment of a technology standard can facilitate the specialized production of complementary technologies as well as products based on the standard. This, in turn, would open up the strategy space of firms and enable them to focus on either upstream technological development or downstream application development (Arora, Fosfuri & Gambardella 2001).

Furthermore, by centralizing and pooling the intellectual property rights of owners over the essential pieces of standards, patent pools reduce the risk of ‘opportunistic behavior’ by both pool members and potential adopters. Modern pools, thus, can facilitate a synergic relationship between standard owners, upstream component developers and downstream product manufacturers (Arora & Merges 2004, Gans & Stern 2003, 2010).

In summary, by standardizing the information exchange rules and simplifying the transaction mechanisms across various parties, I expect patent pools to stimulate higher levels of vertical disintegration in the market where integrated firms are more likely to redirect their investments on follow-on technological innovations towards developing market applications based on the pooled standard. At the same time, the focus of integrated firms on downstream application development would open a space for upstream technology-focused entities to focus on developing complementary technologies in the more vacant upstream market. Therefore, I propose the following two complementary hypotheses:

> H2: following the formation of modern pools, there will be a higher share of follow-on innovations developed by non-integrated entities relative to vertically-integrated firms.
>
> H3: 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 & 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 particularly exclude the citations by the owner of the focal patent to capture the adoption rate by other parties. Also, I use the total amount of patenting in a particular technology class as a proxy for the total amount of innovative activity in that technology class (Lampe & Moser forthcoming).

The key challenge in front of estimating the net 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 (SSOs), I identify the impact of these six 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 types of control samples to estimate the unobserved counterfactual: 1) a set of matched patents selected based on application year and main technology class, and 2) the set of patents that are already added or will be added in the future to one of the six pools in the sample. With the former control sample, I rely on the accuracy of the matching method to be able 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 patents have been added to their respective pools at various 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 have not yet added to a pool can serve as a comparable comparison basis. I use the following difference-in-difference estimating equation:

(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 received by patent i in year t. I exclude any self-citations by the owner of patent i to be able 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 idiosyncratic qualities 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-learn effect of patent age on its yearly citation frequency is captured by age_{it}^{n}, a set of five dummies from a five-degree polynomial age function. Age of patent i in year t is equal to t minus the patent's grant year.

$Pool\_Patent_{it}$ is equal to one if patent i is added to a pool in year t. Hence, coefficient β captures the net effect of inclusion into a pool on the subsequent average yearly citation rate of a typical patent.

The problem with using changes in patent citations is that they might happen due to mechanisms other than those that reflect the effectiveness of pooling arrangements in promoting the adoption of pooled standards. For example, once patents are added to a pool, their observability in searches for prior art might go up and hence patent examiners might 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 which is there to enforce the collective IP rights of pool members.

Given these issues, I use a second set of estimations based on a different empirical strategy that does not rely on patent citations directly. Following the idea introduced by Lampe and Moser (forthcoming), I compare the change in the number of successful patent applications in a technology class once it is assigned a pool patent with that of other technology classes that had already been or would be assigned in the future to other pool patents. This method takes advantage of the fact that these technology classes were assigned to different pool patents at different points of time and with different rates. Hence, at any point of time, each technology class can be compared to other technology classes that are more or less affected by the formation of these pools. More particularly, I use the following estimating equation:

(2) $$Ln(Patent_{it}+1) = \beta.Pool\_TechClass_{it} + Top\_class_i \times Year_t + \alpha + \varepsilon_{it}$$

where $Ln(Patent_{it}+1)$ is the log-transformed number of successful patent applications in the technology class i in year t plus one. In robustness analysis, I use the weighted count of patents where I weight each patent by the total number of citations it has received in the five years following its grant date. The $Top\_Tech\_class_i \times Year_t$ is a set of interaction dummies between the parent class of the focal technology class i and each year in the sample. 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 sub-technology classes similarly in a particular year. $Pool\_TechClass_{it}$ is equal to one if in year t there exists at least one pool patent to which the technology class i is assigned as the primary technology class. Coefficient β, thus, captures the impact of the pool formation on the total number of inventions in technology classes assigned to the pooled patents. In another set of robustness tests, rather than using the zero/one assignment dummy ($Pool\_TechClass_{it}$), I use the total number of pool patents to which technology class i is assigned as the primary class in year t. The idea here is that to the extent that formation of modern pools would influence the total inventive activity in the associated primary technology classes, those classes with more pool patents should be affected more heavily.

