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A TALE OF TWO STANDARDS: PATENT POOLS AND INNOVATION IN THE OPTICAL DISK DRIVE INDUSTRY

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Working Paper 18931
http://www.nber.org/papers/w18931

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
March 2013

I am grateful to Anustubh Agnihotri, Blake Messer, Sankar Rengarajan, and Amin Shams for their invaluable research assistance on this project, and to participants in the NBER premeeting on Patents, Standards, and Innovation conference in May, 2011, and the NBER Patents, Standards, and Innovation conference in January 2012. Without implicating them in my errors, I thank Rudy Bekkers, Shane Greenstein, and Tim Simcoe for very useful comments on a prior draft. This material is based upon work supported by the National Science Foundation under Grant No. 0830389. I note that I first became aware of the fascinating history of these two patent pools while serving as a consultant providing factual analysis to a party involved in antitrust litigation in the optical disk drive industry. The effect of the patent pools on innovation has not been at issue in the litigation. The views expressed herein are those of the author and do not necessarily reflect the views of the National Bureau of Economic Research.

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NBER Working Paper No. 18931
March 2013
JEL No. O3,O31,O33,O34

ABSTRACT

The impact of patent pools on the rate and direction of technological change is an open question in both theoretical and empirical studies. Economic theory makes no unequivocal prediction. By contrast, empirical studies of patent pools, to date, have largely concluded that patent pools have been associated with reduced rates of technical innovation in the industries studied. This study differs from previous empirical studies of patent pools by focusing primarily on direct measures of innovation in product markets, rather than on indirect correlates of innovation (like patents), and by exploiting variation over time in how pools were organized in the same technology area.

The paper analyzes the economic history of two successive sets of patent pools organized in substantially the same technological area—the use of optical discs in data storage peripherals connected to computer systems. These two patent pool episodes differed significantly in their organizational and institutional details. These differences appear to have coincided with very different effects on the structure of product markets, and the rate of technical innovation in optical disc products. The analysis concludes that different approaches to pool organization and licensing policies implemented in these two patent pool examples were associated with very different outcomes. The clear implication is that organizational details matter: no single conclusion is likely to fit all cases. As theory seems to predict, the empirical effects of patent pools on innovation are likely to be ambiguous, dependent on the historical and institutional particulars of the pool and the industry it affects.

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Patent pools—agreements among multiple firms to issue joint licenses to a set of patents owned by individual pool members—became increasingly common in high tech industry in the final decade of the last century.[1] The patent system motivating these pools sits at the intersection of two sometimes conflicting objectives of economic policy. On the one hand, societies typically encourage innovation by granting temporary monopolies (i.e., patents) on new technologies, as a dynamic incentive to induce investment in R&D, the results of which otherwise are often difficult to appropriate by an inventor, absent the state-issued grant of temporary monopoly embodied in a patent. On the other hand, once a particular technology has been created, it is socially optimal to make it available as widely as possible at its marginal social cost of transfer, which is often close to zero, a price that would offer no return to an inventor and discourage new investment in innovation. There is a fundamental tension between these two divergent goals.

Conceptual Issues

Patent pools further complicate this tradeoff. In complex technological systems, which frequently are associated with formal or informal industry standards, it is common for patents owned by different firms to cover distinct elements used in building the high tech system or technology platform. It is now well-established in the industrial organization literature that in this circumstance, a joint licensing arrangement for all patents essential to the standard for the high tech system can have a positive social impact in reducing both transactions and royalty costs for the multiple complementary patent licenses that would be required to implement the system absent a pool (cutting through the "patent thicket," and avoiding "royalty stacking"[2]), thus making the production of such an innovative high tech system less costly and more likely to actually occur. By increasing future profits for the inventors, the prospect of a pool would also encourage investment in innovation.

Offsetting the advantages of a patent pool in encouraging the introduction of a given technological system is its potential to serve as a mechanism for restraining competition in markets for the resulting technological system. A patent pool is an agreement to coordinate in setting prices for technological inputs, and profit-maximizing price-setting from the perspective of the pool members requires their consideration of the impacts of technology license pricing on downstream production costs and sales prices for the technological system, product markets in which pool members frequently

[1] I am grateful to Anustubh Agnihotri, Blake Messer, Sankar Rengarajan, and Amin Shams for their invaluable research assistance on this project, and to participants in the NBER pre-meeting on Patents, Standards, and Innovation conference in May, 2011, and the NBER Patents, Standards, and Innovation conference in January 2012. Without implicating them in my errors, I thank Rudy Bekkers, Shane Greenstein, and Tim Simcoe for very useful comments on a prior draft. This material is based upon work supported by the National Science Foundation under Grant No. 0830389. I note that I first became aware of the fascinating history of these two patent pools while serving as a consultant providing factual analysis to a party involved in antitrust litigation in the optical disk drive industry. The effect of the patent pools on innovation has not been at issue in the litigation.

[2] C. Shapiro, "Navigating the Patent Thicket: Cross Licenses, Patent Pools, and Standard Setting," in A. Jaffe, J. Lerner, and S. Stern, Ed., **Innovation Policy and the Economy**, Vol. 1, (Cambridge: MIT Press), 2001.

also participate. In addition, the existence of the pool, and the recognition and joint defense of all patents in the pool by its members, can protect weak pool patents from possible challenge by other pool members. Further, joint defense by the pool will reduce the costs to an individual pool member of defending against legal challenges to individual patents in the pool by outsiders, again providing additional protection to weak patents that might otherwise be challenged in the courts.[3]

For these reasons, there has been a continuing ebb and flow in attitudes toward patent pools in U.S. antitrust policy. In the period after World War II, up until the early 1990s, antitrust policy in the U.S. largely viewed patent pools as per se illegal.[4] This changed in the 1990s, and the CD patent pool that I analyze in this paper was arguably the first, modern postwar patent pool, whose creation coincided with this change in US competition policy.

The goal of this paper is to analyze the organization and operation of the two seminal patent pool groups of the 1980s and 1990s, the CD patent pools, and their successors, the DVD patent pools, and focus on an assessment of their impact on the pace of product market innovation in the optical disk drive industry.[5] The analysis will also touch on the impact of the pools on the industrial organization of the optical disk drive industry. The primary focus will be to explore how the pace of technological innovation in optical disk drives changed over time, and to study the linkages between the particulars of patent pool licensing arrangements and product market technological change.

Patent Pools and the Rate of Innovation

Since a patent pool increases profits from pool patents for pool members, anticipation of the formation of a patent pool will increase the return *ex ante* on investment in innovation by firms planning to join the pool. Indeed, this may even result in overinvestment (from a social perspective) before the pool is formed.[6]

The impact of patent pools on further innovation after a pool's formation is ambiguous in the economics literature. In effect, a patent pool is a coordination mechanism approximating the creation of

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[3] See N. Gallini, "Private Agreements for Coordinating Patent Rights: The Case of Patent Pools," IEL Paper in Comparative Analysis of Institutions, Economics, and Law No. 5, July 2011, pp. 12-13, available at http://polis.unipmn.it/pubbl/RePEc/uca/ucaiel/iel005.pdf .

[4] R.J. Gilbert, "Anti-trust for Patent Pools: A Century of Policy Evolution," **Stanford Technology Law Review**, vol. 3, 2004.

[5] In this paper, I do not discuss the MPEG patent pool, which was organized after the CD patent pools but just before the DVD patent pools. MPEG video compression technology is important to industry standards adopted for the storage and playback of digital video content, but not needed for other, more general, forms of digital data storage used in the computer industry. The MPEG patent pool was also organized very differently from the patent pools examined in this paper.

[6] For summaries of this literature, see K.M. Schmidt, "Standards, Innovation Incentives, and the Formation of Patent Pools," in A. Fredenberg, Ed., **The Pros and Cons of Standard Setting**, (Swedish Competition Authority: Stockholm), 2010, pp. 64-65, available at http://www.kkv.se/upload/Filer/Trycksaker/Rapporter/Pros&Cons/rap_pros_and_Cons_standard_setting.pdf ; Gallini, 2010, pp. 15-16.

a de facto technological monopolist for the technology standard and platform associated with the patent pool. Kenneth Arrow's seminal 1962 article on the impact of market structure on incentives to innovate pointed out that an unchallenged incumbent monopolist will always have less incentive to invest in the R&D required to create a particular new invention than a firm operating in a competitive product market. With a competitive market, successful development of a new patented invention would create monopoly power—and rents—not previously present in the industry.[7] By contrast, an unchallenged incumbent monopolist operating in the same product market will have a diminished incentive to develop the same innovation, since a technological monopoly resulting from the new innovation would in part be cannibalizing existing monopoly profits. These preexisting monopoly profits would not be present for a firm considering the development of this same innovation in a competitive product market. This reduced incentive for a monopolist to innovate has been dubbed the "replacement effect".[8]

Furthermore, owners of other essential but complementary technology outside the pool would be able to free-ride on the standard supported by pool members, reducing the return on new R&D investments by those within the pool. Rules for allocating pool income may also weaken incentives for those within the pool to undertake further R&D if standard-related R&D results are shared with other pool members. On the other hand, as Gallini points out, the reduced costs of litigation among pool members, and access to patents of other pool members, could have some offsetting simulative effect on further investment in pool-related innovation by pool members.[9]

The most compelling study to date of the empirical effects of a patent pool on innovation is Lampe and Moser's detailed studies of the 19th century sewing machine patent pool. Lampe and Moser conclude that innovation—measured by either patenting or technical metrics—was high before the formation of the pool, dropped for firms both inside and outside the pool during its life, and then increased once again after the pool was dissolved.[10] I find both similarities and differences with this pattern in the optical disk drive industry.

Similarly, Joshi and Nerkar document that both the quantity and quality of patents granted to pool members and their licensees, as well as patents granted to other firms patenting in the optical disk industry fell after the creation of the DVD patent pools discussed in this study.[11] They estimate statistical models of patent numbers and quality over the 1982-2006 period. Their results lead them to conclude

[7] K. Arrow, "Economic Welfare and the Allocation of Resources to Innovation", in R.R. Nelson, Ed., **The Rate and Direction of Economic Activity**, (Princeton: Princeton University Press), 1962.
[8] L.M.B. Cabral, **Introduction to Industrial Organization**, (Cambridge: MIT Press), 2000, pp. 292-298 lays out a spare and intuitive presentation of the basic argument.
[9] Gallini, 2010, pp. 15-16.
[10] R. Lampe and P. Moser, ""Do Patent Pools Encourage Innovation? Evidence from the Nineteenth-Century Sewing Machine Industry," **Journal of Economic History**, vol. 70(04), 2010, pages 898-920, December; "Patent Pools and the Direction of Innovation - Evidence from the 19th-century Sewing Machine Industry," NBER Working Paper 17573, National Bureau of Economic Research, 2011.
[11] A. Joshi and A. Nerkar, "When Do Strategic Alliances Inhibit Innovation by Firms? Evidence from Patent Pools in the Global Optical Disc Industry," **Strategic Management Journal**, vol. 32, 2011, p. 1152.

that both the quantity and quality of patented innovation declined for DVD pool members and their licensees, relative to other industry participants, after 1998, and interpret these results as suggesting that innovation in the optical disk industry was reduced by the creation of the DVD patent pools.

My results suggest that this interpretation may not be entirely correct. In particular, there was an optical disk patent pool already in place during Joshi and Nerkar's "control period" of 1982-1997-- the CD patent pool. The analysis in this paper suggests that the economics of the licensing arrangements adopted by the CD patent pool operated in a substantially different fashion from those later implemented in the DVD patent pool, and that rather than comparing a no-pool control period with a later pool period, they are in fact comparing rates and quality of patenting in the first CD pool period to patent quantity and quality in the later DVD pool period. Viewed in this light, their results are consistent with the central conclusion of this paper-- that the first pool, the CD pool, appears to have adopted policies that on balance seem to have stimulated both competition and innovation, while the later DVD pool adopted policies that inhibited both-- rather than documenting some more general effect of patent pools inhibiting innovation in the optical disk industry relative to a no-pool counterfactual. I arrive at this conclusion based on product market data, complementing the Joshi and Nerkar focus on patenting, an indirect correlate of innovation.

Origins of the Optical Disk Data Storage Industry

Optical disks have been used commercially to store digital data since the introduction of Laserdisc technology in the late 1970s.[12] Laserdisc was a higher quality, though largely unsuccessful, competitor to VHS and Beta magnetic tape cassette video players (just 2% of US households had Laserdisc players in 1998, while 10% of Japanese households had Laserdisc players in Japan in 1999).[13] Dutch multinational Philips (along with US entertainment giant MCA) had jointly developed the Laserdisc.

By 1977, numerous companies had demonstrated prototypes of music players using optical disks. In 1979, Philips had demonstrated a promising initial prototype of a digital audio system. Philips then agreed to cooperate with Sony, jointly defining a common signal format and error-correction methods, and by 1980, the two companies had extended this partnership to other aspects of a common standard for digital audio discs and players.[14] The resulting system, the compact disc (CD), united Sony's

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[12] The video on a Laserdisc was reproduced using an analog signal, but the audio could be stored using either analog or digital formats.

[13] The 2 million US households owning Laserdisc players in 1998 contrasted with 80-90 million US VHS households. (K.R. Brancolini, "New and Emerging Video Technologies: A Status Report," October 1998, available at http://www.dlib.indiana.edu/~brancoli/videostatus.html); J. Flaherty, "Bittersweet Times for Collectors of Laser Disk Movies," New York Times, April 29, 1999, available at http://www.nytimes.com/1999/04/29/technology/bittersweet-times-for-collectors-of-laser-disk-movies.html?pagewanted=print&src=pm .

[14] This chronology is based on J.B. H. Peek and J.P. Sinjou, "The CD System as Standardized by Philips and Sony," in H. Peek, J. Bergmans, J. van Haaren, F. Toolenaar, and S. Stan, **Origins and Successors of the Compact Disc, Contributions of Philips to Optical Storage**, (Springer, 2009).

error correction technology with Philips' optical technology. The two companies announced the proposed standard in 1980, and published it in 1981.[15] It was also adopted by Japan's Digital Audio Disc Committee in 1981. The latter committee had been appointed by Japan's Ministry of International Trade and Industry to recommend a world standard for digital audio.[16] Thus, a powerful government entity overseeing firms headquartered within its borders that were, at the time, the most important international consumer electronics producers, had effectively thrown its support behind what was to evolve into the global standard for digital data storage technology.

The first CD audio players went on the market in 1982.[17] It soon became clear that there would also be a significant market for an optical disk storage system for computer applications. In 1984 Philips and Sony announced the original CD-ROM (CD Read Only Memory) standard, and in 1985 the first commercial CD-ROM players were shipped as peripherals to large computer systems. The standard was also adopted by international standards organizations in that year. There was no standard for organization of the data and file systems on the CD-ROM disks, however, until 1988, when proprietary formats were supplanted by the international standard ISO 9660 file interchange format. Shortly thereafter, in 1989, Philips and Sony were also joined by Microsoft in proposing a unified CD-ROM XA standard which also allowed computers to use multimedia variants of CD discs. These extensions of the CD-ROM format were soon incorporated into computer operating systems, most notably UNIX and Windows. CD-ROM data disk players were first shipped as add-on units to personal computers in 1990.[18]

Table 1 contains a timeline of the principal events in the historical development of optical storage drive technology in the CD format. The CD-ROM patent pool effectively came into being with the joint 1984 announcement of the read-only CD-ROM standard by Philips and Sony. The same two companies, in association with materials industry partners (who brought with them key elements of the materials technology need to produce consumer-writeable CDs), later organized distinct patent pools to jointly license writeable CD formats (CD-R, CD-RW) in the 1990s, after their joint announcement in 1990 of the CD-R format and standard.

Table 1 CD Technology Timeline

1980	Philips-Sony announcement of the CD-DA digital audio standard
1981	MITI Advisory Committee adopts Philips-Sony CD-DA standard, CD-DA standard published
1982	CD-DA audio players introduced, CD-DA patent pool formed
1984	Philips-Sony announcement of CD-ROM standard
1985	1st CD-ROMs shipped, peripherals to large computer systems
1988	Non-proprietary ISO 9660 computer data/file system standard for CD-ROMs

[15] S.G. Stan, "Compact Disc Standards and Formats," in Peek, Bergmans, van Haaren, Toolenaar, and Stan, 2009, pp. 138-9.

