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Evidence from inter-generational competition in optical disk industry

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Dynamic Effects of Patent Pools: Evidence from inter-generational competition in optical disk industry [1]

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Abstract

This paper examines empirically how patent pools affect the research and development (R&D) for a next-generation standard and for improving and exploiting the current standard, based on panel data from the optical disk industry. Our analysis explicitly recognizes the inter-generational competition among standards and the timing difference between the standard agreement and the pool formation for the standard. The major findings are as follows. Both the agreement for the current standard (DVD) and the formation of the pools were followed by more R&D by the pool licensors for a next-generation standard (BD and HDDVD), relative to the nonparticipants of the pools. Furthermore, the formation of the pools was followed by intensified R&D efforts by the pool licensors for improving and exploiting the current standard. Thus, there is no evidence for negative effects of the pools on the innovations by the pool licensors. The R&D of the pool licensees for the next-generation standard also increased with some lag after the pool, suggesting the positive effect of open pool licensing for their learning and innovations toward the next-generation technology. Lower response of the 6C licensors, relative to that of the 3C licensors, may reflect the former's larger sunk cost in the DVD technology. After the formation of the pools, the patenting propensity by the licensors increased with deteriorating patent quality, and such tendency is larger for the 6C patent pool, presumably reflecting their royalty distribution policy based on simple patent counts.

Keywords: Patent pools, Innovation, Inter-generational competition

JEL classification: O31, O34, L24, L4

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1. Introduction

The increasing need for combining technologies and an increasing fragmentation of patent ownership has enhanced the necessity for developing efficient institutional mechanism for aggregating technologies such as a patent pool. Such institution is especially important in implementing an open standard agreement for which the RAND license is the central commitment. A patent pool can provide an important instrument for implementing such commitment, since it provides a facility of aggregating many bilateral license contracts into one single license contract, assessing the essentiality of the patents and committing to the maximum aggregate royalty ex-ante[2]. While there exist persuasive theoretical arguments for economic contributions of a well-designed pool (Lerner and Tirole (2004) and Shapiro (2001)), empirical studies on the pools (Lampe and Moser (2010, 2013) and Joshi and Nerkar (2011)) have more sceptic view of the pool, especially on the innovations by the pool incumbents.

These two strands of the views are not necessarily contradictory, since the theoretical models on the pool mainly focused on the efficient combination of the developed technologies for the pool (avoiding royalty stacking and the pool of the substitutes) and the empirical literature focused mainly on the development of new technologies (innovation incentives). Still this poses a puzzle, since a pool, especially a modern pool guided by competition authorities, is also designed not to hinder competition through innovations. In particular, such pool is dedicated to providing a collective licensing of complementary patents for a specific standard, and should not have power to coordinate the R&D activities for future innovations. This is important, since a standard often evolves over time, and inter-generational competition is important. In the case of optical disk industry, there are three generations of standard: CD, DVD, and BD (Blu-ray Disk (hereinafter BD))/HDDVD. Thus, it is important for the study on the pool to assess such competition, which the existing studies on the pool such as Joshi and Nerkar (2011) overlooked, as will be discussed in detail later.

From a theoretical point of view, a successful pool may still reduce the incentive for the incumbents to undertake R&D for a next-generation technology, because of the sunk investment in the current generation standard or because of the replacement effect (Arrow (1962)). At the same time, the replacement effect may be significantly constrained by a large number of firms with essential patents and by the licensing commitment based on the RAND (Reasonable and Non-discriminatory) principle. If the transaction cost of the pool is high (that is, if the cost for recognizing and licensing inventions becomes inflated with a pool, as seems to be suggested by Joshi and Nerkar (2011)) or if the pool functions to soften R&D competition among the pool licensors, it may reduce their R&D for innovations. Thus, the effects of a pool

[2] A pool formation has not been always successful. One important constrain is the existence of strategic advantage of early commitment to becoming a nonparticipant.

on the dynamic incentives for innovations remain important research agenda.

This paper examines empirically how a standard agreement as well as the patent pools supporting the standard affects the dynamic R&D incentive for improving a current standard and for developing a next-generation standard. We focus on the optical disc industry where inter-generational competition is important. Our main contribution is to incorporate the inter-generational competition among standards into empirical analysis. In this study, we explicitly specify the patents for the current standard (DVD) as well as a next generation standard (BD and HDDVD) and the preceding standard(CD). If the sunk investment cost or the replacement effect are very large, we would expect that a better prospect for launching the current standard through the standard agreement and the pool formation tends to reduce the R&D incentive of the incumbents of the DVD standard (the licensors) to undertake R&D for the next-generation standard, relative to the nonparticipants or to the licensees. Furthermore, if the pool is highly inefficient in incentivizing the innovations even for improving and extending the use of the current standard, we would expect that the pool formation will reduce the R&D and patenting for the current standard, even if the standard agreement itself will increase it, relative to the nonparticipants.

Unlike the past studies, we use both patent counts (with or without citation counts) as well as patent family-based counts (with or without citation counts) as the performance measures of a firm. This is important since a pool often allocates the licensing revenue based on the patent counts (which is the case in 6C), which creates artificial incentive for increasing the filings of the patents using continuation practices (see Nagaoka, Tsukada, and Shimbo (2009)). Thus, using the patent counts can provide an exaggerated picture of R&D performance of the incumbent licensors for the current standard. Using family-based patent counts as well as citation-weighted counts help us to identify genuine R&D efforts from "strategic" patenting efforts.

Briefly, major findings are as follow. Relative to the nonparticipants, both the standard agreement and the formation of the pool for the current standard (DVD) are followed by intensified R&D and patenting efforts by the licensors for a next generation standard (BD and HDDVD). Moreover, both the standard agreement and the formation of the pools accelerated the R&D efforts by the licensors for improving and exploiting the use of the current standard. The pool is also followed by enhanced R&D of the licensees for a next generation standard and for the current standard, relative to those of nonparticipants, although with a significant lag. Thus, there is no evidence that the DVD pools reduced the R&D efforts for developing the next-generation standard by the licensors nor by the licensees. At the same time, patenting counts by the licensors increased more than that of the family-based patent counts for the current standard, with deteriorating quality in terms of citations, in the latter period of the pool, indicating the existence of “strategic patenting”. Such gap is larger for 6C patent pool than for 3C pool, presumably reflecting the difference of royalty distribution policy.

The rest of the paper is organized as follows. Section 2 provides a brief review of prior literature as well as three hypotheses for empirical testing. Section 3 provides a brief description of the evolution of optical disc industry, Section 4 explains the data and the estimation model for our analysis and section 5 provides descriptive statistics. Section 6 and 7 presents the estimation results and the discussion, and section 8 concludes.

2. Prior literature and hypotheses

2.1 Prior literature

This section provides a brief review of related literature as well as empirical literature, focusing on the effects of the dynamic effects of a patent pool for a standard. We differentiate the effects for the licensors (that is, the owners of the pool technologies), the licensees and the nonparticipants. We also differentiate the effects on the R&D for the next-generation standard and on the improvement of the current standard and its applications.

The existing theoretical literature on the patent pool mainly focuses on efficient licensing. Firstly, as long as the pools include only patents that are complementary and necessary for implementing a standard, they reduce the cumulative royalty rates for the users of the standard by eliminating wasteful multiple marginalization (Shapiro 2001, Lerner and Tirole 2004). Secondly, patent pools combine essential patents to be licensed under a single contract, and are expected to reduce transaction costs (Shapiro 2001). The efficient licensing of the current standard promotes the R&D for downstream innovations based on the standard by the licensor and the licensees.

The expectation that the patent pool can efficiently license the essential patents also enhances the ex-ante incentive for R&D for discovering the essential patents, since the elimination of wasteful multiple marginalization increases the size of the downstream market and the total profit of the licensees, as shown by Lerner and Tirole (2008) in a general context. The effects, however, depend on the nature of the pool. Dequiedt and Versaevel (2012) show that if the pool also collects complementary but non-essential patents, the incentive for a firm to develop essential technologies is diluted, resulting in a slower time to market for the pooled technologies. Given that the standard is amended over time as new complementary technologies are added, this ex-ante effect of the pool on the R&D also applies to the R&D for improving the current standard. The formation of the pool gives the assurance that the R&D for improving the standard can be a profitable investment, so that it encourages the licensors to engage in such investments.

To the best of our knowledge, there are no existing theoretical studies which analyze the effects of the pool for a current standard on developing the next-generation standard technology. We can, however, refer to the basic insights of industrial organization literature on this issue. First, the sunk cost investments of a firm in the R&D and in the manufacturing assets will reduce its incentives to undertake R&D for a next-generation technology, relative to outsiders. In the case of the optical disk industry, the thinness of the layer is the key performance parameter determining the memory size of the disc, around which major R&D activities of a firm developing a standard technology are centered. Such R&D assets are significantly sunk. Thus, the firms with large such sunk R&D investments would prefer to improve the current standard, than to make a radical change which would change the basic parameter. The pool of the complementary technologies would tend to make such sunk investments larger, since efficient access to such technologies would make investments in current technology larger.

Second, a pool which is highly profitable will reduce the incentive for the incumbents (the pool licensors) to undertake R&D for a next-generation technology, because of the replacement effect (Arrow (1962)), relative to the nonparticipants or the licensees. The replacement effect is significantly constrained by the dilution of the profit by a large number of the pool licensors (if there are N symmetric licensors, each licensor can obtain only one Nth of the profit). The profit is also constrained by the licensing commitment based on the RAND (Reasonable and Non-discriminatory) principle. Although the exact meaning of the RAND commitment has not yet been fully clarified, it is generally understood that the price of the pool should not be so high to constrain significantly the wide use of the standard.

Third, R&D competition, in particular a number of potentially competing firms in R&D, would strengthen the race for developing a next-generation technology, as suggested by the patent race model yielding strategic complementarity (Tirole (1986)). If the pool results in softening such competition among the licensors members, the pool can reduce R&D competition for the next-generation standard. On the other hand, a pool under the antitrust scrutiny is dedicated to the licensing of the bundle of the essential patents and is not allowed to engage in ancillary restraints in either product or innovation markets.