The 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 rate in technology classes assigned to pool patents – is that they are unlikely to suffer from the same set of biases and identification issues. For example, while mechanical citations added by examiners or strategic citations added by other firms due to litigation fears might lead to an upward bias in the first estimation strategy, they would lead to little or, if any, a potentially negative bias in the second set of estimations. Hence, while none of these two empirical strategies are perfect, their results can complement each other.

In order to construct the sample for the analyses, I use detailed data on six 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. 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 four pools in the list, I acquired the data on the list of patents and their inclusion dates into each pool directly from the MPEG LA LLC which is 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 introduction. Using this method, I could 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 into a pool, I excluded the patents that were added to each pool after 2005. In total, I could identify 489 patents that were added to at least one of these pools between 1997 and 2005. For each of these patents, I also collected the data on its assigned technology classes, its application and grant dates, and its follow-on citations by subsequent patents from the NBER patent dataset (2010 version). The same data was collected for the 4920 control patents matched based on the application year and the primary technology class.

In order to test H2, I test whether there is a decline in the share of vertically-integrated firms that have been citing a pool patent after its inclusion into a pool. To be able 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 the publicly available information on the Internet regarding each firm's activities and products. In particular, I searched for any indication that a firm has been manufacturing any downstream products at 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, universities, research labs, and inventors associated with no institution. Given the large number of firms that have cited the selected pool patents and the intensive time required for identifying the vertical integration status of these firms in each year, I collected this data only for the entities that have cited the MPEG-2 pool patents along with those 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 a similar estimating equation as 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 $VI\_Percent_{it}$ is the percentage of vertically integrated firms that cite patent i in year t. Thus, coefficient β here captures the differential impact of inclusion of patent i into 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).

To test H3 I need to track the innovation rate of vertically-integrated and non-integrated firms that had been working on technologies related to a pooled technology standard before the formation of the pool to see if there is a change in their innovation rates post-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 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 investment direction rather than a decrease or increase in their total R&D investment. Within this sample of firms, I estimate the change in the patenting rate of vertically integrated firms relative to that of technology-focused firms after the formation of the MPEG-2 pool, using the following estimating equation:

$$(4) \quad Ln(Patent_{it} + 1) = \beta . VI_i \times After_{PoolFormation_t} + Firm_i + X_{it} + Year_t + \varepsilon_{it}$$

where $Ln(Patent_{it} + 1)$ is the log-transformed total number of successful patents applied by firm i in year t. Firm fixed effects, $Firm_i$, control for the time-invariant idiosyncratic 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_{it} is a set of firm-specific time-varying 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 $VI_i \times After\_PoolFormation_t$ is equal to one for vertically-integrated firms after the formation of the MPEG-2 pool in 1997. The coefficient β then captures the differential impact of the MPEG-2 pool on the patenting rate of vertically-integrated firms relative to non-integrated, technology-focused ones that had previously built technologies based on one or more MPEG-2 patents. Following the H3, 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 well. Again, I use the number of citations a patent has received in the five years following its grant date as a measure of its quality.