[16] These details can be gleaned from S. G. Stan, "Optimization of the CD-ROM System Towards Higher Data Throughputs," Thesis, Technical University of Eindhoven, Netherlands, 1999, pp. 5-6, available at http://alexandria.tue.nl/extra3/proefschrift/boeken/9901167.pdf ; J.H.B. Peek and J.P. Sinjou, 2009, pp. 53-58.

[17] Stans, 2009, p. 139.

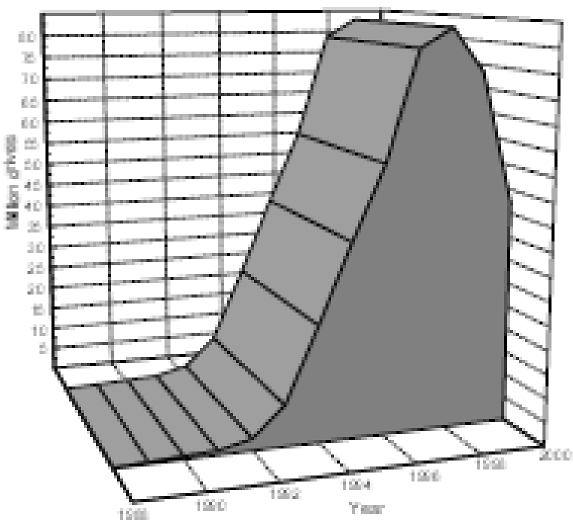
[18] S. Stan, "Compact Disc Standards and Formats," in Peek, et. al., 2009, pp. 143-150; Stan, 1999, p. 5.

1989 Microsoft joins in CD-ROM XA standard
1990 Philips-Sony CD-R standards published; first PC CD-ROM drives shipped
1991 1st CD-R drives shipped
Early 1990s CD-R patent pool formed
1994 US Dept. of Justice investigation into CD licensing practices
Taiwan, Korea producer entry in CD-ROM drives
1996 CD-RW standard published
1997 1st CD-RW drives shipped

Sources: See text; also Stans, 2009.

The CD-ROM market for PCs grew explosively in the mid-1990s, rising from under 5 million units annually in 1993, to a peak of about 85 million units per year just five years later, in 1998 (Figure 1). After 1998, computers increasingly were attached to writeable CD format drives, and later, DVD drives.

Figure 1 Estimated World-wide Sales of Notebook and Desktop CD-ROM Drives



Source: Stans, 1999, p. 8.

Technical Innovation and the Evolution of Product Markets

Rapidly falling prices clearly explain much of the increase in sales. In 1988, the average sales price for a CD-ROM was about $500. In 1990, average unit price was about $300, and by 1995, under $100.[19] This amounts to a fall in average unit price of about 20.5% annually.

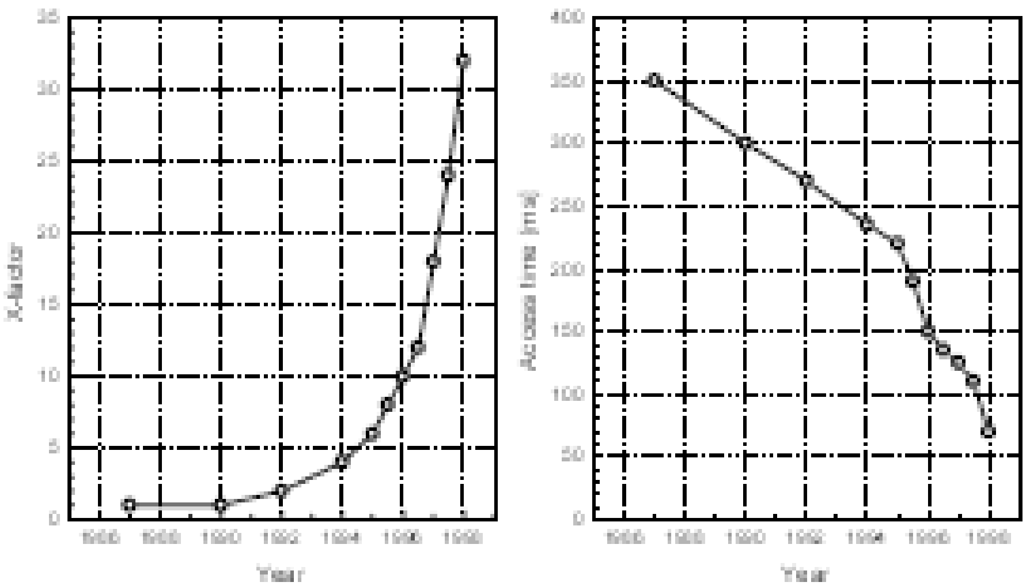
Moreover, this is a lower bound on the rate of quality-adjusted price decline, because the CD-ROM drive sales depicted in the later years in the above figure also capture dramatically higher quality drives than the original CD-ROM units sold back in 1988. Back in 1984, the original specification called

[19] D. J. Lee, "A study on the standards in optical storage device industry," M.S. thesis, Sloan School, MIT, 2000, pp. 17, 20. Lee was an employee of Korean optical drive producer LG Electronics.

for a drive with a sustained data transfer rate of 153.6 kilobits per second (1X speed).[20] By 1998, new versions of the CD-ROM drive specification called for transfer rates 32 times higher (32X).

Figure 2 shows the rapid evolution of the sustained data transfer rate in the Philips-Sony CD format specifications, and the related decline in the average access time to read a random bit of information off a CD-ROM. Figure 3, based on a sample compiled for this study of 318 optical drive reviews available on online from computer magazines and web sites, shows (by year of review) the maximum CD format disk data transfer rates available in optical disk drives reviewed in these industry publications. CD drive write ("burn") performance converged with read performance in 2002. Both readers and burners continued to improve rapidly through 2003, to 52X, and then leveled off after 2003.[21]

Figure 2 Evolution of Philips CD-ROM drive specifications

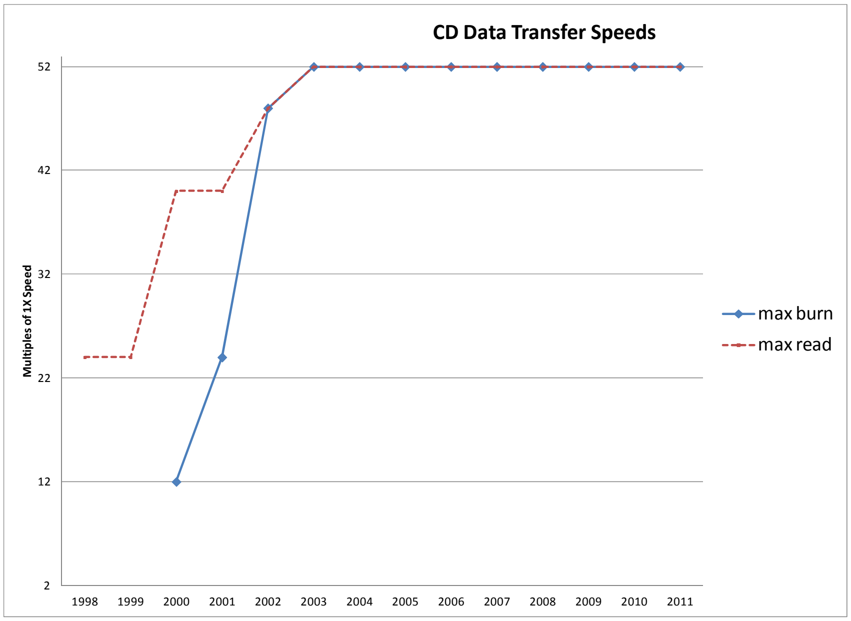


Source: Stans, 1999, p. 9.

[20] While the original CD digital audio specification called for a disk with a capacity of 74 minutes, or 650MB of digital data, the CD-ROM specification expanded disc capacity up to 703MB of digital data, or 80 minutes of audio, on a disk. The initial CD-ROM specification also created a technological improvement over the CD-DA specification, then, by increasing the data storage capacity of a CD format audio disk. Two "flavors" of blank CD-R and CD-RW discs with 650 and 700 MB capacities became de facto standards in the market.

[21] The 52X writers, though widely sold, were not technically incorporated into the CD-R standard. (Drives with 56X write speeds were even marketed at one point.) In 2002, Philips and Sony announced that no further increase beyond 48X data transfer rates for CD writing would be incorporated into the CD-R standards. The official position was that "[s]tressing the system beyond 48X does not pay off in terms of customer satisfaction (i.e., significantly shortening the recording time), while relatively unsafe operating electromechanical conditions are approached by increasing the spinning rate toward 200Hz." Stan, 2009, P. 157.

Figure 3 **Maximum CD Data Transfer Rates in a Sample of 318 Reviewed Optical Disk Drives**



Source: Author's analyses of sample of reviews of 318 optical disk drive models over 1998-2011, published in online magazines and web sites. Year is date of review.

Little in the way of systematic collections of historical prices for CD-format optical data storage drives seems to have survived from the 1980s and 1990s. The best available data appear to be matched model producer price indexes for optical disk storage devices from the Bank of Korea that cover the 1995-2000 period.[22] Table 2 shows massive declines in price over most of this period, accelerating from 46% to 62% annual drops from 1995 through 1997. The price increase in 1998 and more muted (but still large) decline in 1999 coincided with an appreciation of the Korean won against the dollar, and, as we shall see next, with an apparent consolidation in the industry and the beginning of the transition to the successor technology, the DVD. Thus, both anecdotal reports on price and the best available price indexes support the inference of a high rate of technical innovation, and quality-adjusted price decline in the CD format drive era, through the early 2000s.

[22] Though these indexes are presented as constructed using 2005 base period weights, they start in 1995 before the DVD drives that accounted for the vast bulk of production in 2005 were being shipped. Since DVD drives were not being shipped in any significant volume by Korean producers prior to 2000, they clearly must primarily reflect movements in CD optical drive prices in the 1990s. There is no published documentation available on these particular price indexes, and the most likely explanation is that the Bank of Korea spliced earlier optical storage producer price indexes based on 1995 and 2000 weights to the 2005 base index it currently reports. The current (2005 base) price indexes apparently make use of hedonic methods, so it less likely but not impossible that the Bank went back and estimated hedonic price functions for the 1995-2005 period. The Korean price indexes have been converted to a U.S. dollar equivalent basis using average monthly won-dollar exchange rates published online by the St. Louis Federal Reserve Bank.

Table 2, Rates of Change in Dollar Basis Korea Producer Price Index for Optical Disk Drives

Time Period	Percent Change
1/95-1/96	-46.1%
1/96-1/97	-52.6%
1/97-1/98	-62.0%
1/98-1/99	11.2%
1/99-1/00	-25.1%

Source: Author's calculations based on Bank of Korea Producer Price Index for Optical Disk Drives, converted to dollar basis using annual average exchange rates published online by the St. Louis Federal Reserve Bank.

Market Structure

Initially, Philips and Sony were joined by Hitachi as the principal manufacturers of CD-ROM units, primarily for use as peripherals in high end (mainframe and mini-) computer systems. By 1990, Toshiba had also entered the market in force, and soon thereafter, a small Japanese producer of floppy disk drives, Mitsumi, pioneered a lower cost drive unit with a PC-oriented hardware interface. [23] The cheaper Mitsumi-style unit, combined with development of CD-ROM extensions for the Windows operating system, led to an explosion in demand for CD-ROMs for use in PCs, and incorporation of a CD-ROM as a standard peripheral into mainstream PC designs.

By the mid-1990s, Korean and Taiwanese producers had entered the CD-ROM business. The first production of CD-ROMs in Taiwan and Korea, for example, took place in 1994; within two years, Taiwanese producers accounted for 12 percent of global output.[24] By 1996, Korea's LG alone accounted for just under 10% of global sales.[25] Propelled by intense competition from these new entrants, CD-ROM drive prices plummeted.

The numbers of new entrants were impressive. According to data compiled from Disk/Trend (an industry consulting company) reports, the number of optical disk drive producers went from 2 in 1983, to 16 in 1985, to roughly 65 in 1995, then fell to 44 by 1999.[26] Specialist startup firms just entering the optical drive industry were initially disproportionately important in stimulating initial technological improvements to optical drives. Prior to 1988 (when the industry standard ISO 9660 digital storage

[23] See Lee, 1999, pp. 18-21. The Mitsumi design also replaced a separate external "caddy" carrier needed to hold the CD disc when it was inserted into the drive and interfaced with the drive's optical pickup unit, with a simple motorized plastic tray that loaded the disc into the correct position.
[24] G. W. Noble, "Conspicuous Failures and Hidden Strengths of the ITRI Model: Taiwan's Technology Policy Toward Hard Disk Drives and CD-ROMs," Report 2000-02, Information Storage Industry Center, UC San Diego, March 2000.
[25] Lee, 1999, p. 20. Korea's Samsung reported shipping its first CD-ROM drive at the end of 1994. "Driven**," Invest Korea Journal**, vol. 58, no. 3, May-June 2008.
[26] See O. Khessina, "Effects of Entry Mode and Incumbency Status on the Rates of Firm Product Innovation in the Optical Disk Drive Industry, 1983-1999," Report 2002-01, Information Storage Industry Center, University of California, San Diego, October 2002, Figure 2, p. 45. Disk/Trend's own J.N. Porter gives slightly different numbers: he has optical disk companies rising from 16 in 1985 to a peak of 60 in 1995, then falling to 44 by 1999. J.N. Porter, "A Historical Perspective of the Disk Drive Industry," presented at THIC Meeting, San Jose, April 2005, slide 18, available at http://www.thic.org/pdf/April05/disktrend.jporter.050419.pdf .

format was defined), the fastest CD drives shipped--using proprietary data formats-- were consistently coming from new, startup companies, but after the standard was defined, incumbent, existing electronics and computer firms took the lead in shipping faster drives, with the newer firms now trailing close behind.[27]

One time-recordable and rewritable CD standards, which would allow computer users to write data to (and not just read data from) optical disks were defined by Philips and Sony in the early 1990s. A specification for a magneto-optical disk created in 1990 was not widely adopted by others, but did lead to the Sony Minidisc, introduced in 1992. This standard was incompatible with existing CD-ROM drives. Another compatible standard defined in 1990, for a one-time writable CD-R (Recordable) disc, became the de facto standard of the computer industry. Yet another recordable system, for a CD-RW (Rewritable) was specified in 1996.[28] Disks recorded using either the CD-R or CD-RW technologies were compatible with technology used in CD-ROM (read only) drives. Prices of optical disk recorders dropped rapidly, from $15,000 in 1991, to $5,000 in 1993, to under $1,000 in 1995.[29]

The CD Patent Pools

In 1982, Philips and Sony formed a patent pool, and launched a worldwide joint licensing program for the original CD digital audio patents, administered by Philips. This patent pool was later extended to other formats and technologies related to CD standards proposed by Philips and Sony.[30] In the early 1990s, Philips and Sony formed a patent pool for the CD-R technology with Taiyo Yuden,[31] a Japanese materials producer with patents covering the specialized materials technology used in manufacturing recordable CD-R disks. Later, a similar pool was formed by Philips and Sony with Japanese producer Ricoh to license the CD-RW technology's patents.

The CD-ROM patents were reportedly licensed to some drive manufacturers with a running royalty rate of 3 percent of sales of equipment using the technology.[32] Another manufacturer in 1994 acknowledged paying about a 2% royalty rate on each CD player sold.[33] Similarly, the royalty rate for CD drives in 1995 was reportedly 2-3% of sales.[34] This low royalty rate ("a reasonable level for a new

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[27] See O. Khessina, op. cit., Figure 3.
[28] Stans, 2009, p. 151.
[29] "The hows and whys of optical proliferation. (interview with Carl M. Rodia), " **Tape-Disc Business**, vol. 10, no. 12, December 1995; L.S. Kempster, "A Media Maniac's Guide to Removable Mass Storage Media," **Nonvolatile Memory Technology Conference**, 1986, p. 184. See also S.L. Adkins, "CD-ROM: A review of the 1994-95 literature," **Computers in Libraries**, vol. 16, no. 1, Jan. 1996.
[30] M.A. Pena-Castellot, "Commission settles allegations of abuse and clears patent pools in the CD market," European Union, **Competition Policy Newsletter**, No. 3, Autumn 2003, p. 57.
[31] Judge Sidney Harris, **Initial Determination, In the Matter of CERTAIN RECORDABLE COMPACT DISCS AND REWRITABLE COMPACT DISCS**, Investigation No. 337-TA-474, U.S. International Trade Commission, 2003, p. 140.
[32] Lee, 1999, p. 18. The author, Lee, worked for LG Electronics, a major Korean manufacturer of CD-ROMs.
[33] W. Sekiguchi, "U.S. probes Sony-Philips CD-license pact, Manufacturers Complain of Hefty Fees, Fear Patent Extension," **Nikkei Weekly**, July 18, 1994.
[34] D.J. Parker, "High-density & re-inventing the disc," **CD-ROM Professional**, vol. 8, no. 6, June 1995.

entrant"[35]) is of great interest, because, as we have just seen, it facilitated entry by large numbers of new entrants into the optical drive business, and intense price competition. This royalty structure contrasted markedly with the very different royalty rate structures adopted later by the DVD patent pools.