There are two highly relevant recent empirical papers on the effects of pools on innovations. Lampe and Moser (2010) find that the sewing machine pool appears to have discouraged patenting and innovation, in particular for the members of the pool. Lampe and Moser (2013) find that the creation of the patent pool encouraged innovation in the chain stitch technology, which was a substitute technology of the lockstitch (pool) technology. Joshi and Nerkar (2011) find that the creation of the DVD and MPEG-2 patent pools was followed by a decline in patenting by the licensors and the licensees.

These two empirical papers are based on difference-in-differences framework, but in our view their research methods are not proper. Lampe and Moser (2013) compared between the number of patents per patent class in the two technologies before and after the creation of the pool, but there is a major difference between the number of the USPTO technology classes identified for each technology[3] and the number of customized classes for the lockstitch technology (16) is almost three times larger than that for the chain stitch technology (6). In fact, the aggregate number of patents in the lockstitch (pool) technology increased after the creation of the pool significantly more than that of the substitute technology, but they concluded that the pool discouraged innovation in the lockstitch technology, simply because more number of patent classes were identified for the lockstitch technology, even though the patent classes are not standardized across the two technologies. In addition, there is a possibility that the patents for the chain stitch technology increases sharply after the pool not because of high price of the lockstitch technology (the price was prohibitive before the pool) but because the pool started to license the technology, which they did not apparently investigate.

The paper Joshi and Nerkar (2011) on optical disk industry seems to have two problems. First, they do not consider inter-generational competition at all, since their study aggregated all broadly defined optical disc patents for an empirical analysis. However, competition between three generations of technologies (CD, DVD, and BD) is important in optical disk industry. Patent pools were designed individually for each generation of the pool. Thus, if we are to analyze the innovation effects of the DVD pool, we need to assess their effects on the R&D for improving the DVD standard and on those for the next-generation standard such as BD/HDDVD. On the other hand, it would not be appropriate to add the R&D for the CD patents in such assessment, since the decline of the R&D for CD occurred due to the DVD standard replacing the CD standard. Our study identifies separately the patents for the three generations of standard for econometric analysis.

The second problem is that they do not consider the delay of the pool formation relative to the agreement on the standard. In fact, however, the pool formation typically occurs significantly later than the agreement on the standard, since the initiators of the pool need significant time to develop the business rule and the organizations, solicit the participations of the members, and seek the clearance from the antitrust authorities. In the case of the DVD, there were three years lag between the two events (1995 for the standard agreement and 1998 for the pool formations). Since the firms significantly anticipate the formation of the pools for the standard when the standard is agreed, their R&D and patenting activities also are chosen to anticipate the pools. Given this, it would not be appropriate to compare the period before and after the pool formation for assessing the effects of the patent pool. In our analysis we choose

[3] They use the USPTO classes but the USPTO apparently gave different classifications for the two technologies.

the period before the standard agreement as the base period and assess how the patenting activities of a firm changed before and after the two events respectively, depending on whether it was a pool licensor, a pool licensee or non-participant.

It is well-known that a patenting propensity by a firm can be significantly affected by "strategic" reasons. "Strategic" patenting refers to the strategic use of the patent system for purposes that go beyond the protection of innovation (Hall et al. 2013). Hall and Ziedonis (2001) shows that there was a significant increase of the patenting activity of semiconductor firms in around 1984, and find that patents came to be more used as a defense against hold-up behaviors of the competitors (that is, the threat of production shutdowns due to the injunction orders). In the case of a patent pool for a standard, the patent pool makes an ex-ante commitment to the maximum royalty for the bundle of the patents of its member firms, so that the hold-up behavior by the pool is under strict control. However, an individual firm can increase its share of royalty income by using continuation applications and increasing the number of its essential patents, if the royalty income is distributed among the patentees according to the number of the essential patents owned by these firms. Nagaoka et al. (2009) find that continuation applications are used extensively by the pool members and there is no evidence that such practices are more used by a firm with pioneering inventions for the standard. Thus, it is important for us to take this into account in assessing the performance of the pools. We use both the number of forward citations and the number of families to differentiate strategic patenting from those generated from genuine inventions.

2.2 Hypotheses

We focus on the DVD patent pools and assess how the pools affected the innovation of a firm, depending on whether it is an incumbent licensor (a DVD pool licensor), an incumbent licensee (a DVD pool licensee) or a non-participant. We examine the responses of its R&D for the next-generation standard and for the current generation standard to the two events: the standard agreement and the actual pool formation. As referred to earlier, the standard agreement also implies the initiation of the organizational effort by the firms with essential patents for the patent pool, so that we assume that pool formations are already significantly anticipated at the stage of the standard agreement.

The standard agreement is a key event for the development of a new market based on the standard, so that it will affect the opportunities for the development of the next-generation standard technology. The DVD pool licensors have both an important advantage and disadvantage in R&D for the next-generation standard, relative to licensees or a non-participants. One important advantage of a DVD pool licensor is its capability built from the experience of the developing current generation technology. Such capability will help an earlier start of the

R&D for the next-generation technology. A related disadvantage of a licensor, relative to a licensee or to a third party, is the sunk cost in the current technology. Given an increasing marginal cost of R&D and/or a lower marginal cost of production based on the current technology, the firm with significant sunk cost will choose R&D for the current standard rather than that for the next-generation standard. This sunk cost disadvantage is larger for a firm with a large investment on the current DVD technology.

In addition to these basic advantage and disadvantage of the licensors, there are two competition related effects of the pool which are potentially relevant. The first one is the replacement effect (Arrow (1962)), if the current standard is expected to be highly profitable. The replacement effect, however, is significantly constrained by the dilution of the profit by a large number of the licensees as well as by the licensing commitment based on the RAND (Reasonable and Non-discriminatory) principle. The second potential effect of the pool is a possibility that the pool may cultivate a tacit agreement among the licensor not to compete hard for the next generation standard, before reaping the profit from the current technology. This is constrained by the dedication of the pool to a licensing of the essential patents.

While the (pure) licensees do not have capability to conduct R&D for the standard development in the optical disc industry initially, the experience of using the technology will provide an opportunity for them to learn the technology and to build up their capabilities in conducting new research in this area. Thus, unlike non-participants, they may start contributing technology for the next generation technology of the optical disc industry over time.

Summarizing these effects of the pools on the next generation standard, we have the following three hypotheses;

Hypothesis 1 on the effects of a pool on the R&D for next generation standard

(1a) The agreement on the current standard as well as the pool formation will increase R&D for the next generation standard by the current pool licensors, relative to the others, if their capability advantage dominates the other effects such as sunk cost.

(1b) These R&D promoting effects would be smaller for the licensors with larger sunk R&D investment on the current standard technology.

(1c) The formation of the pool for the current standard will enhance the R&D capability of the current pool licensees for developing the next generation standard technologies, relative to non-participants, over time.

The agreement on the standard opens up the opportunities for improving the standard and for developing complementary technology for the standard, realizing the network externality. The DVD licensors of the essential patents have a clear advantage for developing technologies for improving the DVD standard, relative to the DVD licensees and nonparticipants, since they have important core patents on which they can build on and the R&D capabilities for the current standard technology. They have also better appropriation mechanism for developing the technologies complementary to the essential patents for the standard, since the licensing revenue from the essential patents will increase with the expansion of the DVD market the size of which depends on the entire complementary technologies for this standard. Thus, we expect that the standard agreement will stimulate the licensors (cum licensees) to expand their R&D most among the three types of the firms. Among the licensees and the nonparticipants, we expect that the standard agreement and the pool will stimulate the licensees of the essential patents to develop the complementary technologies more, since they have better appropriation mechanism (they have complementary assets which can exploit the DVD technologies in manufacturing and sales). Thus, they will also expand R&D, more than the nonparticipants.

The pool will assess the essentiality of the new contributions to the current standard and distribute the royalties according to the formula of each pool. The pool imposes the non-exclusive grant back requirements on the licensees for their newly obtained essential patents to the standard, so that the licensors will have automatic RAND based access to these complementary patents. If the pool functions efficiently in licensing and aggregating the complementary patents, it will enhance the R&D incentives of the licensors as well as licensee for improving and exploiting the current standard, relative to those for nonparticipants. On the other hand, if the pool works inefficiently for recognizing and rewarding the inventions, the pool may reduce the incentive of the licensors for improving and extending the use of the current standard, relative to those for nonparticipants. The sources of such inefficiency could be the dilution of incentives due to the inclusion of many non-essential patents and free-riding due to the compensation based on the patent counts.

Summarizing the effects of the pools on the current standard, we have the following hypothesis;

Hypothesis 2 on the effects on the R&D for the current standard

(2a) Both the agreement on the current standard and the pool will increase R&D for improving that standard by the incumbent licensors, relative to those by the licensees or by the nonparticipants, unless the pool works very inefficiently.

(2b) Both the agreement on the current standard and the pool will increase R&D for improving that standard by the incumbent licensees, relative to those by the nonparticipants, unless the pool works very inefficiently.

It is important for us to assess the importance of "strategic" patenting by the incumbent licensors, that is, patenting just for the purpose of increasing the royalty shares. A pool often allocates the licensing revenue based on the patent counts (which is clearly the case in 6C). Such scheme creates artificial incentive for increasing the filings of the patents using continuation practices (Nagaoka, Tsukada, and Shimbo (2009)). We use both citation data and family data to identify "genuine" patents from R&D from "strategic" patents. If a firm has incentive to strategic patenting, its patents have low knowledge contents so that they are not cited by the other firms so much (Trajtenberg 1990). On the other hand, if a firm makes genuine innovation, the quality of the patents is high and they are cited more by other firms. By using family counts, we can also control the effects of continuation application practices on the number of patents. This strategic patenting is more important for the pool which uses the royalty sharing based on a simple patent counts.

Thus, we have the following hypothesis.

Hypothesis 3 on "Strategic" patenting and royalty sharing rule

(3a) A pool creation can lead to an increase in the number of patents of the licensors for the current standard technology, exceeding that of family-based patent counts, with deteriorating quality for the current standard, relative to those of the nonparticipants.

(3b) Such effect is stronger for the pool with the royalty payment based on the simple patent counts.

Note that this effect would become significant only after the pools are established and relevant for the R&D improving the current standard but not for the next-generation standard.