Results

Summary statistics are presented in Tables 1a, 1b and 1c. Table 1a provides the relevant summary statistics for the set of patents included in the six selected pools and their matched counterparts. Pool patents receive on average 0.589 citations every year during the sample period. In comparison, matched control patents receive about 0.357 citations per year. The difference between the two is significant which suggests that pool patents are on average more impactful and more economically significant than the matched patents. Column 1 of Table 2 shows the relationship between the yearly number of citations a typical patent received before 1997 (the year of the formation of the first modern pool) and whether or not the patent is a pool patent, controlled for a host of variables such as application year, technology class, patent age, and citation year. The estimated coefficient for the pool patent dummy suggests that pool patents received about 0.194 more citations per year relative to the matched control patents in the years prior to the formation of the first modern pool in 1997. This difference can potentially cause bias in the subsequent estimations. To make sure that the pool patents are indeed matched with a comparable set of control patents in terms of quality and impact, for most of the following estimations I only use the top 40% cited patents in the control sample. The summary stats for this subset of control patents (presented at the bottom of Table 1a) suggest a higher similarity level between pool patents and top cited control patents. Estimates in column 2 of Table 2 repeats the regressions in column 1 with the top 40% cited matched patents as control. The regression results do not show any significant difference between the yearly citation rate of pool patents and the top 40% cited matched patents before 1997.

The summary stats in Table 1a further suggests that about 27% of citations to MPEG-2 patents per year have been by vertically-integrated firms. The yearly shares of citations by vertically-integrated firms for the whole set of control patents (matched to MPEG-2 patents) and for the subset of top 40% cited ones are 33% and 28% respectively. Overall, the top 40% cited matched patents seem to be quite similar to the selected pool patents on the two dimensions of average yearly citation rate and the share of citations by vertically-integrated firms.

Table 1b presents the summary statistics for the technology classes assigned to pool patents. There are about 8 patents in each technology class in a typical year between 1985 and 2010. The average yearly weighted patent count in a typical pool class is about 51. Also, a typical technology class contains about 0.870 pool patents per year. The number of pool patents to which these technology classes are assigned range from 0 (for the period when the class is still not assigned to any pool patents) to 32.

Finally, Table 1c 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 firms and non-integrated ones respectively. Both groups have relatively similar yearly rate 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 compared to non-integrated technology-focused firms. Both set of firms are comparable in terms of capital intensity level.

Table 3 presents the estimation results for the impact of inclusion into a pool on the follow-on yearly citation rate of a patent (Equation 1). Column 1 shows the results for the estimation with the full set of matched control patents. The estimated β suggests that inclusion into a pool increases the subsequent yearly citation rate of a patent by approximately 4%. Column 2 repeats the estimations with the set of top 40% cited control patents. This time, the estimated β suggests an increase of about 22% in the yearly citation rate of patents once they are added to a pool. The third column presents the results for the sample excluding all the control patents. As explained in the methodology section, here the change in the yearly citation rate of a patent after its inclusion into a pool is compared to the yearly citation rate of other pool patents that had already been included into a pool or would be included in the future. The estimated β suggests an approximately 15% increase in the yearly citation rate of patents once they are included into a pool.

One might be concerned that the increase in the yearly citation rate of pool patents had started to grow before their inclusion into the pool. In other words the increase in yearly citation rates of pool patents might have started before their additions to the respected pools due to other factors such as their disclosure to the relevant standard setting organisations. 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 into a pool to 9 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 due to the more conservative nature of the estimation method. Nevertheless, the graph shows little sign of an upward trend in the yearly citation rates prior to the inclusion of the patents to a pool. Both figures suggest an increase in the yearly citation rate of pool patents starting about one year after their inclusion into a pool.

Table 4 reports the results for the impact of modern pools on the rate of innovation activity in technology classes assigned to the pool patents (equation 2). Column 1 shows the change in the patenting rate in technology classes with at least one pool patent relative to technology classes that have not yet assigned to any pool patents (but would be in the future). The estimated β shows an increase of about 40% increase in the average patenting rate in a technology class once it is assigned to at least one pool patent. In column 2, the zero/one dummy indicating whether a technology class is assigned to a pool patent is replaced with the total number of pool patents to which the technology class is assigned in any given year. The results show that the assignment of a technology class to one extra pool patent is associated with an increase of about 9% in the patenting activity in that class. 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 classes associated with its patents increases subsequently.