It is notable that the initial choice of the Philips-Sony CD audio standard by the Japanese industry advisory group in 1980 had immediately followed an unsuccessful attempt by MITI in the mid-1970s to pressure the Japanese consumer electronics industry to adopt Betamax as its sole video player standard.[36] That, and the bruising standards battle between Betamax and VHS that was in full swing when the CD standard was blessed in 1981, likely played some role in Philips and Sony setting a low royalty rate. Both Philips and Sony certainly would have wanted to avoid any further standards battles with unhappy Japanese licensees with alternative competing optical storage technologies in their portfolios.

Indeed, Philips actually had a previous history of lowering royalties in order to attract support for its proposed standards. In the early 1960s, for example, it had invented the audio cassette. After failing to attract support from other companies when it attempted to charge a royalty for the technology (and some hard bargaining by Sony), Philips ultimately made the technology freely available to any company supporting the standard.[37]

One can speculate that some informal understanding about a low royalty rate may have figured into the decision by the MITI advisory committee—which would have included participants tied to Sony's Japanese competitors—to choose the Philips-Sony CD standard proposal in 1980. In March 1979, a team from Philips had visited most of the major players in the Japanese consumer electronics industry, and MITI's Digital Audio Disc Committee, to lobby for its system, which at the time was competing for

[35] Lee, 1999, p. 18.

[36] M.A. Cusumano, Y. Mylonadis, and R.S. Rosenbloom, "Strategic Maneuvering and Mass-Market Dynamics: The Triumph of VHS over Beta," **Business History Review**, vol. 66, no. 1, Spring 1992.

[37] H.J. Braun, **Music and Technology in the Twentieth Century**, (Baltimore: JHU Press), 2002, p, 161; J. Barker, "Computers: Who really invented the compact disc? Somebody stands to make a fortune out of the compact disc revolution, but it certainly won't be Philips," **The Guardian**, London, November 15, 1990; "Making a penny or three from digital discs," **New Scientist**, Nov. 5, 1981, p. 374. Sony reportedly used its market position in tape recorders to pressure Philips into royalty-free licensing for the audio tape cassette, per Sony's official corporate history: "Philips initially suggested that it receive a payment of 25 yen for each unit sold by companies in Japan. [Sony's] Ohga thought this was excessive and did not agree to it. A few days later, Philips showed some flexibility and asked for 6 yen per unit, a figure it said other companies had agreed to. Masanobu Tada, Operations Division manager, recommended that Sony accept the offer, but Ohga still refused, insisting that unless Philips waived royalties altogether, Sony would collaborate with Grundig. Finally, Philips agreed to waive royalties, but did not give Sony exclusive rights to the technology. In 1965, based on a patent that guaranteed compatibility, Philips made the technology available free of charge to manufacturers all over the world." From Sony Corporation, **Sony History**, Part II, Chap. 5, available at http://www.sony.net/SonyInfo/CorporateInfo/History/SonyHistory/2-05.html .

designation as the standard against alternative solutions developed by other Japanese consumer electronics firms.[38]

A rather different licensing fee structure was set for the removable disks going into CD players. Here, Philips had bitter memories of not collecting any royalties on the manufacture of the audio tape cassettes it had pioneered two decades earlier. For blank writeable disks, a fixed fee per disk manufactured was charged—what Philips had initially sought unsuccessfully two decades earlier with audio cassettes.[39] A base fee of three cents per disk had been established for U.S. licensees in 1982, and an escalation clause linked increases in this fee to the Consumer Price Index. By 1995, this fee had risen to five cents per disc, and with a dramatic reduction over time in manufacturing costs for discs, the cost of the license fees paid to the patent pool by 1995 had risen to almost a third of the costs of manufacture for a recordable disc.[40]

The Department of Justice began an active antitrust investigation into the CD format disc licensing practices of Sony and Philips in 1994,[41] and a private antitrust suit over licensing practices for CDs and CD players was also filed against Philips and Sony in 1995.[42] The Justice investigation reportedly led to a settlement in which the two firms agreed to no longer compel licensees to license all patents in a technology package, but instead to permit licensing of subsets or even individual patents from the pool portfolio. (This was to become standard policy for later patent pools approved by the Justice Department.) This antitrust suit and Justice scrutiny led Philips to formally organize the successor to the Sony-Philips CD patent pool, the DVD 3c patent pool (discussed next), as a formal, official patent pool, and to seek a so-called "comfort letter" from the Justice Department officially blessing its existence several years later.[43]

Still later, in 2002, Philips sued Taiwanese CD-R manufacturer Princo and 20 others, filing a complaint before the U.S. International Trade Commission asserting that CD-R (blank) disks being imported into the U.S. infringed patent pool patents. Princo's response alleged that Philips' licensing practices constituted patent misuse, and an administrative law judge initially found the pool patents unenforceable by reason of patent misuse in 2003. This decision was ultimately appealed and

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[38] And it is reasonable to surmise that ranges of royalties to be charged for its system would have been a topic of conversation with these groups as it lobbied for support. On the 1979 Philips visit to Japan, see Peek and Sinjou, 2009, p. 54.
[39] And of course, Sony was on the same side of the bargaining table with Philips this time.
[40] Parker, 1995.
[41] The license fees were reportedly about 6 cents per disk at this time. B. Holland and M.A. Gillen, "Sony, Philips Under CD-Patent Scrutiny? U.S. Justice Dept. to Conduct Antitrust Investigation," **Billboard**, July 23, 1994; W. Sekiguchi, "U.S. probes Sony-Philips CD-license pact, Manufacturers Complain of Hefty Fees, Fear Patent Extension," **Nikkei Weekly**, July 18, 1994; "U.S. Investigates CD Trade Practices," **International Herald Tribune**, July 14, 1994; A. Sandler, "Justice looking into Sony-Philips deals," **Daily Variety**, July 13, 1994; E. Corcoran, "Justice Probing Compact Disc Industry; Licensing Agreements by Firms Said to Be Under Scrutiny," **Washington Post**, July 13, 1994.
[42] A. Sandler, "CD Lawsuit targets Sony, Philips," **Daily Variety**, May 5, 1995.
[43] R.P. Merges, "Institutions for Intellectual Property Exchange: The Case of Patent Pools," in R. Dreyfuss, Ed., **Intellectual Products: Novel Claims to Protection and Their Boundaries** (Oxford Univ. Press, 2001).

overturned, and the U.S. Supreme Court declined to hear a final appeal by Princo in May 2011.[44] A Federal circuit court decision in 2010 had revisited this legal doctrine in a controversial analysis, and, it is argued, reinterpreted the legal doctrinal bounds placed on patents that may be included in pools (in this case, for example, nonessential patents apparently were included in the pool). Putting aside legal issues, the U.S. ITC investigation and proceedings shed considerable light on the economic structure of the CD-R patent pool and its fees and licensing provisions.

In particular, the U.S. ITC proceedings established that the CD-R license agreements required a payment of 3% of net sales price per disc, with a minimum per unit royalty of 10 Japanese yen.[45] The effective royalty rate in 1996, at the time the Justice antitrust investigation was settled, was the relatively small 3%, at a time when CD-R disks sold for about $7 and the dollar was worth about 101 yen.[46] By 2000, however, the price of a CD-R had declined to under 50 cents, and the now binding 10 yen minimum fee translated into an 18 percent royalty.[47]

After peaking in 2000, the number of CD-R disk manufacturers began to decline.[48] Despite the low cost Asian competition, CD-R pool members Sony, Philips, and Taiyo Yuden still accounted for about 13 percent of global CD-R disk sales in 2002. (Sony, Philips, and Ricoh accounted for a smaller--under 10 percent-- share of production of the more expensive CD-RW disks.) Nonetheless, by 2003, over 70 percent of the world's CD-R disk production was produced by manufacturers with a pool license.[49]

The ITC proceedings also established that disks sold by licensed disk manufacturers to pool members paid no royalties to the pool. That is, rather than paying a royalty to the pool on subcontracted outside production, then dividing the resulting revenues according to the pool's income allocation formula, subcontracted production paid no royalties at all.[50] Effectively, in a competitive disk manufacturing market, this would mean that pool members paid incremental manufacturing cost for disk production they had contracted out, while third parties faced an incremental cost that was roughly 22 percent higher, in 2000, after accounting for the royalty. It is understandable then that Philips, Sony, and Taiyo Yuden continued to successfully produce and market blank discs despite increasing competition from relatively low cost Asian entrants into optical disk production.

Effectively, the royalty structure encouraged a globalized production network, with manufacturing contracted out to efficient, low cost, producers in Taiwan and China, and pool members collecting the royalty wedge between manufacturing cost and market price. A competitive fringe of arms-length, licensed producers could ultimately be squeezed out by the pool members simply setting

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[44] Greg Stohr, "Philips Wins Princo Patent Clash as High Court Rejects Appeal," available at http://mobile.bloomberg.com/news/2011-05-16/philips-wins-princo-patent-clash-as-high-court-rejects-appeal .
[45] The original CD-R license agreement called for the 3 percent of net sales royalty with a 10 yen minimum; the agreement in force in 2003 called for a royalty of 6 cents per disk if in "full compliance" with license obligation, 10 yen if not fully compliant. The joint CD-RW disk license had a 10 cent per disk royalty. Harris, p. 372.
[46] Manufacturing cost for Taiwanese CD-R disk producer Gigastorage was 97.5 cents in 1997. Harris, 2003, p. 394.
[47] Harris, 2003, pp. 141, 144-145.
[48] Ibid., p. 172.
[49] Ibid., pp. 172-173.
[50] Ibid., p. 183.

their blank disc prices just a little lower than the sum of the most efficient contract manufacturer's cost and the pool royalty to external licensees. It is therefore not surprising that there seems to have been a rapid decline in the number of independent, third party (non pool-affiliated) producers in the blank disc market after 2000.

Of course, there was nothing to prevent the pool members from dropping the final sales prices on their subcontracted production closer to the purchase price (and their marginal cost) paid to their subcontractors, in order to steal market share, and royalty profits, from their fellow pool members. If such a price war were to break out, however, it would force royalty-paying arms-length licensees out of business, push down prices for all disks as subcontracted production ramped up, and ultimately, reduce the profits pool member collectively derived from both licensing fees and their sales of contracted-out production. There is no evidence in the historical record, however, that this sort of technology rent-eliminating, Bertrand-style price competition among the pool members ever broke out.

It is useful to contrast this arrangement with the terms of the CD-ROM/-R/-RW drive hardware licenses, where licensing fees were apparently capped at 2-3 percent of sales price. As long as a non-pool producer could tolerate a cost disadvantage fixed at this level (perhaps making it up with lower input costs or overhead or scale economies), then, absent a fixed minimum royalty, even the precipitous decline in price typically observed in these sorts of high tech products would not put them at an increasing and ultimately ruinous disadvantage relative to pool producers and their subcontractors.

The USITC proceeding also established that royalties were not paid internally within the patent pool, i.e., that pool members did not pay royalties to each other. Indeed, it seems to be the case that no royalties were also paid by cross-licensees outside the pool as well. "Philips maintains that in the case of discs sold to cross-licensees, there are no royalties, because the royalty has, in effect, already been paid "in kind" by the cross-license back to Philips."[51] This would create a second source of disadvantage for third party disk manufacturers with no cross-licenses with pool members, since standards-related patent holders outside the patent pool who had negotiated cross-licenses with pool members would be able to require that still an additional royalty be paid to them by third parties even if they had a pool license. At the end of the day, with this type of license structure in place in a highly competitive manufacturing environment, one would expect to see remaining in the industry only the patent pool members, their subcontractors, and third parties in possession of a cross-license with the pool members. That seems to have been precisely the situation that developed in the DVD drive industry, which adopted a variant of the CD-R disc licensing model.

[51] Ibid., p. 181. Also, third party manufacturers producing discs on behalf of a company with a cross-license with Philips are not required to pay royalties to the Philips. In 2003, there were a number of these cross-licensed non-pool member companies, including some who were active in the manufacture or sale of CD-R or CD-RW disks. Maxell, a subsidiary of Hitachi, was one of those companies. 42% of global CD-R sales and 43% of sales in the Americas did not require royalty payments to Philips. Ibid., p. 410-11.

The DVD Optical Storage Industry

Unlike the CD-R patent pools, the origins of the DVD patent pools have been described in some detail in a variety of other sources.[52] I begin with an overview of the technological innovations that led to their formation.

In 1993, Toshiba, Hitachi, Pioneer, and Panasonic began work on a higher capacity replacement for the CD that would be able to accommodate video data, and in particular, speeds and capacities that would accommodate movies. Philips and Sony reacted by beginning work on their own alternative, next generation digital data disk format, in 1994. Both groups sought allies in the computer and motion picture industries to support their approaches. IBM ultimately brokered a compromise, through an organization (the DVD Forum) that was set up to bring the competing efforts together on a common specification.

This effort was successful in brokering a common specification for video programming, the DVD-Video specification (1996), a read-only computer data format, DVD-ROM (1996), and a rewritable data-only format, DVD-RAM (1997), but the two rival groups were not able to agree on a common specification for the one time-recordable DVD formats. They were also unable to agree to a common, single pool, and license, for their DVD-video patents. As a result, two incompatible DVD recording formats were ultimately introduced, with the Philips and Sony group promoting its DVD+R(2002) and DVD+RW (1999, revised 2001) recordable and rewritable formats, while the Toshiba, Hitachi, Pioneer[53], Panasonic group introduced its alternative DVD-R and DVD-RW recordable and rewritable formats.[54] Each of the two groups also formed its own separate pool to license its patents for DVD-video, in addition to its version of the recordable and rewritable formats. As a result, it was necessary for a third party to take out a license from both groups in order to manufacture DVD-Video players or disks (and possibly licenses to patents held by firms not in either pool, like Thomson). In addition, a different version of the pool's license would be required if manufacturing equipment or disks for one or the other pool's recordable/rewritable formats.

DVD video players were first commercialized in Japan in late 1996, and shipped to the U.S. market in 1997. While the first DVD-ROMs for computer use were made available in 1997, they were not really attractive to early adopters until 1998, when some software vendors began to use them for product distribution. The first writeable DVD-R standard published in 1997 (version 1.0) was not entirely compatible with drives using DVD-ROM and DVD-Video technology, and it was not until an upgrade to

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[52] See Lee, 2000, op. cit.; S. Gauch, "+ vs -: Dynamics and Effects of Competing Standards of Recordable DVD-Media," in T.M. Egyedi and K. Blind, Ed., **The Dynamics of Standards**, (E. Elgar), 2009; R. Bekkers, E. Iversen, and K. Blind, "Patent pools and non-assertion agreements: coordination mechanisms for multi-party IPR holders in standardization," August, 2006; R. Aoki and S. Nagaoka, "Coalition formation of a standard consortium and a patent pool: Theory and evidence from MPEG2, DVD, and 3G," March 2007; R. P. Merges, "Institutions for Intellectual Property Exchange: The Case of Patent Pools," in R. Dreyfuss, Ed., **Intellectual Products: Novel Claims to Protection and Their Boundaries** (Oxford Univ. Press, 2001).

[53] Pioneer was to later shift into the "+" camp and join the DVD 3c consortium.