2.3 Estimation strategy

We assess the changes of the R&D performance for the next generation standard as well as that for improving and exploiting the current standard, in response to the two events (the DVD standard agreement and pool formations), in the framework of the difference in differences. We explicitly identify the patents for the current standard (DVD) as well as for a next generation standard (BD and HDDVD) and assess how the DVD pools affected the R&D for the next generation standard and for the current standard. We consider the R&D performance of the three types of the firms: (1) the licensors of the essential patents for the current standard (DVD) who are either the members of the 6C patent pool or the 3C patent pool, (2) the pure licensees of the essential patents for the current standard (DVD) from the pool, and (3) the other third party firms (the nonparticipants) who do R&D in the optical disc industry area but are neither the licensors nor the licensees of the two pools. Most licensors are simultaneously licensees in the case of DVD standard, since most of these licensors engage in the manufacturing.

The model we estimate is based on the following firm fixed effect model. In this model $y_{i,t}$ represents the R&D performance in terms of the number of patents or families of firm i for year *t*. $Standard_{(1995-1997)}$, $pool_{(1998-2000)}$ and $pool_{(2001-2010)}$ are year dummies for the standard agreement and the pool formation. $Standard_{(1995-1997)}$ and $pool_{(1998-2000)}$ are set to 0 before the respective event and set to 1 for 3 years since the event. $pool_{(2001-2010)}$ is set to 0 other than the year from 2001 to 2010, which is the 4rth to 13th year of the pool. The estimated parameters for these three dummies would differ by *type* of the firm (a DVD pool licensor (3C or 6C), its licensee with the third party as the base). A DVD pool licensor is directly affected by the pool while non-participants are not affected directly by the pool. The licensees are affected only by the licensing policy of the DVD. We use the nonparticipants as the control group. u_i represent firm fixed effects, such as firm size, its capability and its complementary assets. $\alpha_t$control for any yearly changes in the optical disc industry.

$$y_{i,t} = \beta_0 + \left(\sum_{type} \beta_{1,type}\right) Standardization_{(1995-1997)} + \left(\sum_{type} \beta_{2,type}\right) Pool_{(1998-2000)} + \left(\sum_{type} \beta_{3,type}\right) Pool_{(2001-2010)} + u_i + \alpha_t + \varepsilon_{i,t} \qquad (1)$$

3. Background of optical disc industry

In the beginning of 1990s, there were two groups in the development of the next optical disc technology after CD: Sony/Philips and Toshiba/Time warner. Sony and Philips announced MMCD format in December 1994 and eight firms including Toshiba and Time Warner announced SD format. The memory quantity of MMCD was smaller than that of SD format. Nine firms including the above four firms announced the DVD standard based on the SD format in September 1995. This meant that Toshiba and Time Warner won the inter-standards competition. The DVD standard was formally set in December 1995. After that, several formats were set: DVD-RAM(1997), DVD-RW(1997), DVD+RW(1999).

Two patent pools for a DVD technology were established. Six firms, including Toshiba, established 6C, and three firms, including Sony and Philips, established 3C both in 1998. The U.S. DOJ approved 3C on December 1998 and 6C on June 1999.While they originally aimed at providing a one-stop shopping facility for licensing the standard information, the essential patents, and the logo, Thomson decided to license its patents independently. Following this, three firms (Sony, Philips, and Pioneer: 3C) decided to choose independent licensing but collectively. The rest of the firms (Six firms: 6C) decided to collectively license its technology through a patent pool.

Thus, even the firms which participated in the standard development could not form a single patent pool and got split into the three licensing parties. As a result, a manufacturer of DVD players has to currently pay royalties to each of three parties. Both groups widely license its technology. We understand that there existed the disagreement among the firms with respect to the distribution formula of the royalty income of the pool to a participant. 3C and Thomson look to be unsatisfied with such pro-rata formula because Toshiba which created the SD format had more number of essential patents than them. In 6C, the royalty income is shared based on the number of essential patents. In 3C, the royalty income isn't shared based on it. Table 2 in the Appendix provides the information on the major characteristics of the 3C and 6C, including the licensing policy, at the time of it establishment.

Sony and Philips announced DVR-Blue format in 1999. Nine firms including them announced to set BD standard cooperatively. On the other hand, Toshiba and NEC announced HDDVD format in June 2002. Sony shipped the first Blu-ray Disk recorder in 2003. BD standard was set mostly in 2007.

The memory capacity of BD was larger than one of HDDVD because Sony and Philips did not think that the compatibility with DVD was important, and they adopted more new technologies. In 2008, Time Warner which favored HDDVD announced their support to BD. As a result, Toshiba was forced to exit HDDVD in the same year, and announced to enter BD market. Similarly to DVD standard, there are two patent pools in BD standard. One is One-Blue including Sony and Philips which was established in 2011. The other is BD4C including Toshiba established in 2010.

4. Data and estimation model

4.1 Data construction

We constructed our dataset, using the EPO Worldwide Patent Statistical Database (PATSTAT, 2014 spring edition) and the information of essential patents disclosed at websites of IP licensing programs of CD[4] or patent pools of DVD[5] and BD[6] (including patents of HDDVD). Unlike Joshi and Nerkar (2011), we don't include the MPEG2 standard in our scope of analysis. MPEG2 is a standard of audio-visual compression technology and was designed to allow a video to be saved on optical disk, but also to be broadcasted in a digital television. It is used widely outside of the optical disk industry. The licensees of the MPEG2 technology is quite different from those of DVD pools: more manufacturers of the final product in the case of DVD.

In order to capture the R&D activities of the licensors, the licensees and the nonparticipants in the optical disk industry, we need to obtain not only the essential patents of the standards but also the population of the patents in the optical disk area. Thus, first, we extracted from the US granted patents in optical disk area from PATSTAT database by searching the patent classification codes of optical disk (12 classification codes) and the patent

[4] http://www.ip.philips.com/licensing/licensing.html
[5] http://www.dvd6cla.com/
[6] http://www.one-blue.com/

classification codes including at least 100 essential US patents of the CD, DVD, or BD/HDVDV (40 classification codes)[7]. We use the Cooperative Patent Classification (CPC) as the patent classification codes, to identify more correctly population of patents in optical disk technology.

We focus on the firms actively conducting R&D in optical disk area. We selected the firms that have at least 10 US granted patents filed from 1976 to 2010 in the 52 technology classifications for optical disc area. We obtained totally 110 firms (16 licensor firms, 14 pure licensee firms, and 80 non-participant firms in patent pools). As already described, we will analyze the effects of the agreement of DVD standards or of the patent pool formation both on R&D for DVD and on R&D for the next generation optical disk. Thus, we take the patents in optical disk area apart into two samples: one is DVD patent sample, the other is BD/HDDVD (the next generation disk) patents sample.

The *DVD patents* consists of [1]: essential patents of DVD standards, [2]: patents identified by CPC codes for DVD, [3]: direct backward/forward citation patents[8] of [1]/[2] in the 52 technology classifications mentioned above. Next, the *BD/HDDVD patents* (*the next generation patents*) are identified in the same way. That is, it comprises [4]: essential patents of BD standards, [5]: patents identified by CPC codes for BD/HDDVD, and [6]: direct backward/forward citation patents[9] of [5]/[6] in the 52 technology classifications mentioned above. As a result, 7537 US patents are identified as *DVD patents,* and 1796 US patents are identified as *BD/HDDVD patents*.

Based on these patents, we constructed the panel dataset of 110 firms by application year from 1988 to 2010.

4.2 Estimation model

(1) Dependent variables and estimation

We constructed the number of patents, the number of patents weighted by forward citations, the number of INPADOC families of the patents, and the number of INPADOC families weighted by forward citations as dependent variables. We estimate OLS models with firm fixed effects, taking the log of these dependent variables[10]. To examine the effects of the standard agreement and the pool formation on innovations, we use difference-in-differences approach. As we will explain later, we make the interaction terms between the dummies of the standard agreement and the pool formations and the type of the firms and focus on their coefficients. The base of our estimation is nonparticipants and the period preceding the standard agreement on DVD. We use

[7] Appendix table 1.
[8] These patents don't cite either essential patents of CD and BD or patents identified by CPC codes for CD and BD/HDDVD directly, or aren't cited by them directly
[9] These patents don't cite either essential patents of CD and DVD or patents identified by CPC codes for CD and DVD directly, or aren't cited by them directly
[10] We summarize the simple statistics and correlation matrix in appendix table 2 and 3.

the panel data between 1988 and 2010.

(2) Independent variables

Our first variable of interest is the event of standard agreement. As we noted, DVD standard was set in September 1995. *Standardization (1995-1997)* is a binary variable that takes a value of 1 for all observations between 1995 and 1997, and a value of 0 for all observations before 1995 and after 1997.

Pool (1998-2000) is a binary variable that takes a value of 1 for all observations between 1998 and 2000, and a value of 0 for all observation before 1998 and after 2000. *Pool (2001-2010)* is a binary variable that takes a value of 1 for all observations between 2001 and 2010, and a value of 0 for all observation before 2001 and after 2010. *Pool (1998-2000)* reflects the effect on patenting immediately after the pool creation, and *Pool (2001-2010)* reflect the effect on patenting during the period in several years after the pool creation.

Licensor is a binary variable that takes a value of 1 when a firm was a contributor of the essential patents to any pool of the DVD, and 0 when it is a noncontributory of such patents. This variable takes a value of 1 or 0, with no time variation (independent of the existence of the pool).

Licensee is a binary variable that takes a value of 1 when a firm has an inbound licensing of essential patents from any pool of the DVD, and 0 when there is such inbound licensing. Similarly to the *licensor* variable, this variable takes a value of 1 or 0, with no time variation.

(3) Control variables

To capture the other factors relevant in patenting, we include two control variables. Firstly, firms may choose to specialize in a few or to enter into all technology classes in the optical disk area. This may influence its patenting propensity. To control for this effect, we include a variable, *Diversity*, which measures the average number of optical disc technology classes for the preceding three years.

Secondly, there is a variation of the timing of the entry into optical the optical disc industry among the firms. The difference of experience in this industry can influence the patenting they do every year. To control for this effect, we include a variable, *Age*, which measures the time from the year when a firm filed the first patent of the optical disk area. We take its log in our estimation.

Finally, there are variations of technological and/or market opportunities over time. To control for this effect, we include year dummies. These variables also control for a truncation bias of citations.