Similar to the previous set of estimations, one concern is that the increase in the patenting activity in each technology class might have started before the assignment of the class to a pool patent and the estimated β is merely picking up an upward trend in these technology classes. 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 to capture the average change in the total inventive activity in a technology class 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 class, 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, suggesting an increase in the total patenting activity in the years subsequent to the assignment of the class to the first pool patent. The figure shows little evidence of an upward trend prior to 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 do indeed increase the total amount of subsequent technological innovation based on the pooled patents.

Table 4 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 into a pool. In column 1, I simply replicate the impact of pool formation on the yearly citation rate of pool patents (equation 3) to show that the initial results 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 into the pool is about 23% which is very close to previous estimation 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, using the subset of top 40% cited matched patents as control. 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 pool 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 patent once it is added to the pool.

Table 6 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 4). 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 to non-integrated firms after the formation of the MPEG-2 pool in 1997. In the 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 confirm H3.

Robustness Tests

One concern regarding the latest results reported in Table 6 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 from the pool members. To test this idea, I compared the change in the financial performance of vertically-integrated firms with investments in technologies related to the MPEG-2 standard relative to 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 post-pool formation.

One might still be concerned that a relative decline in the patenting rate of vertically-integrated firms does not necessarily mean that they have redirected their focus to downstream application development. In an unreported analysis, I further tested the change in the investment direction of vertically-integrated firms with patents related to the MPEG-2 pool by using the information they had disclosed to investors in their annual 10-K reports. More particularly, I first created a sample of all the publicly listed firms with patents related to the MPEG-2 standard and its main competitors in 1997. I also constructed a control sample of all the other publicly-listed firms in the same four-digit SIC codes as the firms with MPEG-2 related patents. I then extracted the annual 10-K reports of all the collected firms in the top six representative industries from the SEC's EDGAR database for the years between

1994 and 2001. Subsequently, I identified the first report in which each firm mentions a product compatible with the MPEG-2 standard or a plan to implement it in current or new products.

I used a two-step approach to test the shift in the focus of vertically-integrated firms with MPEG-2 related patents after the pool formation. In the first step, using a hazard model analysis and a complementary logistic regression, I could verify that vertically-integrated firms with MPEG-2 related patents were significantly more likely to mention MPEG-2 implementation in their annual reports after the formation of the pool compared to other firms in the control samples. In the second step, I found that firms that mentioned any effort to implement MPEG-2 technology did indeed experience a significant decline in their patenting rate relative to other firms after the formation of the pool. Taken together, the results suggest that any attempt towards downstream product development based on the MPEG-2 standard was indeed associated with a lower patenting rate post-pool formation.

Finally, I tested the sensitivity of estimates reported in Tables 2 and 3 to other functional forms such as negative Binomial and Poisson. The estimates are essentially similar in terms of size and significance.

Discussion and conclusion

In this paper, I explore the effectiveness of modern patent pools as a collaborative platform to promote the adoption of fragmented technology standards in follow-on complementary technologies. The results suggest that modern patent pools can indeed boost the development of subsequent innovations based on the pooled standards. However, the findings further suggest that follow-up innovations are disproportionally developed by non-integrated, technology-focused entities, while vertically-integrated firms seem to be shifting their focus towards downstream application development.

Furthermore, the findings provide a more nuanced understanding of the heterogeneous impact of modern patent pools and more broadly technology standards on the industry structure and the competitive position of firms. Prior works on the impact of standards on the industry structure are largely limited to theoretical and conceptual works or qualitative studies. For instance, using an inductive qualitative method, Jacobides (2005) shows that the emergence of “standardized information” and “simplified coordination” have led to vertical disintegration in the mortgage banking industry, providing a space for vertically specialized firms to enter and participate in the industry. The results here provide further large-sample empirical support for the impact of technology standards on vertical disintegration of industries and the broader competitive landscape.