[54] Dates for the specifications shown here are taken from S.G. Stan, "Digital Versatile Discs," chap. 5, in Peek, Bergmans, van Haaren, Toolenaar, and Stan, 2009.

version 2.0 in 2000 that DVD-R discs could be read in DVD-ROM and DVD-Video players.[55] Thus, the true commercial advent of writeable DVD storage dates to 2000, when the expensive and incompatible writeable DVD-R 1.0 technology that first shipped in 1997 was superseded by the mature, fully compatible DVD-R 2.0 technology standard. This was further formalized in 2001 when the DVD Forum issued a specification for a fully compatible product it dubbed a "multi" DVD recorder-- a unit that would read or write DVD-Video, DVD-ROM, DVD-R/-RW, and DVD-RAM discs.

Similarly, the initial version of the Philips/Sony group's +RW (1999) recordable standard had compatibility issues with DVD-ROM technology that were not fixed until an upgrade to a later version of the standard published in 2001. While +RW drives were first sold in 2000, the first fully compatible DVD +RW drives were not shipped until the end of 2001. In 2002, a write once +R standard was also defined. Thus, the +R/+RW technology was not available as a fully mature technology standard until 2002. In 2003, Microsoft announced it would support all DVD format standards, and producers began to advertise "super multi" DVD drives-- multi drives that could all read and write the "+" as well as the "-" formats. A summary timeline of the development of DVD technology is shown in Table 3.

Table 3, DVD Timeline

1996	First DVD Video players shipped
1997	First DVD-R (1.0) , DVD-ROM players shipped
1998	DoJ "comfort letter" for DVD 3c patent pool; Taiwan, Korea entry into CD-R/RWs
1999	DoJ "comfort letter" for DVD 6c patent pool; first DVD-R (2.0), DVD-RW, +RW (incompatible) units shipped
2000	+RW recorder (incompatible) sold
2001	DVD+RW recorder (compatible) shipped; DVD Multi standard (read/write -R/-RW/-RAM/-ROM/Video discs) defined
2002	DVD +R recorder shipped; Blu-ray, DVD-dual layer tech intro
2003	1st Blu-ray players shipped; Microsoft announces it will support all DVD standards
2005	HD-DVD player shipped

Sources: Described in text.

The DVD Patent Pools

The Philips and Sony "+" standard group, augmented by Pioneer, formed the so-called DVD 3c patent pool, and as remarked earlier, sought a “comfort letter” approving its formation from the Justice Department. (The DVD 3c pool was later joined by LG in 2003.[56]) The official blessing from Justice

[55] The definitive discussion of the evolution of these standards is Stans, 2009, Ibid.
[56] “LG partakes in 3C DVD licensing group,” **EE Times Asia**, August 2003.

followed in December 1998.[57] The licensing fees described in this letter, for video players and DVD-ROMs, was 3.5% of net sales, subject to a $5 per unit minimum, and 5 cents per disc for DVD disks.[58]

When considering the issue of "foreclosure of competition in related markets"[59], the Justice letter made two significant statements. "First, the agreed royalty is sufficiently small relative to the total costs of manufacture that it is unlikely to enable collusion among sellers of DVD players or discs. Second, the proposed program should enhance rather than limit access to the Licensors' "essential" patents. Because Philips must license on a non-discriminatory basis to all interested parties, it cannot impose disadvantageous terms on competitors, let alone refuse to license them altogether."[60]

As previously remarked, Justice would have been cognizant, from complaints over CD disc licensing fees that had already surfaced in 1994 and 1995 and prompted it to investigate the CD pool, that a fixed minimum licensing cost that was "small relative to the total costs of manufacture" at the beginning of a high tech product's life cycle could turn into a vastly larger relative cost share as the product matured, and product manufacturing costs and prices dropped sharply. Had Justice analysts reviewed what had happened to CD player and CD-ROM prices over time, they would have realized that the hardware royalties on DVD drives, which unlike the earlier CD drive case (but like the CD disk case) now included a minimum per unit royalty, were likely to become the large share of product cost that royalties were already en route to becoming in CD discs. It seems likely that both Philips and Sony would have understood the ultimate implications of this change in their licensing practices for hardware, just as both firms would have been well aware of the heightened competition from Asian entrants that was reducing the profitability of CD drive manufacture.

The language about non-discrimination in this letter was not very meaningful. As noted earlier, Philips had a long established policy of discriminating among its competitors when fixing royalty rates, depending on whether or not they were fellow patent pool members or held cross licenses with Philips. As I show below, available evidence suggests that this same policy was followed in the DVD patent pools. This might not be illegal or even harmful on balance from an economic point of view, but it certainly did impose economically "disadvantageous terms" on potential new market entrants who needed access to the essential patents to do business. For a pool member (or a third party cross-licensed to the pool member), the marginal cost per unit of using other pool members' patents under the CD pool rules was zero, quite different from the steadily rising share of royalties in product cost that was faced by an outsider who did not belong to this club. A patent is in fact a legally granted right to exclude controlled by the patent holder, but the Justice letter to some extent buries this cold reality beneath noble rhetorical flourishes about non-discriminatory licensing.

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[57] The DVD 3c comfort letter was actually the second such comfort letter issued; the first one, back in June 1997, blessed the MPEG video compression standard that was also required to manufacture a DVD player. See http://www.justice.gov/atr/public/press_releases/1997/1173.pdf .

[58] The minimum per unit royalty was actually $7 until January 1, 2000, when it was slated to drop to $5. See http://www.justice.gov/atr/public/busreview/2121.pdf .

[59] Ibid., p. 13.

[60] Ibid.

The second DVD (-R/-RW) patent pool, originally composed of Hitachi, Matsushita, Mitsubishi, Toshiba, JVC, and Time Warner (and hence called the 6c patent pool) received its own comfort letter from Justice in June of 1999.[61] The same language on royalties being "sufficiently small relative to the total costs of manufacture that it is unlikely to enable collusion," and licensing on a "non-discriminatory" basis is used as in the DVD 3c letter. The DVD6c patent pool was later joined by Sanyo and Sharp in 2005, and by Samsung in 2006.

In 1999, little immediate reason for concern about royalties foreclosing downstream competition may have been readily apparent.[62] Within a few short years, however, the royalties charged by the DVD patent pools evolved into truly significant sums relative to the total cost of manufacturing optical disk drives (ODDs)—indeed they now account for the majority of manufacturing cost for a potential entrant. This is a very different reality from that considered by Justice back in 1999, when a $15-20 royalty was a relatively small portion of the cost of a recordable DVD drive that typically might sell for many hundreds of dollars.[63]

To understand just how prohibitive a barrier to entry by potential competitors the DVD patent pool royalties became, consider the average price of a recordable DVD optical drive, such as those configured with most computers sold in recent years. According to IDC, the average worldwide price for a DVD burner, on an if-sold-OEM basis, was $30 in 2007, $25 in 2008, and $23 in 2009.[64] In a December 2008 presentation,[65] Hisashi Kato, of Japan's Mitsubishi Electric, estimated that the royalty payable to 4 principal patent pools holding IP related to a DVD recorder to be $17 (of which $14 goes to the DVD6c and DVD3c pools). This is 68 percent of the average selling price of a DVD recorder in 2008, and presumably an even larger share of its cost.[66] (Table 1)

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[61] http://www.justice.gov/atr/public/busreview/2485.htm . One significant difference with the DVD 3c letter is that this letter discusses a "firewall" that Toshiba, as administrator of the pool, is to erect around sensitive information about production and pricing obtained from licensees.

[62] Though this was to change very rapidly.

[63] It should also be noted that as in the previous generation of recordable CD discs, the minimum per unit royalty model was adopted in DVD discs. By 2003, the binding minimum royalty for recordable DVD media amounted to one third of the net selling price of a recordable DVD. Harris, 2003, p. 179.

[64] IDC's Worldwide Blu-Ray, DVD, CD, and Other Optical Storage Drive 2009 - 2013 Forecast and Analysis, Table 20, p. 22.

[65] Hisashi Kato, "Current status and issues such as patent pools in the area of electronics," available at http://www.jisc.go.jp/policy/kenkyuukai/ipr/sympo.html

[66] A similar situation applied to DVD disks. As far back as 2003, "[t]he combined royalties paid by DVD disc manufacturers under the three DVD patent pools that were approved by the DOJ [the two DVD pools and the MPEG pool] in its Business Review Letters represent a total of 33% of the current net selling price of DVD discs." Harris, op. cit., p. 402.

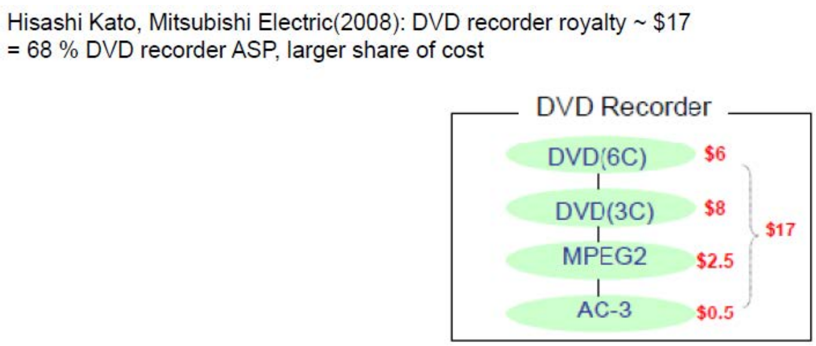

Table 1. DVD Recorder Royalties, Ca. 2008

Along similar lines, Chinese DVD producers estimated that the licensing fees on DVD patents in 2007 for the first time exceeded the cost of manufacturing the DVD player. That is, the royalty rate exceeded 100 percent of manufacturing cost.

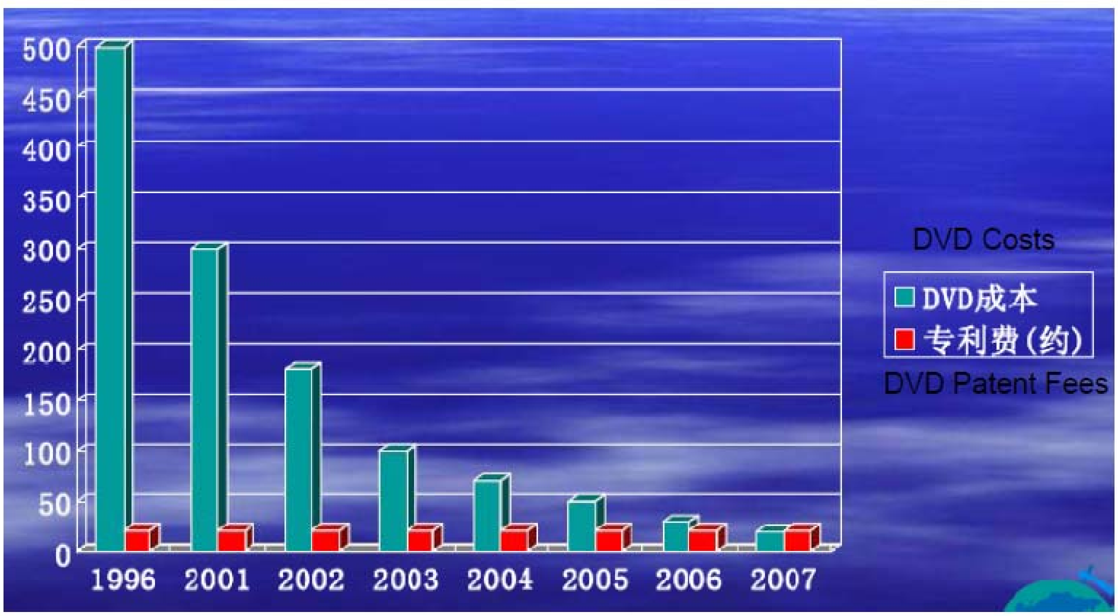

Figure 3. DVD Player Patent Fees in Relation to DVD Manufacturing Costs

Source: Presentation by Huang Tiejun, AVS Working Group, Hong Kong, March 2008, available at

http://www.smpte.org.hk/smpte.org.hk/march12008/huang-part1.pdf .

These data lend credibility to the hypothesis that members of the DVD patent pools have adopted the earlier Philips/Sony CD pool model, i.e., that royalty-free cross licenses within the pools, and between patent pools, are the rule, while outsiders pay stiff royalties. This gives pool members a large competitive advantage relative to potential entrants from outside the ranks of established players, and is a powerful explanation for the increase in concentration in the optical disk drive marketplace that can be observed after 2000.

Impacts on Product Markets

After Sony and Philips came out with their first CD-ROM models in the mid-1980s, Japanese electronics producers Hitachi, NEC, and Toshiba quickly followed with their own versions of these drives. Earlier, I noted that first Mitsumi, and then Korean producers LG and Samsung had followed with lower priced models in the early to mid-1990s. In the late 1990s, Taiwanese producers entered the fray, and their market share soared. By 1996, the market share of the patent pool membership (Sony and Philips) had probably fallen to less than 10 percent of the CD-ROM drive market.[67] By 1999, LG was the largest producer of CD-ROM and DVD-ROMs globally (with a 15% market share), Samsung had 7% of the market, and Taiwan's Acer and Lite-on, together, accounted for another 9% of the market.[68] This contrasted with a 6% market share for Sony.

In response, Japanese producers effectively abandoned low-end products, and switched to high end products—first CD writers and rewriters, then DVD drives, and most recently, Blu-ray (the higher capacity 21st century successor to the DVD) drives. This is clearly visible in Figure 4, which shows Japanese production of optical disk drives, broken out by product types wherever possible. (Yen have been converted to dollars at market exchange rates.) CD-ROMs probably accounted for the bulk of the value of Japanese production until about 1998, when they were surpassed by what would have been mainly CD writers. The value of Japanese optical drive production (in Japan) peaked in 2001, and then went into sharp decline.

U.S. trade statistics show a sharp fall off in the value of imports from Japan over roughly the same time period (Figure 5). Import volumes show quite clearly that the Japanese value share in Figure 5 is very much larger than its share of units (Figure 6), tracking the Japanese shift toward domestic production of only high end product types. The displacement of Japanese imports by inexpensive drives from Korea, Malaysia, and Taiwan is clearly evident in Figure 6, as is the rise of China as the production location for the vast bulk of the world's optical disk drives.

[67] Lee, 2000, op. cit., p. 20.
[68] Ibid., p. 21.

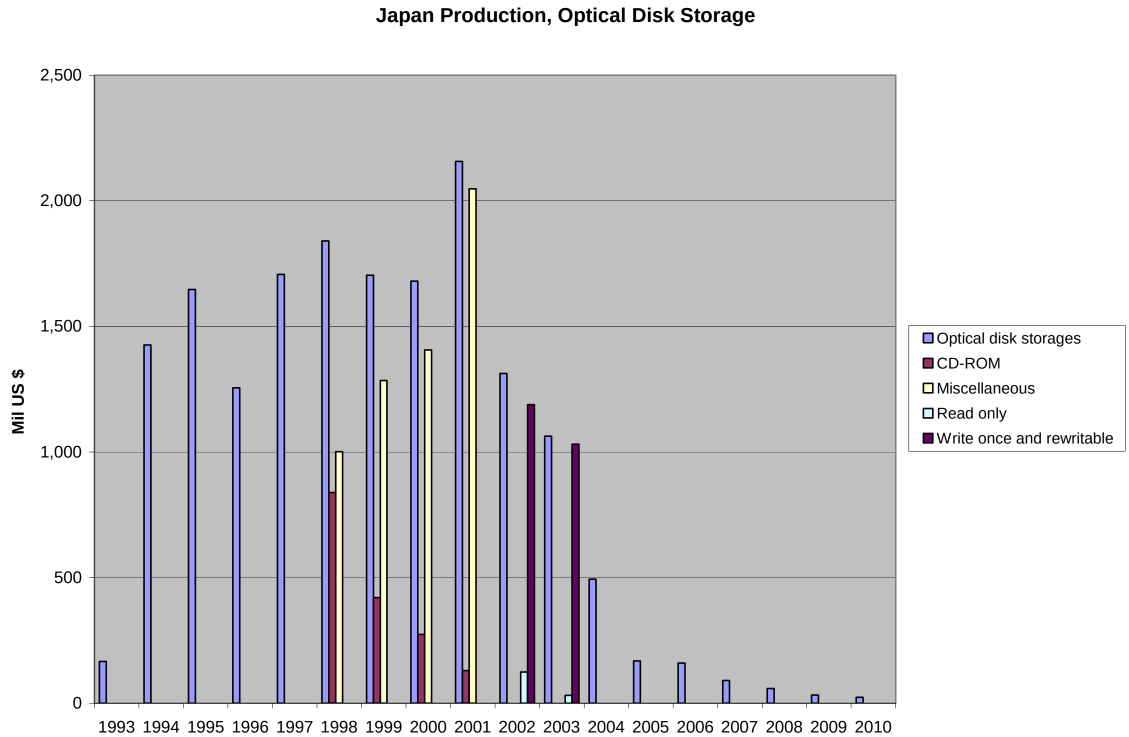

Figure 4, Japanese Production of Optical Disk Storage Units

Source: METI, *Machinery Statistics Monthly*, various years.