5. Descriptive statistics

Figure 1 shows the number of patents and that of families on DVD and BD/HDDVD. In DVD standard, the number of patents and families start to increase early in the 1990s. Especially, they increase rapidly around the standard agreement of DVD (1995). There is a major difference between the patent numbers and their family numbers from the late 1990s. This suggests that the licensor firms use more continuation applications from these years. For the next generation standard, we can not see an increase of the number of the patents and their families before and after the standard agreement of DVD.

Figure 2 shows the log of the number of patents per a firm on the next generation of the three different types: licensors, licensees, and nonparticipants. Figure 3 shows the log of the number of patents weighted by the forward citations per a firm on the next generation of these three different types. The distance between the three curves gives us the percentage difference of the number of patents or the citation weighted number of the patents among the three types of the firms. A major difference in trend between the number of patents and the patents weighted by forward citations of licensors in the 1990s is due to truncations.

Figure 2 suggests that there is an significant increase of the number of patents applied by the licensors, relative to those by the licensees or by the nonparticipants, before and after the year of standardization (1995). Figure 3 shows that the same observation holds for the number of patents weighted by forward citations of licensees, before and after the year of standardization (1995), and also that the licensees' number of patents weighted by forward citations increased relative to that of the licensors in terms of % term, before and after the year of the DVD pool (1998).

Figure 1. Number of patents and families on DVD standard and the next generation

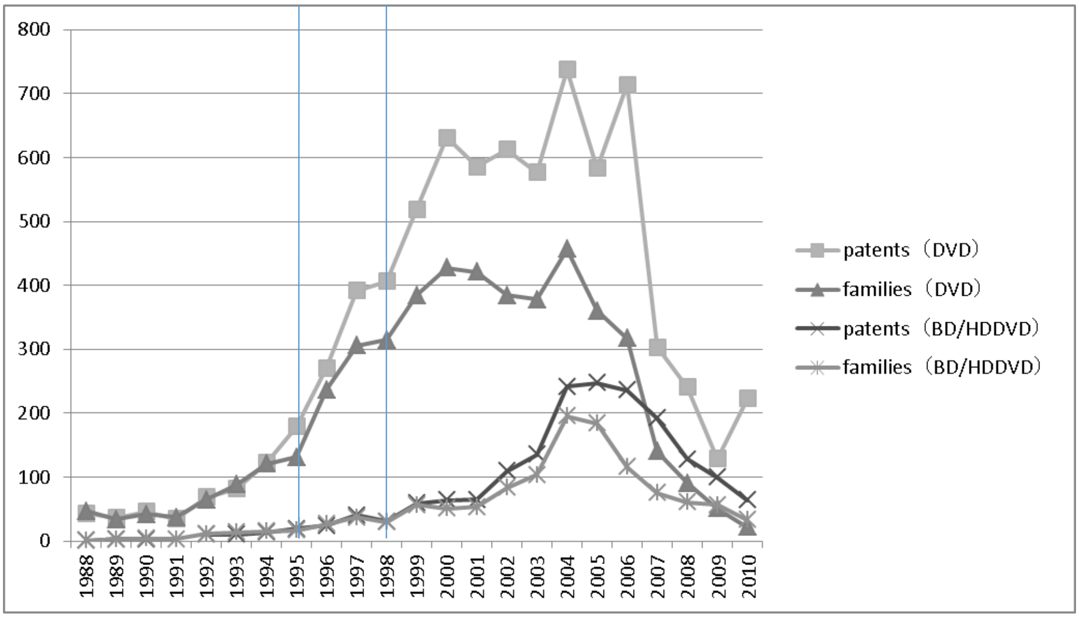


Figure 2. Number of patents on the next generation per a firm of the three different types (the log of the number of patents per a firm)

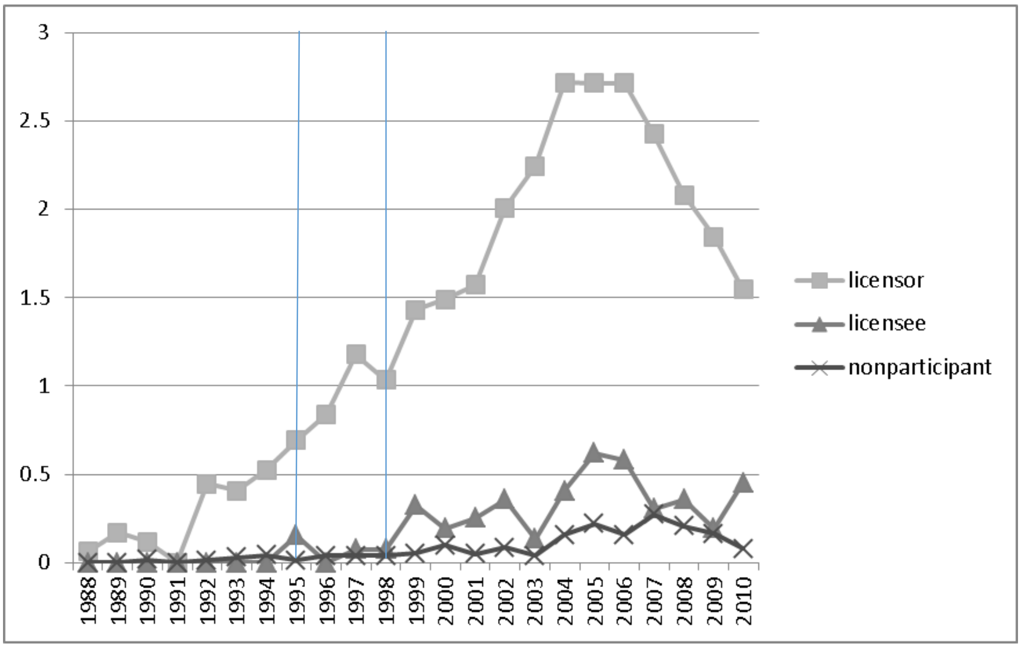


Figure 3. Number of patents on the next generation of the three different types weighted by forward citations per a firm (the log of the number of citation weighted patents per a firm)

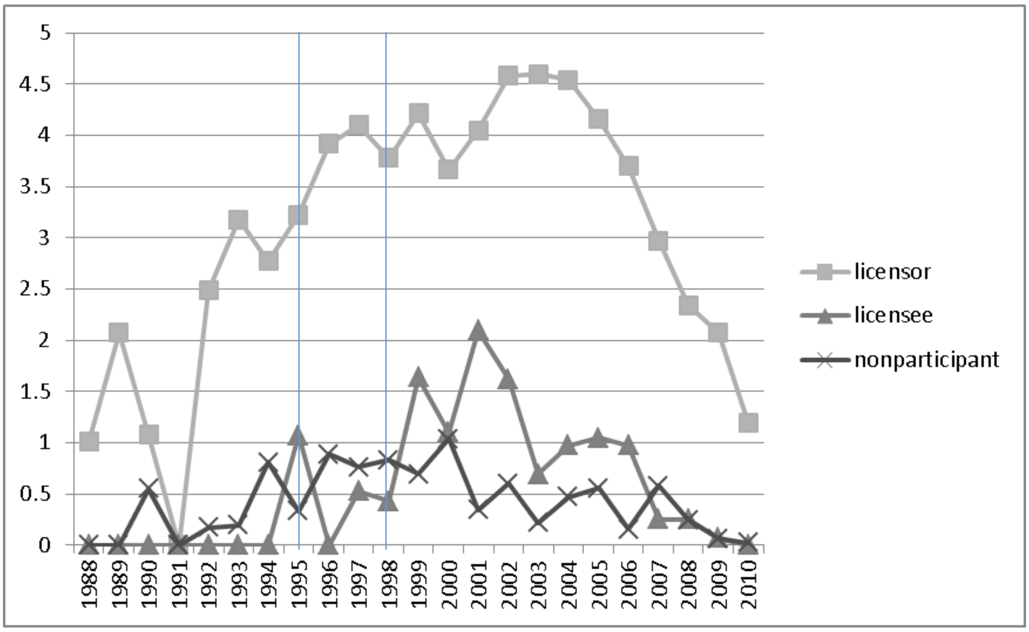


Figure 4 shows the log of the number of patents per a firm for the DVD technology of the three different types: licensors, licensees, and nonparticipants. Figure 5 shows the log of the number of patents weighted by forward citations per a firm on DVD of the three different types. Similar to the case of the next generation standard, it is clear that the number of the patents and the patents weighted by forward citations of the licensors increased, relative to those of the other firms, before and after the year of standardization (1995). On the other hand, while the number of the patents of the licensors increased, relative to those of the other types of the firms, before and after the year of DVD pool (1998), the number of their patents weighted by the forward citations of the licensors decreased relative to those of the other firms, before and after the year of DVD pool (1998). This gap suggests "strategic" patenting, that is, increasing patenting propensity accompanied with declining patent quality of the licensors after the establishment of the pool.

Figure 4. Number of patents on DVD standard per a firm of the three different types (the log of the number of patents per a firm)