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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)

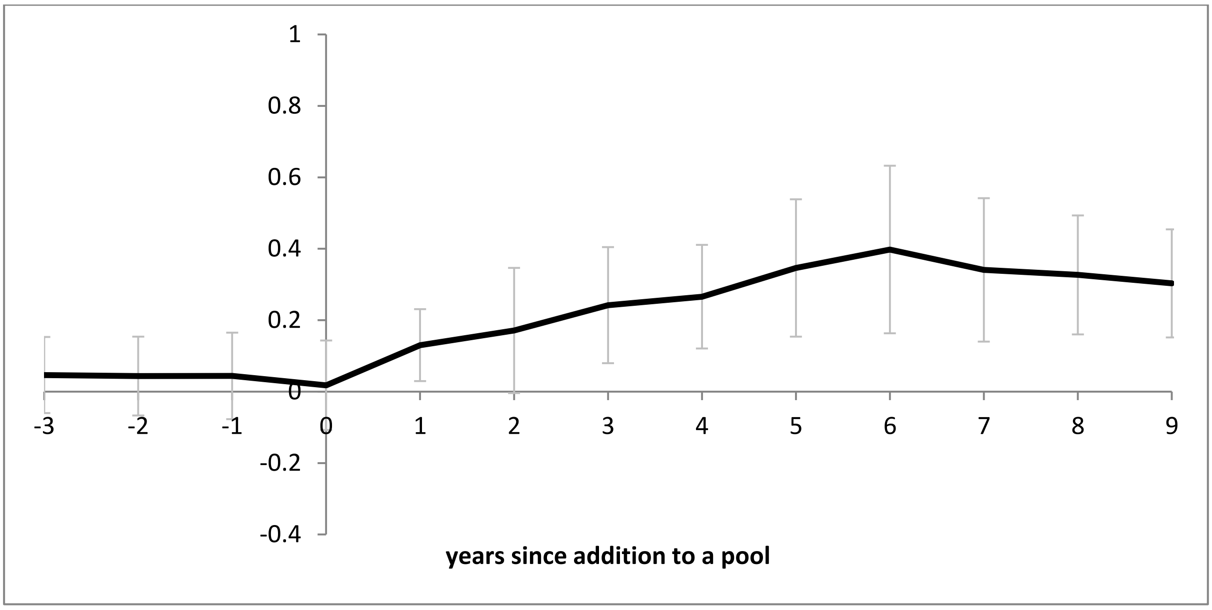

Figure 2- The estimated change in the yearly citation rate of patents (logged) before and after their addition to a pool (only pool patents included in the estimation)