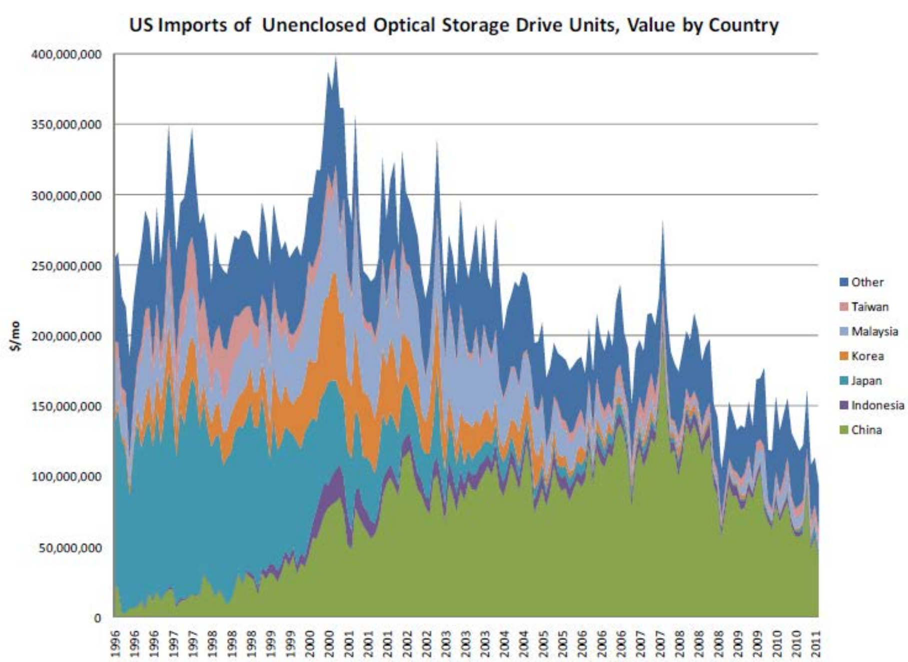

Figure 5 US Imports of Unenclosed Optical Storage Drives, Value

Source: U.S. International Trade Commission import data base.

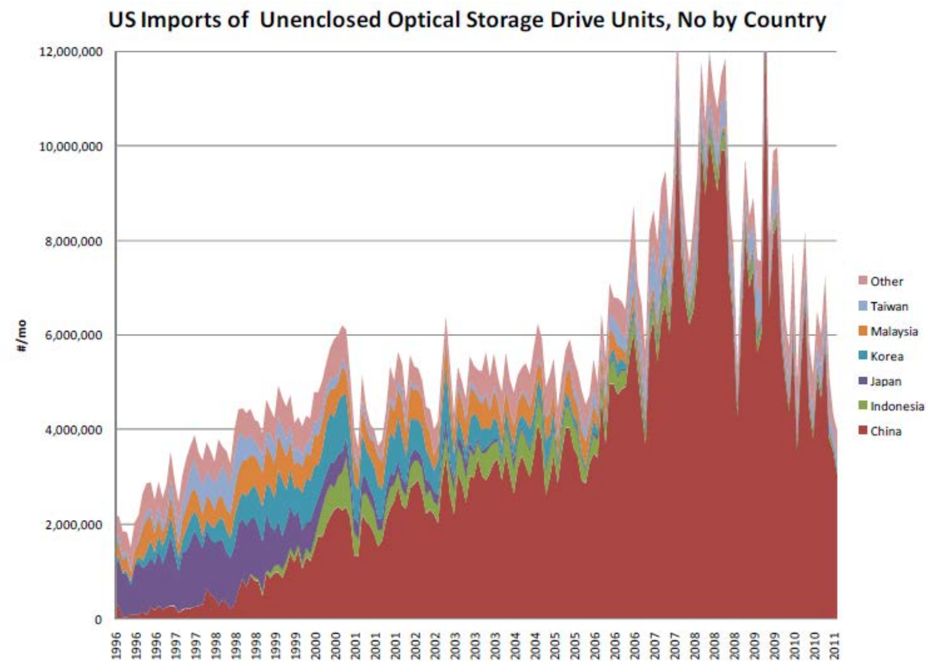

Figure 6 US Imports of Unenclosed Optical Storage Drives, Units

Source: U.S. International Trade Commission import data base.

Increasing Industrial Concentration

Table 2 calculates the change in the Herfindahl-Hirschman Index (HHI) of concentration in optical disk drive (ODD)[69] sales over the period from 2001 to 2008. In 2001, an HHI well under 900 characterized the degree of concentration among producers of optical disk drives. By 2005, the HHI had more than doubled, to over 1950.[70] (Concentration remained at about this same level in 2008, the last year for which I have obtained solid data on the ODD market shares of various producers.)

[69] The ODD figures I am using only include computer data drives, and do not included DVD video player units.

[70] In 2001 through 2008, I calculated upper and lower bounds on the HHI, which is defined as $\Sigma_i s_i^2$, where the s_i's are the market shares of the N firms selling products in the industry. Because the residual category "other" producers aggregates multiple producers together, simply discarding the terms corresponding to the "other" producers (or equivalently, assuming this piece of the market is divided up among a near-infinite number of "other" firms) yields a lower bound on the HHI.

To derive an upper bound, we simply assume, very reasonably, that the largest firm in the residual "other producers" category has a market share that is no greater than the individual producers who are specifically named in any given year. Let the market share of the smallest separately reported producer, producer number M (out of a total of N in the industry--ordered so that the largest number is number 1, and the smallest separately reported producer is number M), be u. Then HHI = $\Sigma_i s_i^2 = \Sigma_{i=1,2,\ldots M} s_i^2 + \Sigma_{i=M+1,..N} s_i^2 = \Sigma_{i=1,2,\ldots M} s_i^2 + \Sigma_{i=M+1,..N} s_i * s_i < \Sigma_{i=1,2,\ldots M} s_i^2 + \Sigma_{i=M+1,..N} s_i{}^* u = \Sigma_{i=1,2,\ldots M} s_i^2 + u\, \Sigma_{i=M+1,..N} s_i$. This last expression is an upper bound because $s_i < u$ for all producers smaller than producer M. This upper bound for HHI is simply the sum of squared market shares for all

Table 2
Herfindahl Hirschman Index (HHI) of Concentration for ODD Market

2001 Entity	2003 Entity	2005 Entity	2001 Market Share (%)[1]	2003 Market Share (%)[2]	2004 Market Share (%)[2]	2005 Market Share (%)[3]	2006 Market Share (%)[3]	2007 Market Share (%)[3]	2008 Market Share (%)[3]
Hitachi / LG	Hitachi / LG	Hitachi / LG	18.8	24.0	28.0	25.6	26.0	30.8	27.9
Samsung	TSST	TSST	13.1	19.0	18.0	21.8	18.9	24.2	23.6
Toshiba			5.3						
LiteOn	LiteOn	LiteOn (PLDS)	10.6	16.0	16.0	26.3	16.9	11.5	14.5
BenQ	PBDS		5.1	7.0	6.0				
Philips			3.4						
Sony	Sony	Sony NEC Optiarc	2.4			7.1	9.9	9.3	15.6
NEC	NEC		3.3		4.0				
MKE/Panasonic			4.5	5.0	6.0	8.4	9.1	8.6	7.0
Pioneer			1.9		4.0	4.4	5.7	6.0	6.3
Teac			6.4	3.0					
BTC			4.7	4.0					
AOpen			2.4						
Mitsumi Electric			2.0						
All Others			16.1	22.0	18.0	6.4	13.5	9.6	5.1
			2001	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
		HHI upper bound	847	1358	1540	1990	1609	1921	1910
		HHI lower bound	816	1292	1468	1962	1532	1863	1878
Market Share of DVD Pool Members, Affiliates (%)			49	55	66	94	87	90	95

Sources:
[1] http://ettrends.etri.re.kr/PDFData/17-6_182_192.pdf, p. 188.
[2] http://merc.e.u-tokyo.ac.jp/mmrc/dp/pdf/MMRC29_2005.pdf, p. 16. 2004 is forecast.
[3] IDC's Worldwide Blu-Ray, DVD, CD, and Other Optical Storage Drive 2009 - 2013 Forecast and Analysis, Table 2, p. 4.

The members or controlled subsidiaries of the two DVD patent pools accounted for less than half of industry sales in 2001. By 2005, this had jumped to 94% of ODD sales globally. (Table 2) In 2008, ODD producers affiliated with (or controlled by) pool members continued to account for 95% of worldwide ODD sales.

The drive toward optical disk drive concentration was kicked off in late 2000, when Japanese ODD producer Hitachi merged its optical disk operations with LG Electronics, of Korea. The joint venture, Hitachi LG Data Systems (HLDS), was confined strictly to design, development, and marketing. Actual manufacturing was contracted out to the parents and their subcontractors.[71] The joint venture also had royalty-free access to the patents of the parents.[72] Hitachi effectively controlled the operation, through both its ownership and its control of key technologies.[73] Indeed, Hitachi's 51% ownership of the JV was

separately enumerated producers, plus the market share of the smallest separately-counted producer times the aggregate market share accounted for by the entire "other producers" category.

[71] "Established to pursue the joint development, design and marketing of optical disc drives, a particular advantage of HLDS was its ability to marry the technological capability of the Japanese partner with the manufacturing expertise of its Korean counterpart." See http://www.investkorea.org/InvestKoreaWar/work/ik/eng/bo/print_added.jsp?bno=805090011&sort_num=29 .

[72] "The competitiveness of the HLDS joint venture was enhanced by having access to the patents and technologies of its parents but without the need to pay royalties." See http://www.investkorea.org/InvestKoreaWar/work/ik/eng/bo/print_added.jsp?bno=805090011&sort_num=29 .

[73] "However, Hitachi does not transfer technologies of key components to HLDS. Key components with integral architecture, such as the optical pick-up and the LSI chipset with microcode, have been provided to HLDS from Hitachi of Japan." See Koichi Ogawa, Junjiro Shintaku, and Tetsuo Yoshimoto, " Architecture-based Advantage of Firms and Nations: New Global Alliance between Japan and Catch-up Countries,"

absolutely critical to its success, since its position as a Hitachi affiliate gave it access to the benefits of Hitachi's cross licenses with other ODD patent holders, and Hitachi's membership in the DVD 6c patent pool. As a Japanese study of the industry concluded:

"It is very important for the industry of the catch-up countries to understand the reason why the percentage of Hitachi's investment to HLDS is 51%, and why Mitsubishi's investment to Digitek [a similar JV between Mitsubishi and Funai Electric] is 51%. The 51% from Hitachi means that HLDS is consolidated subsidiary company of Hitachi and thus all the patent royalty issues are automatically handled by Hitachi. It is said that the actual royalty fee of the DVD business has been significantly decreased because Hitachi has established patent claim to rank with other patent holders, and moreover Hitachi has many cross-licensed partner firms in the world."[74]

Even for less technologically complex consumer DVD players, which could feasibly be assembled and manufactured by new entrants in Taiwan and China, this royalty load rapidly became a major economic factor limiting their ability to compete successfully against the incumbent patent pool members. Prior to 2005, Japanese economists studying the industry had noted:

"It will become very difficult for Chinese firms to run the DVD business by paying all of the royalty which have been claimed from front runner countries, because the percentage of the relative amount of the royalty will become unreasonably higher and higher as the retail price of the DVD player becomes lower and lower. It is a noteworthy fact that, in a case of a major DVD manufacturer in Taiwan, the ratio of the royalty was estimated to be over 50% of the total overhead in year 2004 (Note 5) and have become almost impossible to continue the business if they would keep paying all of the claimed royalty."[75]

This same study notes that "[a]ccording to industry analysts, total sum of the royalty claimed against Chinese firms is estimated to be well over 10 dollars per a DVD player even though the retail price of the player in US market has dropped to 30-50 dollars in 3Q/2005, while royalty claimed against Japanese firms is estimated to be 2-4 dollars because the firms are major license holders in the DVD forum. Further more, the street price of Japanese brand DVD player is 50-80 dollars, which is 50% higher than that of Chinese brand products."[76]

The same 2005 study made this point diagrammatically, using the following figure. The manufacturing cost advantages of the Chinese firms were offset by the very high royalties they needed to pay in order to sell the products abroad. Japanese firms, on the other hand, faced higher overhead costs if they chose to continue funding technological development, but paid minimal royalties. With technological progress in semiconductors and optical devices, and economies of scale continuing to dramatically reduce costs of the materials, parts, and chips needed to manufacture a DVD drive, the costs of the royalties came to dominate the costs of manufacturing an ODD for potential competitors in ODDs without low cost access to the ODD patent pools.

Manufacturing Management Research Center, University of Tokyo, Working Paper MMRC-F-48, September 2005, p. 12.

[74] See Ogawa, Shintaku, Yoshimoto, September 2005, p. 12.

[75] Ogawa, Shintaku, and Yoshimoto, p. 12.

[76] Ibid., p. 17.

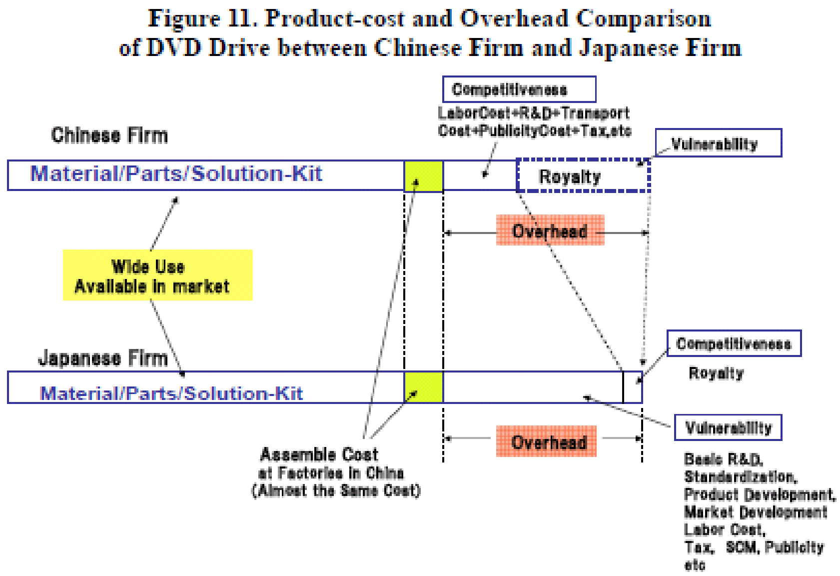

Figure 7 Cost Structure of Japanese and Chinese DVD Producers

Source: Ogawa, Shintaku, and Yoshimoto, 2005, p. 14.

Hitachi's ability to manufacture at a much lower cost through its joint venture with LG, yet still avoid payment of increasingly burdensome royalties by virtue of its 51% ownership of the joint venture giving it Hitachi's preferred position inside the patent pool, was critical to the business success of what became a profitable joint venture. Ogawa, Shintaku, and Yoshimoto note:

> Since 2003, only three years after the joint venture company has started, HLDS has turned into one of the most profitable subsidiary companies of Hitachi group. It has been said that without moving on to the alliance, Hitachi would have been forced to withdraw from the optical storage industry. The joint venture company between Mitsubishi Electric and Funai Electric also shows similar success story that Funai is exceptionally a profitable firm among the DVD suppliers in Japan because Mitsubishi Electric is the majority (51%) among the investors and is one of the major license holders in the DVD Forum.[77]

This model was quickly emulated by others. In 2001, Japan's JVC, another patent pool member, formed a similar 51%/49% joint venture with Taiwan's Lite-On.[78] As with HLDS, the patent pool member, JVC, held the controlling interest (though in the case of HLDS, LG was later allowed to join the patent pool).