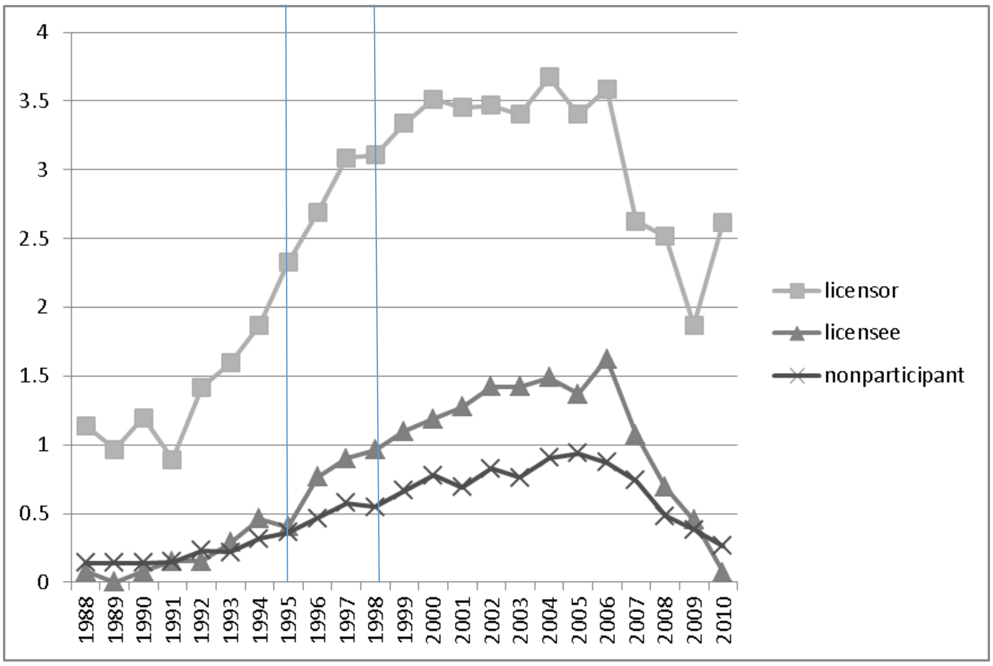
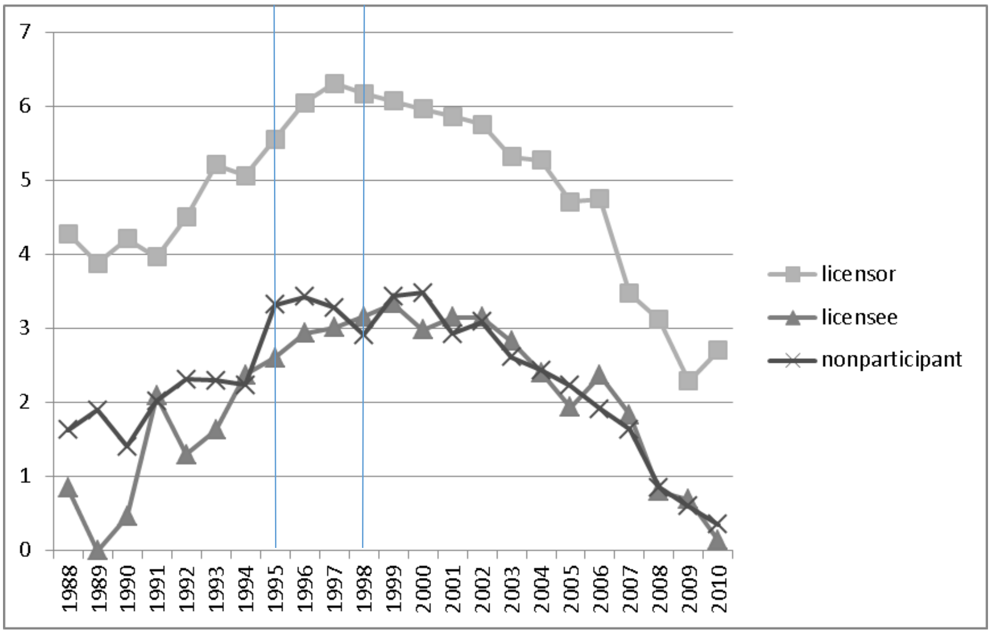


Figure 5. Number of patents weighted by forward citations per a firm on DVD standard of the three different types (the log of the number of patents per a firm)



6. Estimation results

In Table3, we summarize the result of OLS estimation with firm fixed effects for patents, families, cited patents, and cited families on the next generation (BD/HDDVD) standard on our independent variables of interest. The base of our estimation is nonparticipants (third parties) and the period preceding the standard agreement on DVD. In table 4, we divide licensor dummies into 6C and 3C. In model 1 we do not use two control variables (the technological diversity and the age of a firm), and in model 2 we use two control variables. In both models, the coefficients of *Standardization (1995-97)*×licensor, *Pool (1998-2000)×Licensor,* and *Pool (2001-10)×Licensor* are all positive and significant. This means that the standard agreement and the pool creation positively affected the number of patents of the pool licensors for the next generation standard, relative to the nonparticipants.

We can see the same results in other models, but there is a major variations of the coefficients of each interaction terms over three stages: *Standardization (1995-97), Pool (1998-2000)* and *Pool (2001-10)*. In model 1 and 2 for a simple patent counts, the coefficients of *Pool (2001-10)×Licensor* are larger than the other interaction terms. In model 7 and 8 for citation weighted family counts, the coefficient of *Standardization (1995-97)×Licensor* is larger than the other interaction terms. This means that the licensors of the current standard (DVD) made significant inventions for the next generation immediately after the standard agreement of the current standard. As shown in Table 4, such effects exist for both 3C and 6C, although the effect is much stronger for 3C. These results support H1a, and suggesting that the capability advantage of the licensors dominate the other effects such as sunk cost effect for the R&D efforts of the pool licensors for developing the next-generation standard.

The DVD standard was based on the SD format, and the firms which developed SD format created 6C. Therefore, they had many essential patents, especially Toshiba, indicating that 6C pool licensors had more sunk investment in the DVD, which can constrain the 6C group more than the 3C group, in particular, in choosing more radical departure from an existing standard. Table 4 provides the results consistent with this view. In all models, the coefficients of the interaction terms for 3C are larger than those for 6C (around twice as much). The results imply that, although the standard agreement on the DVD encouraged all licensors of the DVD to make R&D for the next generation, the effects for the 6C group were weaker than those for 3C group, consistent with a larger sunk investment of the former group. These results support Hypothesis 1b.

While the effect of the standard agreement on the licensees is not significant, the effect of the pool becomes positive and significant in the second phase of the pool formation (2001-2010). The effect is significantly stronger in the citation weighted patents or in families counts than in simple counts in patents or in families. This suggests that the licensees have built up gradually their capabilities in conducting research for the next generation technology of the optical disc industry while using the DVD technology for commercial acivities. This provides significant evidence of the positive effect of open pool licensing for innovations, supporting Hypothesis 1c.

Table 3. Fixed effect OLS –Dependent variables are patents on the next generation

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Patents	Patents	Cited patents	Cited patents	Families	Families	Cited families	Cited families
Standardization(1995-1997)×Licensor	0.531***	0.466***	1.812***	1.688***	0.462***	0.412***	1.532***	1.433***
	(0.085)	(0.094)	(0.254)	(0.257)	(0.099)	(0.108)	(0.245)	(0.260)
Pool(1998-2000)×Licensor	0.823***	0.742***	1.849***	1.695***	0.659***	0.595***	1.494***	1.372***
	(0.148)	(0.153)	(0.338)	(0.349)	(0.168)	(0.173)	(0.396)	(0.402)
Pool(2001-2010)×Licensor	1.202***	1.135***	1.506***	1.386***	0.876***	0.821***	1.091***	0.998***
	(0.268)	(0.275)	(0.410)	(0.427)	(0.209)	(0.217)	(0.348)	(0.365)
Standardization(1995-1997)×Licensee	0.049	0.022	0.143	0.089	0.050	0.029	0.163	0.119
	(0.031)	(0.030)	(0.114)	(0.104)	(0.032)	(0.029)	(0.121)	(0.112)
Pool(1998-2000)×Licensee	0.099	0.081	0.262	0.228	0.095	0.080	0.274	0.247
	(0.080)	(0.071)	(0.255)	(0.233)	(0.078)	(0.069)	(0.251)	(0.231)
Pool(2001-2010)×Licensee	0.156**	0.096*	0.344**	0.228*	0.145**	0.099**	0.331**	0.238**
	(0.062)	(0.055)	(0.137)	(0.121)	(0.057)	(0.049)	(0.129)	(0.114)
Diversity		0.053***		0.103***		0.040***		0.083***
		(0.016)		(0.026)		(0.013)		(0.023)
Age		-0.023		-0.027		-0.022		-0.016
		(0.042)		(0.075)		(0.034)		(0.062)
Constant	0.011	-0.019	0.027	-0.047	0.009	-0.009	0.025	-0.041
	(0.023)	(0.046)	(0.048)	(0.088)	(0.021)	(0.039)	(0.049)	(0.085)
Year fixed effect	yes	yes	yes	yes	yes	yes	yes	yes
Firm fixed effect	yes	yes	yes	yes	yes	yes	yes	yes
Observations	2,361	2,361	2,361	2,361	2,361	2,361	2,361	2,361
R-squared	0.302	0.320	0.181	0.198	0.219	0.233	0.129	0.141
Number of firm	110	110	110	110	110	110	110	110

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4. Fixed effect OLS –Dependent variables are patents on the next generation

	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
	Patents	Patents	Cited patents	Cited patents	Families	Families	Cited families	Cited families
Standardization(1995-1997)×6C	0.446***	0.370***	1.679***	1.535***	0.378***	0.318***	1.308***	1.192***
	(0.076)	(0.078)	(0.273)	(0.264)	(0.084)	(0.092)	(0.263)	(0.275)
Pool(1998-2000)×6C	0.699***	0.606***	1.547***	1.374***	0.448***	0.375**	1.092**	0.952**
	(0.154)	(0.161)	(0.379)	(0.403)	(0.151)	(0.158)	(0.429)	(0.443)
Pool(2001-2010)×6C	1.016***	0.945***	1.292**	1.171**	0.694***	0.635**	0.822*	0.726
	(0.326)	(0.330)	(0.505)	(0.518)	(0.255)	(0.258)	(0.428)	(0.439)
Standardization(1995-1997)×3C	0.711***	0.668***	2.218***	2.137***	0.716***	0.682***	2.061***	1.996***
	(0.202)	(0.212)	(0.529)	(0.541)	(0.216)	(0.221)	(0.489)	(0.495)
Pool(1998-2000)×3C	1.178***	1.111***	2.705***	2.580***	1.151***	1.097***	2.473***	2.372***
	(0.288)	(0.279)	(0.565)	(0.525)	(0.349)	(0.340)	(0.747)	(0.712)
Pool(2001-2010)×3C	1.690***	1.613***	2.152***	2.019***	1.303***	1.239***	1.759***	1.654***
	(0.477)	(0.472)	(0.729)	(0.714)	(0.359)	(0.362)	(0.599)	(0.592)
Standardization(1995-1997)×Licensee	0.044	0.017	0.130	0.077	0.049	0.028	0.150	0.106
	(0.032)	(0.030)	(0.115)	(0.104)	(0.032)	(0.029)	(0.121)	(0.112)
Pool(1998-2000)×Licensee	0.095	0.077	0.255	0.221	0.091	0.076	0.266	0.239
	(0.080)	(0.071)	(0.255)	(0.232)	(0.078)	(0.068)	(0.251)	(0.230)
Pool(2001-2010)×Licensee	0.149**	0.087	0.339**	0.221*	0.138**	0.090*	0.326**	0.229**
	(0.062)	(0.054)	(0.137)	(0.120)	(0.058)	(0.049)	(0.129)	(0.113)
Diversity		0.055***		0.107***		0.042***		0.087***
		(0.014)		(0.024)		(0.011)		(0.021)
Age		-0.033		-0.037		-0.032		-0.025
		(0.036)		(0.067)		(0.029)		(0.055)
Constant	0.010	-0.012	0.027	-0.042	0.009	-0.003	0.024	-0.036
	(0.022)	(0.039)	(0.046)	(0.079)	(0.020)	(0.033)	(0.047)	(0.076)
Year fixed effect	yes	yes	yes	yes	yes	yes	yes	yes
Firm fixed effect	yes	yes	yes	yes	yes	yes	yes	yes
Observations	2,361	2,361	2,361	2,361	2,361	2,361	2,361	2,361
R-squared	0.322	0.341	0.193	0.211	0.239	0.254	0.141	0.154
Number of firm	110	110	110	110	110	110	110	110

