Stanford
Center for International
Development

Working Paper No. 524

Do Patent Pools Encourage Innovation? Evidence from 20 U.S. Industries Under the New Deal

by

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August 2012

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NBER WORKING PAPER SERIES

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Working Paper 18316
http://www.nber.org/papers/w18316

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
August 2012

We thank Tim Bresnahan, Christian Helmers, Eric Hilt, Rick Hornbeck, Pete Klenow, Annika Lorenz, Mark Lemley, Josh Lerner, Shaun McRae, David Mowery, Tom Nicholas, Roger Noll, Paul Rhode, Tim Simcoe, John Wallis, Gavin Wright, Peter Zeitz, and seminar participants at the All-UC Economic History Conference on Science and Innovation, the Clio Meetings in Arizona, DePaul, Berkeley, Loyola, the NBER Conference on Patents, Standards, and Innovation, the Summer Institute of the NBER' Development of the American Economy Program, Northwestern Economics, Northwestern's Searle Center, Stanford University, and U.C. Irvine for helpful comments. Librarians at the National Archives in Chicago, Kansas City, New York City, Riverside, and San Francisco were instrumental in facilitating access to primary documents. Siyeona Chang, Josh Wagner, Aleksandra Goulioutina, and Marina Kutyavina provided valuable research assistance. Moser thanks the Stanford Institute for Policy Research (SIEPR) and the Olin Center for Law and Economics at Stanford for financial support. Lampe thanks the Driehaus College of Business and the Department of Economics at DePaul University for financial support. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

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JEL No. K0,L4,N22,O3

ABSTRACT

Patent pools, which allow competing firms to combine their patents, have emerged as a prominent mechanism to resolve litigation when multiple firms own patents for the same technology. This paper takes advantage of a window of regulatory tolerance under the New Deal to investigate the effects of pools on innovation within 20 industries. Difference-in-differences regressions imply a 16 percent decline in patenting in response to the creation of a pool. This decline is driven by technology fields in which a pool combined patents for substitute technologies by competing firms, suggesting that unregulated pools may discourage innovation by weakening competition to improve substitutes.

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Patent pools, which allow competing firms to combine their patents as if they are a single firm, have emerged as a prominent policy tool to address a key problem with the current patent system: Imperfect boundaries of intellectual property rights allow multiple firms to own mutually infringing patents for the same technology, which they use to threaten litigation and prevent each other from producing the technologies. Patent pools can mitigate this problem by allowing firms to combine their patents in a "pool" which all firms can access to produce the technology and license it to outside firms. For example, pools have been proposed to cover improvements in smart phones, tablet computers, video compression technologies, malaria and HIV drugs, and diagnostic test kits for breast cancer.

Whether pools encourage or discourage innovation, however, is difficult to predict without systematic empirical analyses. Pools are expected to strengthen incentives to invest in R&D by reducing litigation risks (Shapiro 2001; Gilbert 2004) and by lowering the transaction costs of licensing (Merges 2001). Pools may also encourage the adoption of new technologies by preventing double-marginalization (or "royalty stacking"), which occurs when individual firms charge excessive license fees for complementary parts of the same technology (Merges 2001; Shapiro 2001, p. 134).[1] Pools may, however, also *dis*courage investments in R&D by pool members, because returns to R&D will be shared, and members may choose to free ride on other members' research efforts (Vaughan 1956; Lerner, Strojwas, and Tirole 2007).[2]

Most importantly, perhaps, regulators caution, that in the absence of effective antitrust policies, pools may form that harm competition: "participants in the pool might be able to use it to collude, for example, by exchanging competitively sensitive information, such as pricing, marketing, or R&D information through the mechanism of

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[1] Pools may also enhance welfare if a subset of firms is vertically integrated, and the existence of a pool allows upstream firms to coordinate input prices and internalize the impact on vertically integrated downstream members (Kim 2004). Pools may, however, be unstable, if firms choose exit the pool instead of contributing their technologies (Aoki and Nagaoka 2004).

[2] Vaughan (1956, p. 67) observes that the 1917 aircraft pool discouraged innovation by members because "pooling all patents of members and giving each the right to use the inventions of the other took away each member's incentive for basic inventions."

the pool" (Department of Justice and Federal Trade Commission 2007). Theoretically, such changes in the intensity of competition may also discourage innovation by weakening competition to improve substitute technologies, but empirical evidence is scarce.

Existing empirical analyses have been limited to less than a handful of individual industries. Historical data on patents and alternative measures of innovation in the 19th-century sewing machine industry indicate that the creation of a pool discouraged innovation (Lampe and Moser 2010), and diverted firm entry towards technologically inferior substitutes that did not compete directly with the pool (Lampe and Moser 2012a).[3] By comparison, qualitative evidence for the CD industry, indicates an increase in innovation (Flamm 2012), while data for optical disk drives suggest a decline in innovation comparable with that for sewing machines (Joshi and Nerkar 2011; Flamm 2012). In the open source software industry, the creation of a pool was followed by a modest increase in entry for technologies in which IBM contributed patents to the pool (Ceccagnoli, Forman, and Wen 2012).