[77] Ibid., p. 15.

[78] See Junjiro Shintaku , Koichi Ogawa, and Tetsuo Yoshimoto, "Architecture-based Approaches to International Standardization and Evolution of Business Models," Manufacturing Management Research Center, University of Tokyo, Working Paper MMRC-F-96, September 2006, p. 12.

In early 2003, Taiwanese ODD producer BenQ and Philips formed a joint venture, Philips BenQ Digital Storage (PBDS). The jointly owned company would develop, design, and market ODDs; all manufacturing would be contracted out to BenQ.

Also in 2003, ODD producers Samsung Electronics and Toshiba concluded an agreement to integrate their ODD operations into a single entity, Toshiba Samsung Storage Technology (TSST). As was the case with the HLDS and PBDS, the JV was purely for design, development, and marketing efforts; all manufacturing was to be contracted out to Samsung. As Korea's national investment promotion agency describes on its web site:

> Essentially, the two companies had agreed to spin-off their ODD businesses, and transfer them to the joint venture. Mirroring the Hitachi/LG deal, majority control was vested in the Japanese parent with 51 percent of the equity compared to 49 percent for the Korean partner. Again, company headquarters would be in Japan, this time, within Toshiba's head office in Kawasaki. Again the Japanese parent company would bring technical know-how to the venture, as well as international brand power supported by a global sales and service network. Manufacturing also, in the case of TSST, would be the province of the Korean partner. …[79]

In 2005, ODD producers NEC and Sony announced an agreement to merge all ODD activities of their two companies in a joint venture, Sony Optiarc. The new JV was to undertake all development, design, marketing and sales related to optical disk drives; all manufacturing (except a small amount of manufacturing of magneto-optical drives, Sony's Minidisc division) was to be subcontracted out to third parties.[80]

Like the previous joint ventures between patent pool members and outsiders discussed earlier, this one too had a majority ownership share controlled by the patent pool member (Sony), giving it the same cost advantage in royalties. In late 2008, NEC sold off its interest in Optiarc to Sony, and Optiarc finally became a wholly owned Sony subsidiary.

In early 2006, Taiwanese ODD producer Lite-On purchased BenQ's ODD production facilities in China, and took over BenQ's manufacturing ties to PBDS. BenQ exited the ODD contract manufacturing business. In 2007, BenQ sold its interest in PBDS to Lite-On, completely exiting the ODD business. The joint venture with Philips was renamed PLDS (with Lite-On's 'L' replacing BenQ's 'B').[81]

By 2005, the most significant effects of this consolidation within the ODD industry had been felt. The shrinking number of producers is all the more remarkable given the continuing growth in the size of the ODD market over this period. (See Table 3; sales reported for 2009 are a forecast.) In 2008, for example, the very last independent Taiwanese ODD brand (Asustek) disappeared, leaving only Lite-On

[79] http://www.investkorea.org/InvestKoreaWar/work/ik/eng/bo/print_added.jsp?bno=805090011&sort_num=29 .
[80] See http://ec.europa.eu/competition/mergers/cases/decisions/m4139_20060331_20310_en.pdf, p. 5.
[81] See http://ec.europa.eu/competition/mergers/cases/decisions/m4502_20070216_20310_en.pdf .

and Quanta Storage remaining in once was once a crowded, fast growing technology sector in Taiwan (with both remaining firms primarily producing as contract manufacturers for pool members).[82]

Table 3
Global Optical Disk Drive Sales, 2001 - 2009

	2001	2002	2003	2004	2005	2006	2007	2008	2009
Blu-ray (M)	0	0	0	0	0	0	1	5	14
DVD-W (M)	2	5	25	55	124	179	238	235	215
Other (M)	177	198	203	191	178	123	92	72	53
Total Units (M)	179	203	228	246	303	301	331	312	281
Total $ (B)	9.3	9.8	10.5	9.8	10.4	9.6	9.3	7.9	6.8

Sources & Notes
For 2001 through 2004, this chart uses historical data from www.stephenz.com/storageEvent/pdfs/SSI_NYC_Storage_Event_ODD.pdf
Data from IDC's Worldwide Blu-Ray, DVD, CD, and Other Optical Storage Drive 2009 - 2013 Forecast and Analysis, Table 8, p. 18
and Table 9, p.20 is used for subsequent years. Numbers used for 2005 through 2008 are historical sales, while 2009 sales are a forecast.
Total $ for 2005 through 2009 is based on average ODD prices If-Sold-OEM.

Effects on Product Market Innovation: Quality-Adjusted Prices

Optical disk drives are priced in a highly integrated global market. As ODD producers reported to the European Union during a 2007 merger review, "[w]ith respect to the geographic product market, the parties submit that the overall PC ODD supply market is world-wide or at least EEA-wide in scope. Prices do not vary significantly in world regions."[83]

The Bank of Korea is the only government statistical agency that apparently was tracking prices for optical disk drives with a price index back in the 1990s, when CD-ROMs first hit the marketplace. The Bank of Korea's matched model price index for this period was converted to a dollar basis using current exchange rates. The index shows a compound annual decline rate of 38 percent over 1995-2000. This is

[82] With respect to Quanta, from opening statement by T.D. Garnett, Ricoh v. Quanta (06-CV-462-BBC), "Stenographic Transcript of First Day of Trial, Afternoon Session Held Before Chief Judge Barbara B. Crabb, and a Jury," Madison, Wisconsin, November 9, 2009, pp. 19-20:

"Now, as I already mentioned, Quanta Storage is an assembler of optical disc drives. And I have a graphic that I think will help illustrate their business model. Quanta Storage will buy, for example, a laser and a motor and the controller chip and it will assemble those components together into a functioning disc drive.

Now, for the last several years, Quanta Storage has had only one main customer and that customer is Sony Optiarc. You may have heard of the company called Sony. Well, Sony owns Sony Optiarc. You will learn that Quanta Storage sells almost no disc drives under its own brand name. It assembles the disc drives for Sony Optiarc.

Now, Sony Optiarc helps Quanta Storage design the disc drives. Sony Optiarc puts its brand name on the disc drive and then Sony Optiarc sells the disc drive to brand name computer companies, companies that you are likely familiar with -- HP, Apple, Dell, for example."

See also Digitimes, " Taiwan ODD sector, DIGITIMES Research ICT Report – 4Q 2008," February 2009; "Quanta Storage Licenses Sony Patents for Slim DVD Burners," Digitimes, November 15, 2006.

[83] Commission of the European Communities, **Case No COMP/M.4502 -LITE-ON / PBDS**, (Luxembourg: Office for Official Publications of the European Communities), February 2007, p. 4.

very comparable to rates of quality-adjusted price for the most innovative high tech products of the era, like computer processors and memory chips.[84]

The Bank of Japan constructs and publicly reports two producer price indexes for optical disk drives manufactured in Japan after 2000. I can convert these to a common currency basis (dollars), and use these as measures of price movements in global markets. These price indexes control for differences in the mix of products being produced, and hold constant the quality and types of products being produced, over time.

One of the two Japanese producer price indexes holds the sales mix of products constant using 2005 market shares, and measures changes in the price of this 2005 "bundle" of ODDs from one time period to the next (an earlier version started in 2000 and used year 2000 weights). A second Japanese price index updates the weights from one year to the next, beginning from a 2005 base. The latter calculation using "chain weights" is considered a better measure of price change for products like optical disk drives which are undergoing rapid technological and quality change (and there is also an earlier year 2000 version of this index).

In addition, there is also a Japanese producer price index for imported optical disk drives. As with the PPIs for domestically produced ODDs, there is a 2000 base version of this index, and a 2005 base version of this index. Given our earlier discussion of the changing pattern of ODD production in Japan, I interpret a post-2000 domestic producer price index to be a product bundle made up predominantly of "high end," leading edge drives, while the import price index reflects pricing for more mature, "commodity" ODD product types manufactured elsewhere in Asia.

Differences in weights as they evolve over time are likely to create some differences in movements between the two price indexes. Table 4 compares annual rates of change in these price indexes, converted to a common dollar basis, over time. As expected, the chain weighted Japanese price index shows price declines that are slightly greater, reflecting its more accurate reflection of movements in market prices due to introduction of newer and more innovative products.

[84] See, for example, A. Aizcorbe, K. Flamm, and A. Khurshid, "The Role of Semiconductor Inputs in IT Hardware Price Decline: Computers versus Communications," in E. R. Berndt and C. Hulten, Ed., **Hard-to-Measure Goods and Services: Essays in Honor of Zvi Griliches**, (Chicago: University of Chicago Press), 2007, Table 12.1, p. 361.

Yr	BoJ PPI, 2000 Chain-weighted	BoJ, PPI, 2000 Weights	BoJ, Import Price Index, 200 Weights	BoJ PPI, 2005 Chain-weighted	BoJ, PPI, 2005Weights	BoJ, Import Price Index, 2005 Weights	BoK ODD PPI
1996							-60.2%
1997							-41.2%
1998							-45.3%
1999							-20.7%
2000							-16.5%
2001	-29.2%	-28.9%	-14.4%				-45.6%
2002	-21.9%	-21.6%	-17.1%				-23.9%
2003	-24.6%	-23.6%	-10.8%				-27.1%
2004	-22.0%	-19.9%	-10.1%				-28.6%
2005	-27.5%	-20.3%	-17.6%				-5.8%
2006	-19.3%	-13.1%	-13.1%	-19.3%	-18.8%	-15.0%	-2.8%
2007	-8.1%	-6.6%	-13.6%	-8.9%	-8.0%	-16.5%	-11.3%
2008				8.5%	9.7%	-14.6%	-29.8%
2009				5.1%	6.3%	-4.7%	-18.3%
2010				-4.6%	-5.6%	-1.8%	-1.5%

Table 4, Percentage Rates of Change from Previous Year, Various ODD Producer Price Indexes
Source: See text.

Despite differences in index weights, the two indexes broadly display a remarkably consistent picture of slowing innovation in optical disk drives. The various indexes seem to have considerable noise, and show somewhat divergent changes from year to year, but broadly speaking, all of the indexes show a notable trend toward diminishing rates of price decline in recent years.

This is particularly evident if we simply graph these various producer price indexes. Figure 8 shows visible evidence of a trend toward slower rates of price decline in optical disk drives, particularly during the second half of the first post-millenial decade.

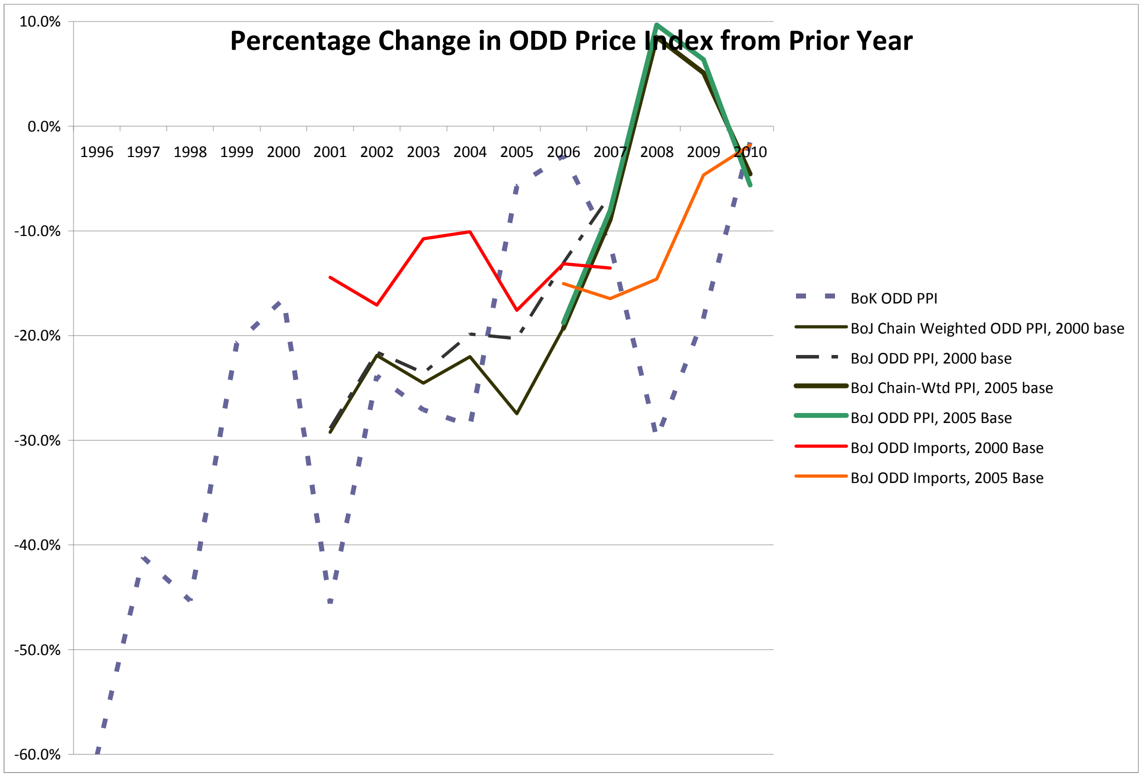

Figure 8 Annual Rates of Change in ODD Price Indexes

Sources: See text.

A Hedonic Price Analysis

Data on optical disk drive pricing (as well as characteristics of optical disk drives) is difficult to come by. With considerable effort, a database was constructed. This database consists of 862 observations on optical disk drive "bargains" from the second quarter of 2006 through 2011, harvested from the website of deal aggregator bensbargains.net. Considerable characteristics data was generally available for most of these drives. I estimated three models using this data. The first version is a parsimonious log linear hedonic model, with log price as a linear function of the most significant characteristics of the optical disk drive, using data for pairs of adjacent quarters, and including a quarterly time shift indicator variable and a linear within-quarter time trend variable (normalized so the quarterly time shift indicator variable describes deviations from a price level for the middle month of the quarter). This first model can be written as

(I) $\text{Ln } P_{it} = X_{it}'\beta + u_{it}$,

where vector X' includes time-constant characteristics of a given model i of optical disk drive on sales date t, including unit type indicator variables (CD writer, DVD-ROM, DVD writer, Blu-ray ROM, Blu-ray combi [DVD writer + Blu-ray ROM], Blu-ray writer), interaction terms between maximum speed with unit type indicator variables[85], interaction terms between unit type indicator and a binary indicator for dual layer disc capability, a set of indicator variables for interface/internal/external type (PATA, IDE, SATA, ESATA, USB, USB2, USB3), and indicator variables for form factor (half height or slim). In addition, there are time-varying trend variables capturing time trends in overall ODD prices: a binary time shift indicator variable for the later quarter in the two adjacent quarters used in every regression, and a quarter-specific time trend variable equal to -1 in the first month of the quarter, zero in the middle month of the quarter, and +1 in the last month of the given quarter, zero otherwise. The u_{it} are mean zero random disturbances that are assumed to be exogenous with respect to the included covariates.

This latter assumption means that model (I) is effectively a "random effects" model, though I will be estimating it using pooled ordinary least squares. The model effectively uses the "time dummy" method of estimating a quarterly hedonic price index, using adjacent pairs of quarters, and implicitly assumes that the coefficients of time-constant characteristics in the hedonic function are approximately constant within any pair of adjacent quarters.[86] The quarterly time indicator variable measures the shift in price from the middle month of one quarter to the middle month of the next quarter, holding all model characteristics constant. The time trend variable lets monthly prices deviate from the quarter midpoint in a linear way, and reflects the fact these types of high tech product prices can change significantly within a quarter, in a systematic way, with the passage of calendar time—this linear approximation to within quarter change is modeled somewhat flexibly, allowing for different slopes within each of the pairs of adjacent quarters.

The data set is unbalanced, with varying numbers of observations for any given model by quarter, and with only a subset of product models having data extending across pairs of quarters. Models contributing observations that are only observed in one quarter or the other contribute indirectly to the estimate of the quarterly price index shift term by affecting the linear within quarter price trend estimates, and the estimated coefficients on time-invariant ODD characteristics.