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

In Table 5, we summarize the result of OLS estimation with firm fixed effects for patents, families, cited patents, and cited families in DVD standard technology area. In Table 6, we divide licensor dummies into 6C and 3C. In all models, the coefficients of *Standardization (1995-97)×Licensor* and *Pool (1998-2000)×Licensor* are all positive and significant. This implies that the standard agreement and the pool creation in its first phase positively affected the number of patents of licensors than they do on nonparticipants. As in the case for the R&D for the next-generation standard, while the effect of the standard agreement on the licensees is not significant, the effect of the pool becomes positive and significant in the second phase of the pool formation (2001-2010), relative to non-participants. These results support Hypothesis 2a and 2b that unless the pools work very inefficiently, the pools promote improvement and exploitations of the current standard by the licensors and licensees.

On the other hand, the results of the coefficients of *Pool (2001-10)×Licensor* are different. In model 17 and 18 for simple patent counts, the coefficients are positive and significant, but in model 19 and 20 for citation-weighted patent counts, the coefficients are not significant (a negative coefficient is reported in model 20). We can see the same results in model 21, 22, 23, 24. Furthermore, the coefficient of the patent counts became significantly larger than that of the family counts in the period of 2001-2010. Comparison between model (17) and (21) shows that coefficients of *Standardization (1995-97)* are very similar between the two, but the coefficients of *Pool (2001-10)* are different, with that of the patent counts significantly exceeding that of the family counts. These imply that while the standard agreement and the pool creation positively affected the number of patents of licensors than that of nonparticipants for all three periods, the average quality of the licensors decreased in the third period (2001-2010), due to more use of continuation and divisional practices. This supports Hypothesis 3a, suggesting that the patenting of licensors were significantly affected by the motivations for increasing the patent counts.

There is a difference in the sharing rule of the royalty between 6C and 3C, as noted earlier. As the result, we can also predict that the members of 6C have more incentive to do “strategic” patenting than the licensors of 3C. As shown in model 32 based on citation-based family counts, the coefficient of *Pool (2001-10)×6C* is negative and significant, but the coefficient of *Pool (2001-10)×3C* is not significant. On the other hand, as shown in model 30 based on simple family counts, the coefficient of *Pool (2001-10)×6C* is also positive and significant. This means that the members of 6C patented more than nonparticipants, but the quality was lower than them. This is supportive to our Hypothesis 3b in which the licensors of 6C have more incentive to strategic patenting, due to its pro-rata royalty sharing formula.

Table 5. Fixed effect OLS –Dependent variables are patents on DVD standard

	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)
	Patents	Patents	Cited patents	Cited patents	Families	Families	Cited families	Cited families
Standardization(1995-1997)×Licensor	1.089***	0.897***	1.372***	1.046***	0.986***	0.847***	1.550***	1.301***
	(0.159)	(0.158)	(0.361)	(0.324)	(0.151)	(0.154)	(0.390)	(0.368)
Pool(1998-2000)×Licensor	1.593***	1.352***	1.581***	1.185***	1.343***	1.172***	1.433***	1.134**
	(0.189)	(0.201)	(0.390)	(0.340)	(0.205)	(0.212)	(0.484)	(0.452)
Pool(2001-2010)×Licensor	1.153***	0.960***	0.172	-0.082	0.705***	0.580***	-0.262	-0.429
	(0.248)	(0.237)	(0.445)	(0.372)	(0.165)	(0.157)	(0.421)	(0.357)
Standardization(1995-1997)×Licensee	0.072	-0.011	-0.093	-0.242	0.129	0.068	0.143	0.025
	(0.152)	(0.119)	(0.328)	(0.265)	(0.132)	(0.110)	(0.297)	(0.252)
Pool(1998-2000)×Licensee	0.319	0.265	0.451	0.368	0.311	0.274*	0.472	0.411
	(0.195)	(0.162)	(0.410)	(0.352)	(0.191)	(0.164)	(0.425)	(0.374)
Pool(2001-2010)×Licensee	0.485***	0.306**	0.776***	0.460**	0.506***	0.375***	0.863***	0.615***
	(0.170)	(0.129)	(0.267)	(0.218)	(0.161)	(0.126)	(0.260)	(0.214)
Diversity		0.159***		0.289***		0.118***		0.229***
		(0.018)		(0.031)		(0.016)		(0.034)
Age		-0.053		0.050		-0.012		0.092
		(0.045)		(0.077)		(0.035)		(0.081)
Constant	0.216***	0.112*	0.776***	0.453***	0.200***	0.098*	0.726***	0.421***
	(0.041)	(0.061)	(0.122)	(0.147)	(0.036)	(0.054)	(0.122)	(0.147)
Year fixed effect	yes	yes	yes	yes	yes	yes	yes	yes
Firm fixed effect	yes	yes	yes	yes	yes	yes	yes	yes
Observations	2,361	2,361	2,361	2,361	2,361	2,361	2,361	2,361
R-squared	0.314	0.391	0.189	0.251	0.275	0.329	0.191	0.231
Number of firm	110	110	110	110	110	110	110	110

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 6. Fixed effect OLS –Dependent variables are patents on DVD standard

	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)
	Patents	Patents	Cited patents	Cited patents	Families	Families	Cited families	Cited families
Standardization(1995-1997)×6C	1.003***	0.779***	1.206***	0.833**	0.853***	0.688***	1.369***	1.078**
	(0.217)	(0.216)	(0.450)	(0.410)	(0.201)	(0.206)	(0.474)	(0.459)
Pool(1998-2000)×6C	1.352***	1.081***	1.235***	0.796**	1.014***	0.816***	0.960	0.621
	(0.255)	(0.281)	(0.423)	(0.401)	(0.266)	(0.286)	(0.581)	(0.582)
Pool(2001-2010)×6C	0.995***	0.799**	-0.117	-0.363	0.500**	0.367*	-0.634	-0.800*
	(0.337)	(0.325)	(0.511)	(0.447)	(0.215)	(0.208)	(0.464)	(0.407)
Standardization(1995-1997)×3C	1.156***	1.030***	1.414**	1.214**	1.159***	1.067***	1.509**	1.355**
	(0.243)	(0.233)	(0.646)	(0.561)	(0.232)	(0.214)	(0.714)	(0.647)
Pool(1998-2000)×3C	1.828***	1.632***	1.813**	1.508***	1.763***	1.622***	1.815**	1.584**
	(0.198)	(0.142)	(0.762)	(0.557)	(0.189)	(0.125)	(0.807)	(0.636)
Pool(2001-2010)×3C	1.382***	1.168***	0.489	0.213	0.939***	0.793***	0.076	-0.114
	(0.381)	(0.314)	(0.924)	(0.705)	(0.219)	(0.172)	(0.854)	(0.675)
Standardization(1995-1997)×Licensee	0.052	-0.029	-0.126	-0.271	0.112	0.050	0.101	-0.015
	(0.153)	(0.119)	(0.329)	(0.265)	(0.133)	(0.110)	(0.299)	(0.253)
Pool(1998-2000)×Licensee	0.287	0.234	0.406	0.328	0.281	0.244	0.423	0.365
	(0.197)	(0.164)	(0.412)	(0.353)	(0.193)	(0.165)	(0.427)	(0.376)
Pool(2001-2010)×Licensee	0.466***	0.283**	0.758***	0.440**	0.487***	0.350***	0.841***	0.589***
	(0.171)	(0.130)	(0.267)	(0.218)	(0.162)	(0.127)	(0.260)	(0.216)
Diversity		0.164***		0.294***		0.124***		0.235***
		(0.018)		(0.031)		(0.017)		(0.035)
Age		-0.072		0.039		-0.030		0.080
		(0.044)		(0.076)		(0.036)		(0.082)
Constant	0.214***	0.122**	0.774***	0.456***	0.199***	0.107**	0.724***	0.424***
	(0.044)	(0.057)	(0.124)	(0.146)	(0.038)	(0.050)	(0.123)	(0.145)
Year fixed effect	yes	yes	yes	yes	yes	yes	yes	yes
Firm fixed effect	yes	yes	yes	yes	yes	yes	yes	yes
Observations	2,361	2,361	2,361	2,361	2,361	2,361	2,361	2,361
R-squared	0.303	0.385	0.186	0.250	0.269	0.326	0.189	0.230
Number of firm	110	110	110	110	110	110	110	110