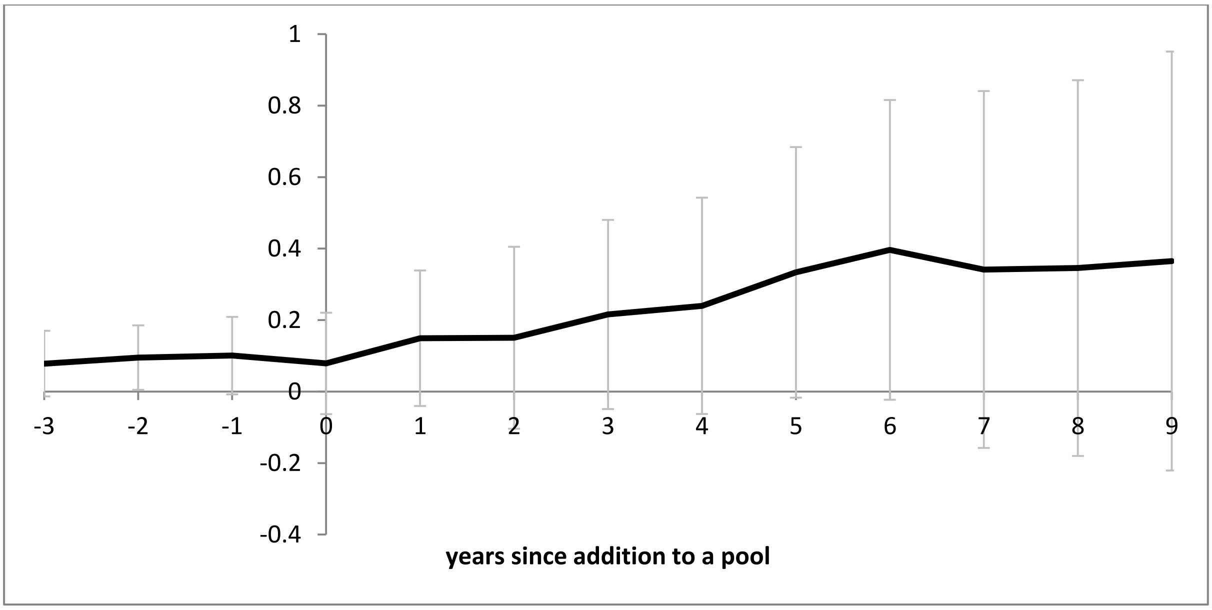

Figure 3- The estimated change in the yearly patenting activity (logged) in technology classes assigned to pool patents before and after their first assignment

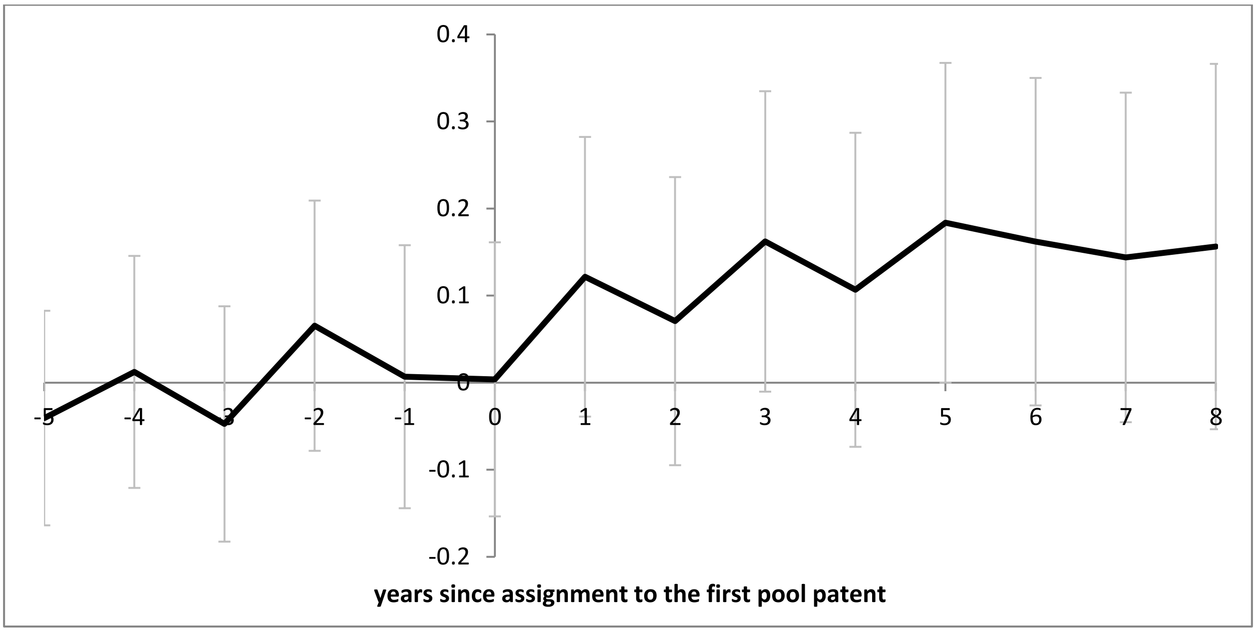

Table 1a – Summary statistics for pool patents and matched control patents

	Stats
Pool Patents	
Yearly citation rate (excluding self-citations)	0.589 (0.780) Obs: 7140
Yearly count of vertically-integrated firms citing the patent (MPEG-2 patents only)	.269 (0.335) Obs: 726
Matched control Patents	
Yearly citation rate (excluding self-citations)	0.357 (0.608) Obs.: 61451
Yearly number of vertically-integrated firms citing the patent (only patents matched to MPEG-2 paetnts)	.335 (0.391) Obs: 3572
Top 40% cited matched control Patents	
Yearly citation rate (excluding self-citations)	0.665 (0.763) Obs: 25641
Yearly number of vertically-integrated firms citing the patent (only patents matched to MPEG-2 paetnts)	0.281 (0.352) Obs: 2515