An alternative model relaxes the assumption that any unobserved heterogeneity (including unmeasured but relevant characteristics of ODDs) is uncorrelated with the observed covariates. Instead I assume that a product-specific disturbance term is the sum of an idiosyncratic, exogenous, time-varying random disturbance plus a time-constant linear function of the time-averaged group means of observed covariates, by product model (so a time-invariant component of unobserved heterogeneity is constant over time, but now is permitted to be correlated with observed covariates). This more flexible

[85] Maximum speed was CD write speed for CD writers, DVD read speed for DVD ROMs, DVD write speed for DVD writers, read speed for Blu-ray ROM and combi units, write speed for Blu-ray writers.

[86] In principle, it is possible to let the coefficients vary from quarter to quarter and test their constancy across quarters, or calculate a so-called "full imputation" characteristics price index if they are not constant, but there are insufficient observations to permit doing this reliably in the current version of the data set. With the log linear hedonic model I am employing here, approximate constancy of characteristics coefficients across the two adjacent time periods, assumed here, implies that the time dummy price index is identical to a full imputation price index. See J. de Haan, "Hedonic Price Indexes: A Comparison of Imputation, Time Dummy and Other Approaches," (Statistics Netherlands), September 2007; J. Triplett, **Handbook on Hedonic Indexes and Quality Adjustments in Price Indexes**, (OECD: Paris), 2004.

model has been dubbed the “correlated random effects” (CRE) model by Wooldridge[87] and others, and can be written as

(II) $\text{Ln } P_{it} = X_{it}'\beta + \ddot{X}_i'\xi + v_{it},$

where the $\ddot{X}_i'$ are time averages for all time-varying covariates. For time-invariant covariates, the β are now not identified without restrictions on ξ, since elements of the X_{it}' that are time-invariant are perfectly collinear with their corresponding element in $\ddot{X}_i'$. Estimated coefficients for any time-invariant covariate will confound a structural effect β with determinant of unobserved heterogeneity ξ unless one is willing to assume that specific time-invariant covariate is uncorrelated with any unobserved heterogeneity (i.e., that the element of ξ for that particular covariate equals 0).

Finally, we can estimate a so-called fixed effects (FE) model,

(III) $\text{Ln } P_{it} = X_{it}'\beta + c_i + v_{it},$

where c_i represents unobserved (but time invariant) heterogeneity that is correlated with the X_{it}, and v_{it} is an idiosyncratic error term. As is well known, by subtracting off time means from all variables and estimating the resulting linear model in the time-demeaned variables (for time-varying variables only), or equivalently, estimating (III) using dummy variables for the c_i and dropping all time-invariant variables, consistent estimates of the β are produced.

A useful result is that the estimates of β for time-varying variable coefficients in the CRE model (II) are exactly identical to the FE estimates of the β in model (III), and a test that the ξ are jointly equal to zero for time-varying variables in CRE model (II) is equivalent to a Hausman test for the “random effects” hedonic null hypothesis embedded in model (I)—that the hedonic specification has controlled for all relevant characteristics that affect price that might be correlated with other relevant but unobserved characteristics--against the fixed effects specification (III), which yields consistent estimates of structural coefficients β even if unobserved and relevant time-invariant characteristics are correlated with the observed ones.

Our initial focus of interest is on the β for the time-varying coefficients (in this case, the quarterly shift dummy for price, and the within-quarter price time trend coefficients for the initial and final quarters in our pair of quarters. The CRE hedonic model (II) can be estimated with robust standard errors and a fully robust Hausman test for the basic (“random effects”) hedonic model (I) constructed by test the joint hypothesis that coefficients on within product means of time-varying variables are equal to zero.

Finally, in all three models, for t set equal to the middle month of a quarter (since all time trend variables have a value equal to zero at the middle month of a quarter), we have

(IV) $\text{Ln } P_{it} - \text{Ln } P_{it-3} = \text{Ln } (P_{it} / P_{it-3}) = \beta_D + (v_{it} - v_{it-3})$,

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[87] See J. M. Woodridge, “Correlated Random Effects Models with Unbalanced Panels,” (Michigan State University), July 2009.

where β_D is the coefficient of the quarter shift indicator variable. Then exponentiating both sides, taking conditional expectations, and taking advantage of exogeneity assumptions about idiosyncratic disturbances, we have

(V) $E[P_{it} / P_{it-3} \ |X] = \exp(\beta_D) \ E[\exp(v_{it} - v_{it-3})]$.

Since P_{it} / P_{it-3} -1 equals the mid-quarter to mid-quarter rate of change in our price index, an unbiased estimate of the expression on the left-hand side of (V), less one, yields an unbiased estimate of the quarterly rate of price change.

Unfortunately, simply exponentiating our estimate of β_D and subtracting off one will give a biased estimate of price change, since $E[\exp(v)] \neq \exp(E[v]) = \exp(0) = 1$. Following Duan[88], current practice is to calculate a nonparametric transformation bias correction assuming idiosyncratic errors v_{it} are iid, which in this context implies

(VI) $E[\exp(v_{it} - v_{it-3})] = E[\exp(v_{it}) \ (1/\exp(v_{it-3})] = E[\exp(v)] \ E[(1/\exp(v)]$.

With appropriate smoothness assumptions, these last two expectations can be estimated consistently and non-parametrically by simply calculating sample averages of exponentiated model residuals, and inverse exponentiated residuals, respectively. Multiplying the exponentiated estimated coefficient of the quarterly shift dummy variable by the product of these two sample averages of functions of the estimated residuals, we have an unbiased estimate of price change from quarter to quarter.

Empirical Results: Specification Tests

Table 5 shows estimates of a robust Hausman test for the “random effects” model specification (I). The null hypothesis is that coefficients on time-averaged, time-varying explanatory variables in the CRE model are jointly zero.[89] A robust estimated covariance matrix (allowing for heteroskedasticity by observation, but assuming no correlation among disturbances across all observations) has been used here. As can be seen, the null of uncorrelated heterogeneity is rejected in 8 of 21 quarters at the 10 percent level, and in 5 of 21 quarters at the five percent level, suggesting that in a substantial number of quarters, a “random effects” specification (and the uncorrelated unobserved effects assumption) based on the hedonic specification that can be readily estimated is not convincing.

Table 6 again calculates robust Hausman tests, this time assuming the much more flexible cluster robust covariance structure among the model disturbances in the CRE specification, i.e., permitting arbitrary correlation in disturbances across time by product model, but maintaining the assumption of uncorrelated disturbances across models. The “random effects” specification cannot be

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[88] See N. Duan, “Smearing Estimate: A nonparametric retransformation method,” **Journal of the American Statistical Association**, vol. 78, 1983; also, C. Cameron and P. Trivedi, **Microeconometrics Using Stata**, (College Station: Stata Press), 2009, pp. 103-104 for a pithy description of the procedure used to do this.

[89] Note that since there was only partial data available for the last quarter of 2011, only two –time varying coefficients (not 3) were identified and available for use in a Hausman test in the last pair of quarters in my sample.

rejected for most periods, but is still rejected in 4 out of 21 time periods at the 10 percent level, and 3 out of 21 at the 5 percent level, more than would be expected, on average, if the null was true for all time periods at either of these significance levels.

One potential problem in using cluster robust standard errors is that we have a relatively small number of models, ranging from 16 to 37, depending on pairs of quarters. Models/clusters that contribute directly to estimation of the quarterly shift dummy variable are even fewer in number, ranging from 4 to 16, depending on which of the 21 quarter pairs is being used. Since the distribution of our F-test statistic is an asymptotically valid approximation, as the number of clusters gets large, the properties of tests assuming large numbers of clusters, in this relatively small sample, are undoubtedly poor. The much more restrictive assumption of uncorrelated but possibly heteroskedastic disturbances across our entire sample, if true, would yield larger effective sample sizes and much more credible approximations to correctly sized tests, but this is a much more restrictive assumption (though one that is still consistent with the assumption that the v_{it} in models (II) and (III) are iid, after controlling for any time invariant contribution of product model to the unobserved heterogeneity). In any event, all of these results point to the FE or CRE model as the only reasonable and safe choice, since our parameter estimates would be still be consistent even if the estimated disturbance covariance matrix—and test statistics—had poor finite sample properties.

Empirical Results: Rates of Change in a Hedonic Price Index for Optical Disk Drives

Next, I review my estimates of quarter-to-quarter price change for an index of optical disk drive prices. My starting point is Table 7, which shows point estimates of the coefficient of the quarterly shift indicator variable, estimated in all 3 models using data for pairs of adjacent quarters. While the pooled OLS model result is shown for completeness, note that this estimate is not consistent if the implicit "random effects" assumption is not correct. Note also that the coefficients for CRE and FE models are identical, and are also the same whether robust or cluster-robust estimates of the standard error are used. The standard errors shown are robust ones, and may be questionable if correlation in idiosyncratic disturbances over time within products remains even after controlling for time shift terms in the regression equation. But possible questions about quality of standard error estimates do not alter the fact that the coefficient estimates remain consistent estimates of the underlying parameter.

This coefficient would be a consistent and unbiased estimate of the log of the ratio of the price levels in the two adjacent quarters, but as previously noted, we are interested in the untransformed price relative, and simply exponentiating this coefficient yields a biased estimate of the ratio of price levels in the two quarters. Instead, I adopt the procedure outlined in (VI) above, multiplying the exponentiated coefficient by the sample averages of exponentiated residuals and inverse exponentiated residuals. (This procedure maintains the hypothesis that the idiosyncratic disturbance terms in models (II) and (III) are iid.)

Table 8 shows the estimated rates of price change that are produced when adopting this procedure, with the CRE and FE models. Note that although the CRE and FE models yield identical parameter estimates before applying a bias correction, the bias-corrected estimate of the rate of price change are not the same in the two models, since residual estimates of idiosyncratic errors in the two models are not identical. [90] A common estimated coefficient multiplied by different estimates of the bias correction yields different bias-corrected estimates. I also show a geometric mean of the bias-corrected rates of price change for the two models.

A price index based on these quarter to quarter price changes is trivial to construct. Table 9 summarizes third quarter to third quarter, annual rates of price decline, from Q3 2006-2007, through Q3 2010-2011. There seems to have been a relatively slower decline in prices in the period from 2006 through 2008, which then sped up again after the latter part of 2009. In 2010-2011, our bias-corrected estimate of annual price decline for quality-adjusted optical disk drive prices was about 33.6%.

Figure 9 graphs quarter-to-quarter rates of decline in ODD prices over the Q3 2006 through Q4 2011 period. As just noted, on average, the earlier part of the period seems to have witnessed slower rates of price decline than the latter years. The average rate of decline over 2006-2010 of about 25.9% annually, a significantly slower decline than the rates of price decline observed earlier, in the 1990s. But these rates of quality-adjusted price decline are substantially faster than those reported in the PPIs we looked at earlier.

Table 10 gathers together price index estimates from all sources discussed earlier for the period from 2001 on. Overall, the impression is of a slower price decline in the second half of the decade that ended in 2010. My hedonic price index falls at rates broadly similar to the Japanese import price indexes around 2005, the base year for the product weights being used in these indexes. But my hedonic index shows faster decline rates than this matched model in the latter part of this period (as perhaps might be expected, since the measured product bundle is updated infrequently in the statistical agency indexes, and may miss important elements of quality improvement—particularly speed and data density—if a substitution method is used to replace rapidly changing models).

It is also possible that my index—which covers only relatively inexpensive “consumer” ODDs used in the PC marketplace, misses higher end ODD drives where price may have fallen at slower rates. It may also simply reflect the fact that these are “bargain” disk drives, where selection as “bargains” is perhaps related to the fact that their prices are falling at rates significantly faster than overall averages for ODDs. My index, which only covers the second half of the 2000 decade, falls at a rate exceeding twice the rate of the Bank of Japan’s import price index, and the Bank of Korea’s ODD producer price index. My results are mute on the issue of whether the rate of price decline slowed overall for the second half over decade, but the PPIs suggest that it did.

[90] The FE model was estimated using Stata’s “areg” procedure.

Table 5

Robust Hausman Test for "Random Effects" Hedonic Model, with Robust Estimated Covariance

	# Constraints:	df	Fval (# constraints, df):	p Value
2006.04	3	56	2.197	0.0985
2007.01	3	47	0.774	0.515
2007.02	3	45	3.276	0.0295
2007.03	3	37	1.537	0.221
2007.04	3	44	0.828	0.486
2008.01	3	67	1.828	0.151
2008.02	3	92	2.539	0.0613
2008.03	3	96	1.992	0.120
2008.04	3	88	1.416	0.243
2009.01	3	85	1.296	0.281
2009.02	3	66	5.532	0.00189
2009.03	3	51	12.00	0.0000046(
2009.04	3	41	2.821	0.0506
2010.01	3	55	1.990	0.126
2010.02	3	77	0.261	0.853
2010.03	3	85	1.104	0.352
2010.04	3	73	0.847	0.473
2011.01	3	64	0.776	0.512
2011.02	3	55	1.471	0.233
2011.03	3	54	3.117	0.0335
2011.04	2	33	3.833	0.0319

Table 6

Robust Hausman Test for "Random Effects" Hedonic Model, with Cluster-Robust Estimated Covariance

					Cluster robust Hausman test, Wald F test:			
	N	Models/ Clusters	# Models Spanning Quarters	N for Models Spanning Quarters	# Constraints:	df	Fval (# constraints, df):	p Value
2006.04	68	22	9	45	3	21	1.348	0.286
2007.01	59	24	4	19	3	23	0.662	0.584
2007.02	57	18	6	35	3	17	2.477	0.0964
2007.03	50	16	7	35	3	15	1.768	0.196
2007.04	57	19	5	22	3	18	3.719	0.0306
2008.01	82	24	6	39	3	23	1.110	0.365
2008.02	109	22	13	93	3	21	1.134	0.358
2008.03	116	28	10	66	3	27	1.556	0.223
2008.04	108	27	7	54	3	26	1.623	0.208
2009.01	103	21	9	84	3	20	1.437	0.262
2009.02	85	20	8	64	3	19	13.80	0.0000516
2009.03	70	22	6	33	3	21	9.795	0.000304
2009.04	61	21	7	32	3	20	1.877	0.166
2010.01	73	24	7	37	3	23	1.509	0.239
2010.02	98	25	15	77	3	24	0.317	0.813
2010.03	107	35	16	77	3	34	0.898	0.452
2010.04	95	37	15	67	3	36	0.612	0.612
2011.01	85	34	14	53	3	33	0.636	0.597
2011.02	76	31	8	32	3	30	0.832	0.487
2011.03	74	24	9	42	3	23	1.688	0.197
2011.04	48	18	7	24	2	17	2.067	0.157

Table 7

Estimates of Quarterly Time Shift Coefficient, Various Models

(Robust Standard Errors Reported)

		Pooled OLS			CRE			FE			N
2006.04		-0.0530	(0.0918)		-0.199*	(0.0755)		-0.199***	(0.0488)		68
2007.01		-0.0624	(0.0968)		0.117	(0.140)		0.117*	(0.0543)		59
2007.02		0.0132	(0.0447)		-0.0382	(0.0416)		-0.0382	(0.0274)		57
2007.03		-0.155**	(0.0509)		-0.144***	(0.0316)		-0.144***	(0.0315)		50
2007.04		0.0111	(0.0295)		-0.0372	(0.0377)		-0.0372	(0.0289)		57
2008.01		-0.131***	(0.0216)		-0.109***	(0.0281)		-0.109***	(0.0250)		82
2008.02		-0.0620***	(0.0170)		-0.0729***	(0.0178)		-0.0729***	(0.0150)		109
2008.03		-0.0731***	(0.0154)		-0.0888***	(0.0147)		-0.0888***	(0.0154)		116
2008.04		-0.146***	(0.0155)		-0.127***	(0.0186)		-0.127***	(0.0187)		108
2009.01		-0.0249	(0.0195)		-0.0263	(0.0215)		-0.0263	(0.0222)		103
2009.02		-0.0922***	(0.0206)		-0.104***	(0.0193)		-0.104***	(0.0199)		85
2009.03		-0.0424	(0.0362)		-0.122***	(0.0185)		-0.122***	(0.0172)		70
2009.04		-0.0801**	(0.0297)		-0.118***	(0.0254)		-0.118***	(0.0178)		61
2010.01		-0.0856*	(0.0418)		-0.117**	(0.0423)		-0.117**	(0.0361)		73
2010.02		-0.0590**	(0.0190)		-0.0524*	(0.0210)		-0.0524*	(0.0198)		98
2010.03		-0.0912***	(0.0197)		-0.111***	(0.0182)		-0.111***	(0.0173)		107
2010.04		-0.209***	(0.0295)		-0.183***	(0.0297)		-0.183***	(0.0286)		95
2011.01		-0.0406	(0.0425)		-0.0809	(0.0593)		-0.0809	(0.0513)		85
2011.02		-0.0163	(0.0379)		-0.0596	(0.0382)		-0.0596**	(0.0185)		76
2011.03		-0.105**	(0.0327)		-0.117**	(0.0345)		-0.117***	(0.0227)		74
2011.04		-0.126*	(0.0474)		-0.0764	(0.0445)		-0.0764*	(0.0288)		48
Standard errors in parentheses			* p<0.05	** p<0.01	*** p<0.001						