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

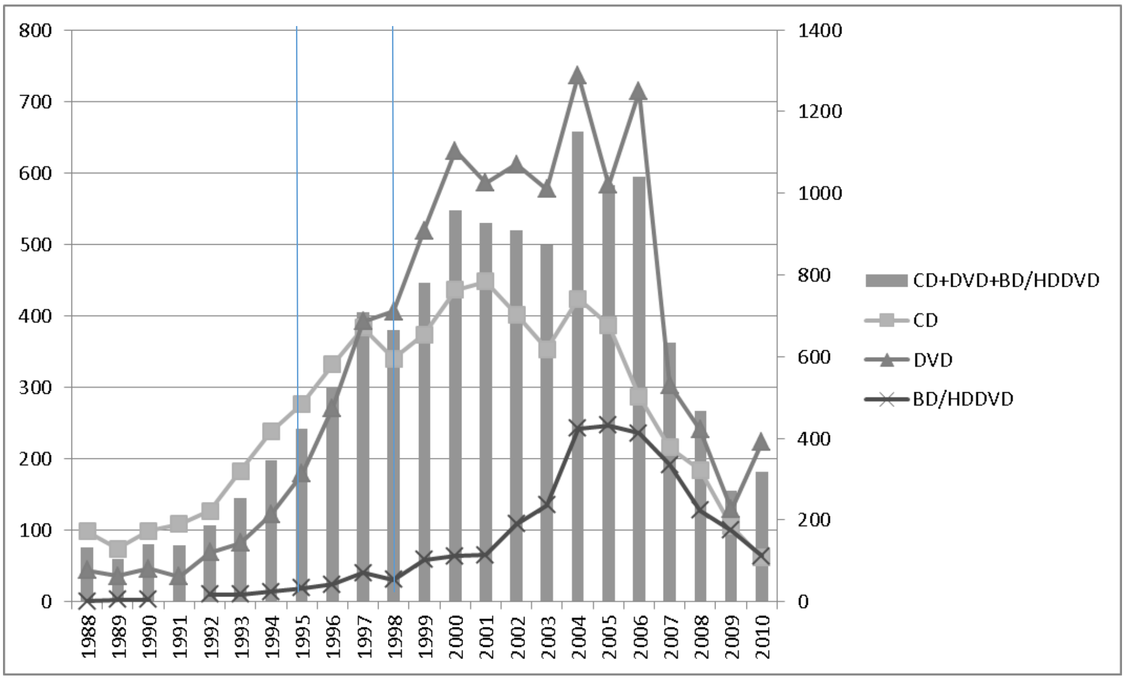
7. Discussions

We will discuss the estimation results in this section, focusing on the following three points: the difference of our results from Joshi and Nerkar (2011), the source of sunk cost and the effects on licensee. The first point is why our results are sharply different from those of Joshi and Nerkar (2011). The first source of the difference is the technological scope of the optical disk industry.

Joshi and Nerkar (2011) made the sample of the patents for their study, based on the USPTO technology classes, and included MPEG-2 pool. In our view, this sampling strategy resulted in over-broad definition of the optical disc industry. As a result, nonparticipants in the pool have many patents outside of the optical disk industry. Specifically, the number of patents in Joshi and Nerkar (2011) is 93,707 from 1976 to 2006, but that in our research is 7,537 for the DVD area and 1,796 for BD/HDDVD area from 1988 to 2010. The second source is that Joshi and Nerkar (2011) did not take into accounts the close link between the standard agreement and the pool for the optical disc industry. Actually, the pool is established to support the licensing of the essential patents of the standard and the firms with such patents already anticipate the formation of the pools when the agreement of the standard is done. Thus, our base period is the pre-standard period not the pre-pool period unlike Joshi and Nerkar (2011). However, even if we use the pre-pool period as the base, we will not get the significantly negative results of the R&D effects of the pools, as suggested by the estimation results from Table 3 to Table 6: *Standardization (1995-97)×Licensor* and *Pool (1998-2000)×Licensor* have similar size of positive coefficients.

The third source of the difference is that we explicitly took into accounts the inter-generational competition in the optical disc industry, while Joshi and Nerkar (2011) pooled them all together. In our view disaggregating data so as to reflect inter-generational competition among standards is critical since the DVD patent pool covers only the DVD patents and there is no a single giant pool governing the evolution of standards in this industry. Thus, we examined how the standard agreement and the pool formation on DVD affected the innovation of the current generation technology (DVD) and that of the next generation technology (BD/HDDVD) separately. In such analysis, we excluded the CD patents. On the other hand, Joshi and Nerkar (2011) pooled them all together. This makes a huge difference. Figure 6 shows the number of patents on CD, DVD and BD/HDDVD on the first axis, and their sum on the second axis. This figure is based only on the patents from the CPC classifications and the essential patents in the pools of CD, DVD and BD. We can see that there are more CD patents than the other generations early in 1990s but such relationship got reversed since late 1990s. Thus, when CD patents are included in the sample, the effects of the DVD standard agreement and the DVD pool formation on the innovations (the development of the next-generation standard or for upgrading or exploiting the DVD technology) would be clearly underestimated.

Figure 6. Number of patents on CD, DVD and BD/HDDVD



The second point is the source of sunk cost. As we explained earlier, eight firms including Toshiba and Time warner won in the competition for a standard replacing of the CD, and they built 6C. Therefore, we hypothesized that the members of 6C will be more influenced by the sunk cost effects for the competition replacing the DVD technology, and our result supports the hypothesis. A question is the source of such sunk cost, R&D investment cost or investment cost in manufacturing and sales assets, which could account for the different behaviors of 3C and 6C.

In our view, there are important differences in sunk R&D investment in the DVD technology between 6C and 3C. There is a significant progress in the technology of the protection layer between CD, DVD and BD. The protection layer plays a pivotal role in the optical disk industry because the thinner the protection layer is, the larger the size of the memory is. Sony and Philips made the CD standard, and the thickness of their format was 1.2mm. They kept this technology when they were in the competition for a standard replacing of the CD, and developed the MMCD format, the thickness of the protection layer of which was 1.2mm, but they lost the competition. The DVD standard became based on the SD format, the thickness of the protection layer of which was 0.6mm and Toshiba and Time warner developed this technology. Therefore, Sony and Philips had smaller R&D sunk investment in 0.6mm disk technology than Toshiba and Time warner. This difference in sunk cost would explain why Sony and Philips could invest aggressively in the next standard (BD), which had thinner protection layer (0.1mm) than that of DVD, while Toshiba developed HDDVD technology, the thickness of the protection layer of which was 0.6mm, but Toshiba lost the competition against BD partly because the size of memory was less than BD.

On the other hand, the sunk cost in the manufacturing and sales asset does not seem to be very important. This is because the members of 3C had higher DVD market shares collectively than those of 6C members as shown in table 7. In addition, 3C members produced DVD player by themselves, implying that both 6C and 3C invested a large cost in manufacturing and sales of DVD, which however may not be significantly sunk to the current DVD technology.

Table 7. Market shares of DVD player (Worldwide)

	Pool	1998	1999	2000	2001
Panasonic	6C	25	13.9	10.9	12
Toshiba		15	14.2	15.7	13.2
Samsung				4.6	10.6
Sony	3C	27	24.1	22.1	17.7
Pinoneer		24	14.3	12.5	8.4
Philips			5	9	8.7
LG					5.6
Others		7	28.5	25.2	38.1
Number of shipment (10 thousand unit)		282.6	1312.8	1620	2867

Source: Nikkei. *Shijosenyuritsu*

The third point is the effect on licensees. As long as the pools include only patents that are complementary and necessary for implementing a standard, they reduce the cumulative royalty rates for the users of the standard by eliminating wasteful multiple marginalization (Shapiro 2001, Lerner and Tirole 2004). But Lampe and Moser (2013) state that the DVD pools created differential royalty between licensors and licensees (see also Flamm 2013), and this made it difficult for the licensees to compete with the pool technology. Therefore the DVD pool could discourage innovation by licensors. In our results, we could not find the evidence to support this opinion. The creation of the pools did not immediately encourage innovation by licensees compared to nonparticipants, but the pool creation has positive effects on both the number of patents and the number of patents weighted by forward citations owned by the licensees for the DVD standard, as we discovered (see table 5 and 6). Furthermore the pool creation has positive effects on R&D on the next generation technology by licensees (see table 3 and 4). Thus, there is no evidence of a pool discouraging the innovations by the licensee. For example, Fujitsu was a licensee of the DVD pool but became also a licensor of the essential patents for BD. And it has 100 DVD related patents and 12 BD related patents in the sample.

8. Conclusions

This paper examined how the standard agreement and the patent pools for the DVD affected the R&D and patenting by the pool licensors and licensees for developing the next-generation standard as well as for improving and exploiting the current standard, based on the panel data from optical disk industry. Our analysis explicitly recognizes the inter-generational competition of standard, unlike earlier studies, given that each standard and the corresponding patent pools governs only one generation of the standard. We also incorporated the close link between the standard agreement and the pools, given that a pool is established to support the licensing of the essential patents of the standard in the optical disc industry and the firms with such patents already anticipate the formation of the pools when the agreement of the standard is done.

From a theoretical point of view, a very successful pool in terms of aggregating essential patents may still reduce the incentive for the incumbents to undertake R&D for a next-generation technology, because of the sunk cost investment in the current generation standard or because of the replacement effect (Arrow (1962)), although the replacement effect may be significantly constrained by a large number of the licensees of the essential patents as well as by the licensing commitment based on the RAND (Reasonable and Non-discriminatory) principle. The dynamic incentive also depends on how the patent pool works. If the transaction cost of the pool is high (that is, if the cost for recognizing and licensing inventions becomes inflated with pool) or if the pool functions to reduce R&D competition among the pool licensors, it may reduce the R&D even for improving and exploiting the current standard.

Major findings from our econometric analysis are as follow. Relative to the nonparticipants, both the standard agreement and the formation of the pool are followed by intensified R&D and patenting efforts by the licensors for a next generation standard (BD and HDDVD). Thus, there is no evidence for negative innovation effects of the pool for the next-generation standard. Lower response of the 6C for the R&D toward the next-generation standard, however, may reflect its larger sunk cost in the DVD technology.

Furthermore, both the standard agreement and the formation of the pools are followed by intensified R&D by the licensors for improving and exploiting the use of the current standard. Thus, there is no evidence of a gross inefficiency of a pool with respect to improving the technology subject to the pool governance. At the same time, after the formation of the pool, the patenting by the licensors increased more than that of the family-based patent counts, with deteriorating patent quality, and such gap is larger for 6C patent pool than for 3C pool, presumably due to the royalty distribution policy of 6C based on the simple patent counts.

The pool also had positive effects on R&D by the licensees not only for the DVD standard, and but also for the next generation standard (see table 3 and 4). This suggests that open licensing of the pool encouraged innovation competition for the next-generation standard.

There are several policy implications and remaining research agenda. First, the patent pools for the DVD apparently did not constrain the R&D competition for the next-generation standard development. It might have accelerated it by enhancing the perspective of the market opportunity for the next-generation standard, which is bound to be cumulative to the success of the current standard which partly depends on the performance of the pool for the current standard. It is important to note that the DVD pool is narrowly specified so that it has no direct power to control inter-generational competition over standards in the optical disc industry. This could have been very important for a pool to be pro-competitive. If not, the pool operator facing the replacement cost might choose to delay the introduction of the next-generation technology. Moreover, the RAND licensing might have enhanced the opportunities for the licensees to build up their capability for research in the optical disc industry, so that it promoted their entries in the R&D for the next-generation standard. Thus, the competition policy guidelines as announced by the DOJ business review letter might have played an important role for making the pools promote R&D for next-generation standard as well as for improving the current technology.