Table 1b – Summary statistics for pool technology classes

	Stats
Yearly average patent count in the class (1985-2010)	7.633 (15.693) Obs: 5434
Yearly average weighted patent count in the class (1985-2010)	50.909 (127.031) Obs: 5434
Average yearly number of pool patents assigned to each class (1985-2010)	0.870 (2.179) Obs: 5434

Table 1c – 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 2 – The difference between pool patents and full sample of control patents vs. top 40% cited control patents before 1997

	(1)	(2)
Sample:	**Pool patents + full sample of control patents Year < 1997**	**Pool patents + top 40% cited control patents Year < 1997**
DV:	**Ln(citations$_{it}$+1)**	**Ln(citations$_{it}$+1)**
Model:	**Panel OLS with robust standard errors**	**Panel OLS with robust standard errors**
Pool patent	0.194*** (0.038)	-0.016 (0.043)
Patent age dummies	Yes	Yes
Application year dummies	Yes	Yes
Technology class dummies	Yes	Yes
Citation year dummies	Yes	Yes
Constant	-0.250 (0.203)	-0.199 (0.253)
Observations	5387	3140
R-Squared	0.556	0.586

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

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

	(1)	(2)	(3)
Sample:	**Pool patents + full sample of control patents**	**Pool patents + top 40% cited control patents**	**Pool patents**
DV:	**Ln(citations$_{it}$+1)**	**Ln(citations$_{it}$+1)**	**Ln(citations$_{it}$+1)**
Model:	**Panel OLS with robust standard errors**	**Panel OLS with robust standard errors**	**Panel OLS with robust standard errors**
Pool patent	0.042* (0.021)	0.199** (0.023)	0.137** (0.035)
Five degree polynomial dummies for patent age	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes
Constant	0.189** (0.036)	0.364** (0.044)	0.255** (0.058)
Observations	68591	32781	7140
Number of patents	5409	2357	489
F Statistics	213.42**	301.72**	36.76**
R-Squared	0.226	0.351	0.285

Note: All estimates are from panel ordinary-least-squares (OLS) models with patent fixed effects. Robust standard errors are clustered at the technology class 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 tech classes**	**Pool tech classes**	**Pool tech classes**	**Pool tech classes**
DV:	**Ln(patent count$_{it}$+1)**	**Ln(patent count$_{it}$+1)**	**Ln(weighted patent count$_{it}$+1)**	**Ln(weighted patent count$_{it}$+1)**
Model:	**Panel OLS with robust standard errors**	**Panel OLS with robust standard errors**	**Panel OLS with robust standard errors**	**Panel OLS with robust standard errors**
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
Num. of tech classes				
R-Squared	0.500	0.515	0.581	0.584

Note: All estimates are from panel ordinary-least-squares (OLS) models with technology class fixed effects. Robust standard errors are clustered at the technology class 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)
Sample:	**MPEG-2 pool patents + top 40% cited control patents**	**MPEG 2 Pool patents + top 40% cited control patents**	**MPEG-2 pool patents**
DV:	**Ln(citations$_{it}$+1)**	**Percent of VI citers**	**Percent of VI citers**
Model:	**Panel OLS with robust standard errors**	**Panel OLS with robust standard errors**	**Panel OLS with robust standard errors**
Pool patent dummy	0.208** (0.077)	-0.098** (0.034)	-0.096* (0.048)
Five degree polynomial dummies for patent age	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes
Constant	0.652** (0.243)	0.267** (0.050)	0.405** (0.047)
Observations	3241	3241	726
Number of patents	386	386	73
R-Squared	0.144	0.072	0.222

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

Table 6 – The impact of pool formation on the total patenting rate of vertically-integrated firms relative to non-integrated entities

	(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 robust standard errors**	**Panel OLS with robust standard errors**	**Panel OLS with robust standard errors**
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 patents	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