Table 8

Rates of Change in Price Indexes, With and Without Bias Correction

2 Quarters Ending in:	Bias Correction Based on:		
2006.03	**Uncorrected**	**CRE**	**FE**
2006.04	-18.05%	-10.80%	-17.50%
2007.01	12.41%	19.60%	12.80%
2007.02	-3.75%	-2.38%	-3.50%
2007.03	-13.41%	-11.80%	-12.90%
2007.04	-3.65%	-2.94%	-3.19%
2008.01	-10.33%	-9.86%	-10.10%
2008.02	-7.03%	-6.65%	-6.79%
2008.03	-8.50%	-8.23%	-8.32%
2008.04	-11.93%	-11.50%	-11.60%
2009.01	-2.60%	-2.05%	-2.14%
2009.02	-9.88%	-9.56%	-9.59%
2009.03	-11.49%	-11.10%	-11.30%
2009.04	-11.13%	-10.80%	-10.90%
2010.01	-11.04%	-10.50%	-10.70%
2010.02	-5.11%	-4.56%	-4.66%
2010.03	-10.51%	-9.86%	-10.20%
2010.04	-16.72%	-15.50%	-16.20%
2011.01	-7.77%	-6.18%	-7.15%
2011.02	-5.79%	-5.15%	-5.70%
2011.03	-11.04%	-10.40%	-10.80%
2011.04	-7.36%	-6.70%	-7.16%

Table 9

Q3 to Q3 Annual Rates of Price Change

	Annual Decline, from Q3 of previous year, w/CRE	Annual Decline, from Q3 of previous year, w/FE	Geometric Mean
2007.03	-8.1%	-21.8%	-15.2%
2008.03	-25.0%	-25.6%	-25.3%
2009.03	-30.3%	-30.6%	-30.5%
2010.03	-31.3%	-31.9%	-31.6%
2011.03	-32.6%	-34.6%	-33.6%

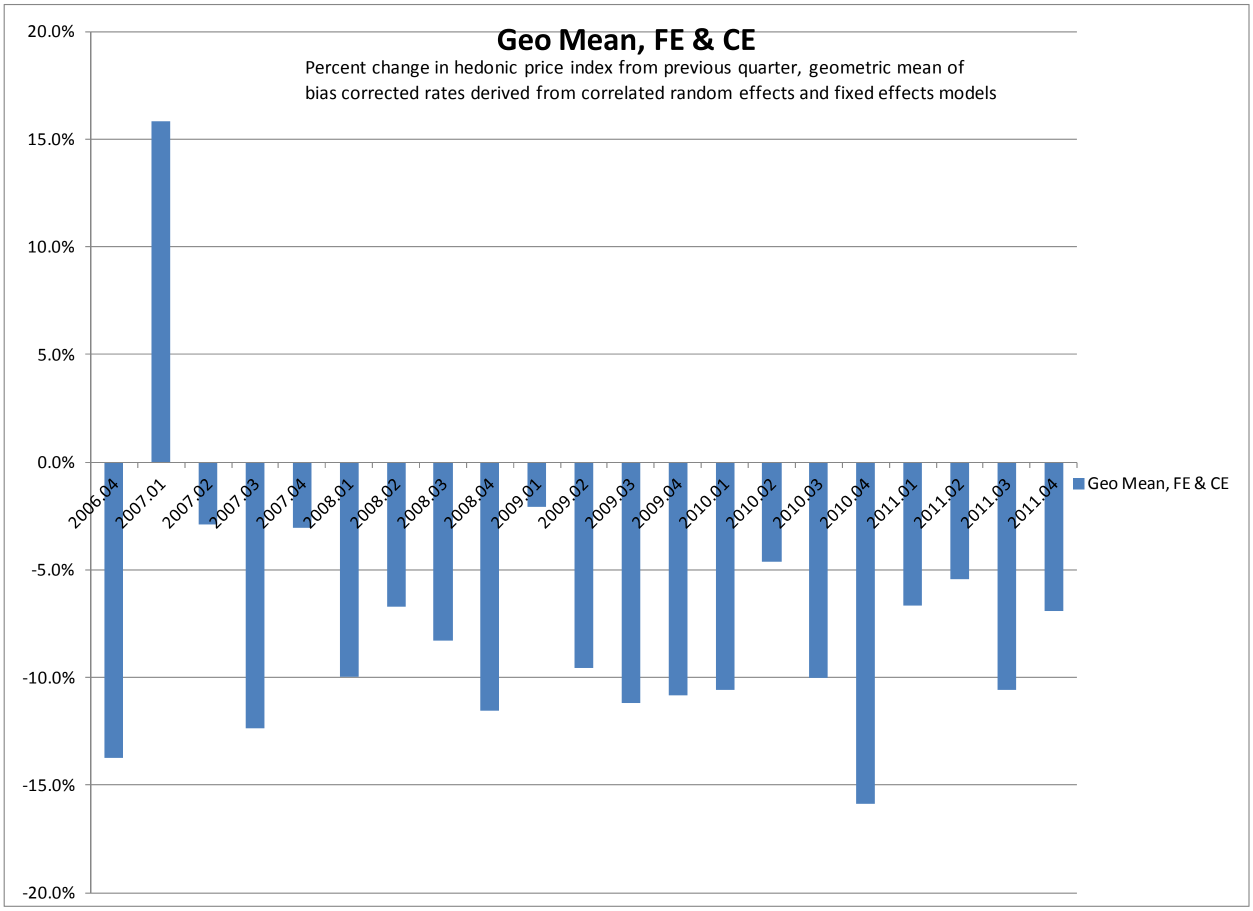

Figure 9 Annualize Rate of Decline from Previous Quarter, Hedonic Price Index

Table 10

Averages of Annualized Rates of Change for Quality-Adjusted ODD Prices, Various Periods

	2001-2006	2006-2007	2006-2010
chn-wtd BoJ	-24.1%	-14.1%	-3.3%
imports, BoJ	-13.8%	-15.8%	-10.5%
ODD PPI, BoK	-22.3%	-7.1%	-12.8%
Flamm Bens		-15.2%	-25.9%

Direct Measures of Product Innovation

A second data set I constructed is comprised of prices and characteristics of ODDs harvested from online data sources, primarily product reviews in online computer publications. Approximately 198 observations on price and characteristics for ODD models sold as retail products in U.S. markets were harvested on the Web over the years 2000 through 2011. (A subset of these data was previously used to chart improvement in CD transfer rates in Figure 3.)

Using this data set, I was able to determine when I first observed a product review of a drive model with some improvement in read or write speed characteristics, one of the principle metrics for ODD product improvement. Figure 10 charts these improvements over the last decade. (Note that the data transfer rate associated with '1X' is significantly different from one type of drive to another, i.e., CD vs. DVD vs. Blu-ray data transfer rates.)

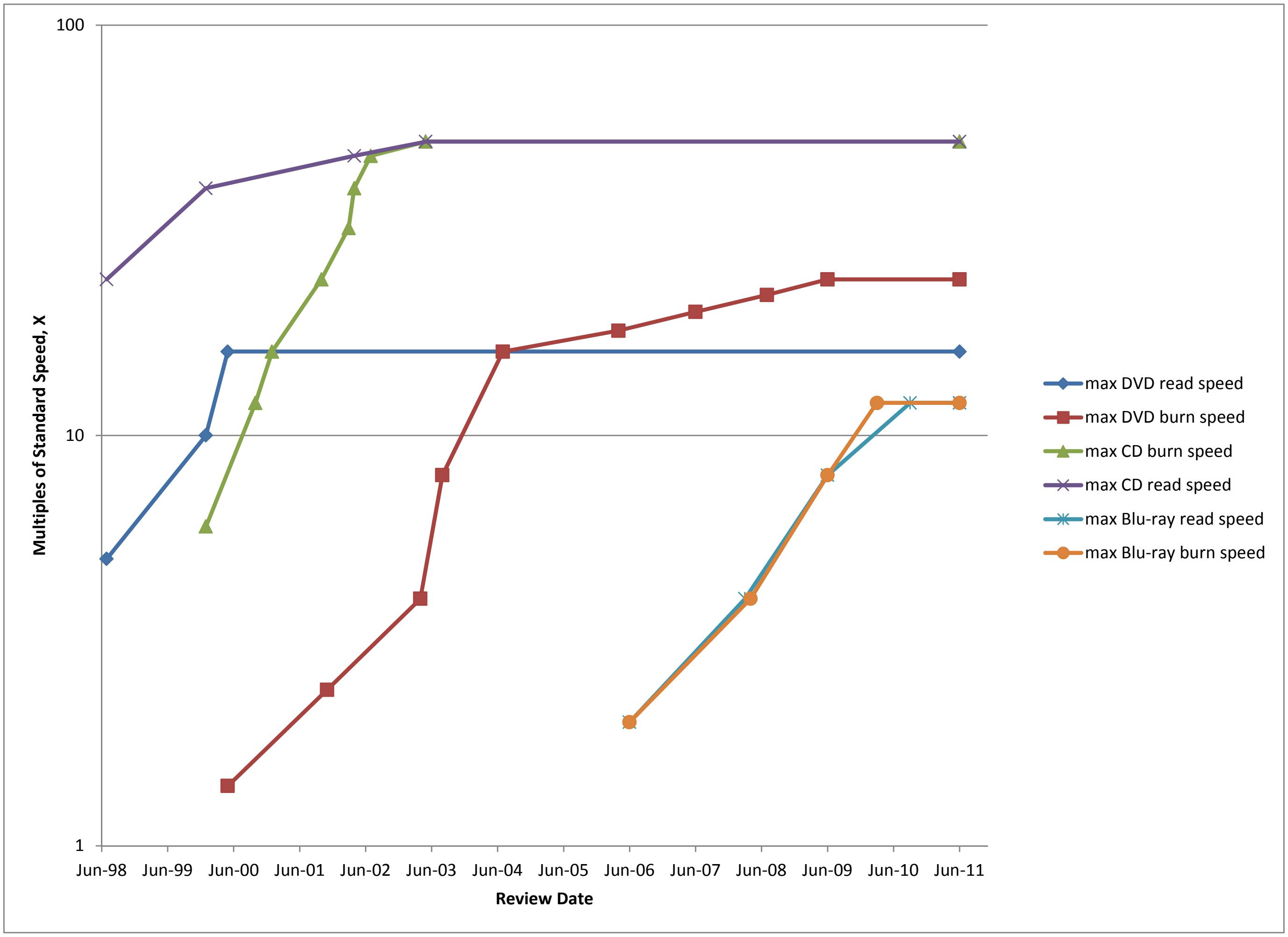

Figure 10 Improvements in ODD Data Transfer Speeds

These data do give some impression that rates of improvement in read and write speeds may have declined over time. (Slopes of these lines, equal to the time rate of change in maximum data transfer speeds, have generally flattened over time. This chart should be contrasted as well with Figure 2.)

Finally, there is some evidence that introductions of qualitatively new products have declined over time. The following figure is derived from a Taiwanese university MBA thesis which attempted to identify all major introductions of new technological changes in the optical disk drive industry over the 1997-2005 period. The clustering of major innovations before 2003 is notable, as is the absence of major new innovations with an impact on the industry since 2002.

Figure 11
ODD Technology Evolution, 1997-2005
Technology Introductions

1997	1998	1999	2000	2001	2002	2003	2004	2005
ImprovedCapacity CD-RW DVD-RAM DVD-R DVD-ROM Optical Reading Head CD-R	DVD+RW DVD-RW HD-DVD	Improved Dye	DVD-Multi		Blu-Ray DVD-Dual			

Year

Source:
Derived from Jheng-Long Wu, The Study of Using Knowledge Discovery Organize Innovative Scenario-- The New Technique Adoption Strategic Analysis for Optical Disk Drive Industry, MBA Thesis, Aletheia University, Taiwan, June 2009, Figure 5.1, p. 25.

I have also created a figure, derived primarily from a recent (2009) technical history of optical disk drive development commissioned by Philips, which takes a different tack by cataloging the first introduction into the marketplace of players based on new ODD standards. As expected, the market introductions depicted in the figure lag the technology development by some time. The pattern is very consistent, however, with a large fraction of all new player introductions occurring prior to 2003, and only two new players (players for the ill-fated HD-DVD standard, and Blu-ray Java players) introduced after 2003. A slackening in the pace of innovation, measured by the introduction of new disk player products, seems to have occurred after 1999.

Figure 12
Market Introduction of Players for New DVD and HD Technologies

1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
DVD-Video	DVD-R 1.0 DVD-ROM	DVD-RAM 1.0	+RW SACD DVD-Audio DVD-RAM 2.0 DVD-RW DVD-R General DVD-R Authoring		DVD+R	DVD+R	Blu-Ray Disc			HD-DVD	BD-Java

Year

Source:
S.G. Stan, "Digital Versatile Discs," in H. Peek, J. Bergmans, J. Van Haaren, F. Toolenaar, and S. Stan, Origins and Successors of the Compact Disc Contributions of Philips to Optical Storage, (Springer), 2009, Figures 5-2, 5-6.
J.A.M.M. van Haaren and M. Kuijper, "Blue Ray Disc," in in H. Peek, J. Bergmans, J. Van Haaren, F. Toolenaar, and S. Stan, Origins and Successors of the Compact Disc Contributions of Philips to Optical Storage, (Springer), 2009.pp. 240-242.
M. Williams, "Timeline: HD DVD vs. Blu-ray Disc," PC World, Feb. 19, 2008.

Conclusion

The impact of patent pools on the rate and direction of technological change is an open question in both theoretical and empirical studies. Economic theory makes no unequivocal prediction. By contrast, empirical studies of patent pools, to date, have largely concluded that patent pools have been associated with reduced rates of technical innovation in the industries studied. This study differs from previous empirical studies of patent pools by focusing primarily on direct measures of innovation in product markets, rather than on indirect correlates of innovation (like patents), and by exploiting variation over time in how pools were organized in the same technology area.

The paper analyzed the economic history of two successive sets of patent pools organized in substantially the same technological area—the use of optical discs in data storage peripherals connected to computer systems. These two patent pool episodes differed significantly in their organizational and institutional details. The first of these pools was arguably the first modern, postwar patent pool to benefit from a 1970s-era change in attitudes toward antitrust policy for patent pools. I showed that different approaches to pool organization and licensing policies implemented in these two patent pool examples were associated with very different outcomes.

The analysis suggested that the economics of the licensing arrangements adopted by the CD patent pool operated in a substantially different fashion from those later implemented in the DVD patent pool. The first pool, the CD pool, adopted policies that on balance seem to have stimulated entry, competition, and innovation, while the later DVD pool adopted policies that inhibited entry, increased concentration, and coincided with a slowing rate of innovation.

In particular, the shift from an *ad valorem* royalty, in the case of CD drives, to the maximum of an *ad valorem* and a fixed, specific per unit royalty, with DVD drives, is notable. Combined with the sharply and continuously declining manufacturing costs typically found in high tech electronics-related industries, and continuation of the prior practice of royalty-free licensing within the CD disk drive patent pools, this change in licensing policy seems to have favored dramatically increasing industrial concentration in the optical disk drive industry. In addition, there is evidence that the rate of technical innovation in optical disc drives subsequently slowed.

The clear implication is that organizational details matter: no single conclusion is likely to fit all cases. As theory seems to predict, the empirical effects of patent pools on innovation are likely to be ambiguous, dependent on the historical and institutional particulars of the pool and the industry it affects. Future analysis of other correlates of innovation in the optical disk drive industry may shed further light on the nature of these complex relationships.