Second, there are some signs of strategic patenting by the licensors, the extent of which seems to be larger for 6C. Given that there is an ex-ante commitment to the maximum royalty, such "excessive" patenting has no consumer harm. However, it can still distort not only patenting but also R&D toward minor improvements. Better design of recognizing the quality of the inventions, including the assessment of patent validity by the pool, could improve the R&D performance.

There are a number of limitations of our study. Our measure of the next-generation technology may be imperfect, since we covered only the two standards which actually competed. There may be failed R&D attempts which we do not recognize. One immediate extension is to assess the effects of the pools on the R&D for CD. Such study provides important evidence on the creative destruction of the old standard by the new standard.

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Appendix

Appendix Table 1. DVD patent pools

Pool Admin., Year	Members of the pool licensors	Essential patents	Non-members	Licensees	Licensing policy	Other Info.
6C,Toshiba, 1998	Toshiba, Matsushita, Mitsubishi Electric, Time Warner, Hitachi, Victor Company of Japan, IBM	180 US patents for player, and 166 US patents for recorders (December 2004)	Thomson	245 firms for hardware (decoders and encoders) 157 firms for discs	1. The contracts run until Dec. 31, 2007 and renew automatically for 5-years terms thereafter. 2. Commitment to royalty (royalties of $.075 per DVD Disc and 4% of the net sales price of DVD players and DVD decoders, with a minimum royalty of $4.00 per player or decoder) 3. A most-favored-nations clause 4. An obligation for licensee to grantback any essential patent on fair, reasonable and non-discriminatory terms.	1. Each firms can license independently. 2. The allocation of royalties depends on the share of patents contributed to the pool.
3C, Philips, 1998	Philips, Sony, Pioneer,LG	131 US patents for DVD players, 106 US patents for recorders (December 2004)		179 firms for hardware (decoders and encoders) 216 firms for discs	1. The contract term is 10 years. 2. Commitment to royalty (royalties of 3.5% of the net selling price for each player sold, subject to a minimum fee of $7 per unit, which drops to $5 as of Jan. 1, 2000 and $.05 per disc sold.) 3. A most favorable conditions clause. 4. An obligation for licensee to grant-back any essential patent on fair, reasonable and non-discriminatory terms.	1. Each firms can license independently. 2. The allocation of royalties is not a function of the number of patents contributed to the pool.

Source: Nagaoka et al.(2009)

Appendix table 1. CPC for population of patents representing optical disc technology

CPC	Number of essential patents	Number of the optical disk patents	Descriprion
G11B27/329	640	3677	{on a disc (VTOC)}
G11B2220/2562	637	3937	DVDs [digital versatile discs]; Digital video discs; MMCDs; HDCDs
G11B27/105	625	5273	{of operating discs}
G11B27/3027	620	3956	{used signal is digitally coded}
H04N9/8042	523	4527	{involving data reduction}
H04N5/85	516	4235	on discs or drums
G11B27/034	471	4996	on discs(G11B27/036 , G11B27/038 take precedence)
G11B2220/216	395	2415	Rewritable discs
H04N9/8063	350	1826	{using time division multiplex of the PCM audio and PCM video signals}
G11B27/34	326	4061	Indicating arrangements(indicating measured values in general G01D){ indicatir
G11B20/1217	316	2279	{on discs}
H04N9/8227	309	1609	{the additional signal being at least another television signal}
G11B2220/20	293	4190	Disc-shaped record carriers
G11B7/00745	260	1411	{Sectoring or header formats within a track(formats in general G11B20/12)}
G11B2220/2575	256	1329	DVD-RAMs
G11B7/007	232	1554	Arrangement of the information on the record carrier, e.g. form of tracks,{actual
G11B2220/218	229	1674	Write-once discs
H04N9/8205	224	1997	{involving the multiplexing of an additional signal and the colour video signal}
G11B27/24	222	1263	by sensing features on the record carrier other than the transducing track(for
G11B7/0037	203	1478	with discs
G11B2220/2545	196	2761	CDs
G11B20/10	175	2666	Digital recording or reproducing(digital computers in which at least part of the
G11B7/00736	170	1505	{Auxiliary data, e.g. lead-in, lead-out, Power Calibration Area(PCA), Burst Cuttir
G11B20/00086	168	3272	{Circuits for prevention of unauthorised reproduction or copying, e.g. piracy(indi
G11B7/00718	168	851	{Groove and land recording, i.e. user data recorded both in the grooves and on tl
G11B27/36	160	2792	Monitoring, i.e. supervising the progress of recording or reproducing{ for digital r
G11B7/0045	154	1606	Recording(G11B7/006 . G11B7/0065 take precedence)
G11B27/19	154	710	by using information detectable on the record carrier
G11B20/10527	144	2583	{Audio or video recording; Data buffering arrangements(G11B20/12 to G11B20/
G11B20/1883	136	1315	{Methods for assignment of alternate areas for defective areas}
G11B19/02	134	1550	Control of operating function, e.g. switching from recording to reproducing
G11B2220/211	132	617	Discs having both read-only and rewritable or recordable areas containing appli
H04N5/775	131	2158	between a recording apparatus and a television receiver
G11B2220/213	129	1156	Read-only discs
G11B20/1251	125	461	{for continuous data, e.g. digitised analog information signals, pulse code modula
G11B7/005	121	1703	Reproducing(G11B7/0065 takes precedence)
G11B27/036	120	1262	Insert-editing
G11B20/12	120	640	Formatting, e.g. arrangement of data block or words on the record carriers{(witl
G11B7/0938	111	770	{servo format, e.g. guide tracks, pilot signals}
G11B19/12	108	1194	by sensing distinguishing features of{or on}records, e.g. diameter{end mark}
G11B7/0053	106	781	{Reproducing non-user data, e.g. wobbled address, prepits, BCA} <u>WA
G11B7/013	104	491	for discrete information, i.e. where each information unit is stored at a distinct
G11B7/24085	102	1009	Pits
G11B2220/2537	101	1090	Optical discs
G11B2220/2583	71	205	wherein two standards are used on a single disc, e.g. one DVD section and one
G11B2220/2541	56	882	Blu-ray discs; Blue laser DVR discs
G11B2220/255	19	104	CD-I, i.e. CD-interactive
G11B2220/2554	16	31	CD-V [CD-Video], CDV, or CD+V, as defined in IEC 61104
G11B2220/2579	12	209	HD-DVDs [high definition DVDs]; AODs [advanced optical discs]
G11B2220/2566	10	76	DVDs belonging to the minus family, i.e. -R, -RW, -VR
G11B2220/257	4	63	DVDs belonging to the plus family, i.e. +R, +RW, +VR
G11B2220/2587	3	190	Laser Discs; Optical disc using analog recording

Appendix table 2. Sample statistics

	Variables	Generation	Mean	SD	Min	Max
1	ln(Patents)	BD/HDDVD	0.20	0.57	0	4.42
2	ln(Cited patants)		0.43	1.15	0	6.78
3	ln(Families)		0.17	0.50	0	3.97
4	ln(Cited families)		0.40	1.12	0	6.68
5	ln(Patents)	DVD	0.59	0.98	0	5.26
6	ln(Cited patants)		1.29	1.93	0	7.65
7	ln(Families)		0.50	0.86	0	4.37
8	ln(Cited families)		1.17	1.86	0	7.93
9	Standardization(1995-1997)		0.13	0.34	0	1.00
10	Pool(1998-2000)		0.14	0.34	0	1.00
11	Pool(2001-2010)		0.45	0.50	0	1.00
12	Licensor		0.16	0.36	0	1.00
13	Licensee		0.13	0.33	0	1.00
14	6C		0.10	0.30	0	1.00
15	3C		0.05	0.22	0	1.00
16	Diversity		2.28	2.30	0	7.00
17	Age		2.14	1.11	0	3.56

N=2361

Appendix Table 3. Correlation matrix

	Variables	Generation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	ln(Patents)	BD/HDDVD	1.000																
2	ln(Cited patants)		0.900	1.000															
3	ln(Families)		0.941	0.879	1.000														
4	ln(Cited families)		0.828	0.934	0.905	1.000													
5	ln(Patents)	DVD	0.712	0.723	0.695	0.686	1.000												
6	ln(Cited patants)		0.513	0.594	0.518	0.577	0.901	1.000											
7	ln(Families)		0.656	0.702	0.685	0.700	0.940	0.862	1.000										
8	ln(Cited families)		0.472	0.580	0.509	0.594	0.828	0.916	0.905	1.000									
9	Standardization(1995–1997)		−0.041	0.025	−0.030	0.028	0.005	0.072	0.014	0.072	1.000								
10	Pool(1998–2000)		0.007	0.058	0.009	0.050	0.083	0.118	0.098	0.124	−0.154	1.000							
11	Pool(2001–2010)		0.180	0.081	0.154	0.057	0.126	−0.020	0.076	−0.066	−0.350	−0.357	1.000						
12	Licensor		0.544	0.569	0.525	0.542	0.619	0.557	0.588	0.538	−0.001	−0.006	−0.012	1.000					
13	Licensee		−0.038	−0.041	−0.032	−0.038	−0.025	−0.050	0.005	−0.028	−0.006	−0.004	0.011	−0.165	1.000				
14	6C		0.361	0.385	0.340	0.367	0.441	0.413	0.395	0.390	0.000	−0.005	−0.009	0.765	−0.126	1.000			
15	3C		0.392	0.392	0.390	0.371	0.389	0.331	0.396	0.331	0.000	−0.003	−0.007	0.527	−0.087	−0.074	1.000		
16	Diversity		0.562	0.576	0.547	0.545	0.758	0.687	0.725	0.646	−0.014	0.061	0.182	0.625	0.066	0.471	0.338	1.000	
17	Age		0.255	0.249	0.246	0.235	0.323	0.270	0.301	0.249	−0.087	−0.010	0.441	0.293	−0.038	0.221	0.149	0.511	1.000

N=2361