This paper extends the empirical evidence with a systematic analysis of 20 industries under the New Deal. New Deal policies, such as the National Industrial Recovery Act (NIRA, 1933-35), which exempted the majority of U.S. industries from antitrust in exchange for higher wages (e.g., Haley 2001, p. 8), create a unique opportunity to investigate pools that would form in the absence of effective antitrust.[4] Under the New Deal, regulators allowed pools to form in the hope that they would

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[3] This result is particularly striking given that the pool did reduce license fees for nine complementary (essential) patents that were required to build a state-of-the-art sewing machine, confirming predictions about pools as a mechanism to eliminate double-marginalization (e.g., Shapiro 2001). Importantly, the pool created differential license fees and litigation risks, which introduced a wedge in production costs that favored members (Lampe and Moser 2012a).

[4] Alchian (1970) conjectures that New Deal policies, which limited competition and increased the bargaining power of unions, kept the economy depressed after 1933. A macro-economic model of intra-industry bargaining between labor and firms, which allows insiders to choose the size of the worker cartel, predicts persistent unemployment and high wages as a result of cartelization policies that limit product market competition and increase the bargaining power of labor (Cole and Ohanian 2004). Field (2003 and 2011), however, documents productivity increases in telephones, electric utilities, railroads, communications, public utilities, transportation, real estate, mining, trade, manufacturing, services, construction, and finance/insurance.

facilitate economic recovery from the Great Depression, arguing that "An interchange of patent rights and a division of royalties…are frequently necessary if technical advancement is not to be blocked by threatened litigation."[5] Enforcement resumed after March 11, 1938, when President Roosevelt appointed Thurman Arnold to reorganize the Department of Justice's Antitrust Division.[6] From 1940 to 1949, Justice brought 38 criminal antitrust cases per year, compared with 8.7 per year between 1930 and 1939 (Posner 1970, p. 376).[7] In 1942, the U.S. Supreme Court broke up *Hartford Empire,* a particularly pernicious pool in the glassware industry. Arguing for the majority decision, Justice Hugo Black observed that "the history of this country has perhaps never witnessed a more completely successful economic tyranny over any field of industry…"[8] After *Hartford Empire*, few pools formed until the Department of Justice revised its antitrust guidelines in 1995 and approved the MPEG and DVD standards pools between 1997 and 1999.[9]

Empirical tests exploit this window of weak enforcement to investigate the potential effects on innovation of pools that would form in the absence of effective antitrust. Baseline specifications compare changes in the total number of U.S. patent applications – by pool members and other firms – across related technologies within the same industry that were differentially affected by the creation of a pool. This difference-in-differences approach allows us to control for changes in demand and other unobservable factors that may have influenced patenting at the industry level.

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[5] *Standard Oil Co. of New Jersey v. United States*, 283 U.S. 163, 167-168 (1931).

[6] Robustness checks drop pools that formed after May 27, 1935, when the U.S. Supreme Court ruled that price and wage fixing, which had been sanctioned by the NIRA were unconstitutional (*A.L.A. Schechter Poultry Corp. v. United States*, 295 U.S. 495 (1935)).

[7] Congressional hearings investigated antitrust violations through cartels and pools (June 16, 1938 to April 3, 1941, *Investigation of Concentration of Economic Power, Hearings before Temporary National Economic Committee on Public Resolution 113, Parts 2 and 3 (Patents) and Part 25 (Cartels),* 75 Cong.). In 1942, the Senate's "Bone Hearings" investigated patents and patent licensing (*Patents, Hearings before Senate Committee on Patents on Senate Resolutions 2303 and 2491, Parts 1-9,* 77 Cong., 2 sess. (Bone)).

[8] Justice Hugo Black in *Hartford-Empire Co. v. United States*, 323 U.S. 386, 436-37 (1945). Having grown to include more than 600 patents for machinery, which produced 94 percent of U.S. glass containers, the pool had imposed production quotas and prevented licensees from adopting competing technologies.

[9] The revised 1995 guidelines treat licensing agreements as pro-competitive unless they can be shown to reduce competition, and allow the formation of pools that combine complementary patents that are necessary to build a specific technology (Gallini 2011, pp. 14-15).

Technologies are defined at the level of United States Patent Office (USPTO) subclasses. Pool technologies are subclasses with at least one patent that was included in a pool; the number of pool patents in a given subclass measures the intensity of exposure to the creation of a pool.

In the main specifications, cross-reference subclasses, which patent examiners have identified as closely related to pool technologies, serve as the control group for pool technologies. Cross-reference subclasses exhibit similar pre-trends in patenting to pool technologies before the creation of a pool. This helps address a common concern with difference-in-difference estimates, which is that observed effects may be due to differential pre-trends. As closely related technologies, cross-reference subclasses may be affected by the creation of a pool, which will lead us to underestimate the true effects of a pool. Robustness checks repeat the analysis with broader and narrower definitions of the control.

Changes in patenting are measured relative to a pool-specific year of pool creation (controlling for calendar year fixed effects), which helps address the issue that changes in patenting over time may be due to unobservable policy changes.[10] Regressions also include subclass and year fixed effects, as well as separate linear and quadratic time trends for pool subclasses, to control for variation in the correspondence between patents and innovations across technologies and over time (e.g., Moser 2012).

The main data consist of 75,396 patent applications across 20 industries between 1921 and 1948; these patent applications cover 1,261 subclasses, including 433 pool subclasses and 828 cross-reference subclasses. Importantly, the large majority of innovations, roughly 97 percent, originate from non-members, even though pool members account for more than 60 percent of output in some industries.[11] This suggests that, to capture their full effects on innovation, analyses of patent pools must consider

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[10] For example, variation in spending or work relief programs under the New Deal (e.g., Wright 1974) may have triggered differential changes in patenting over time.

[11] E.g., variable condensers, which are used to select radio stations (*United States v. General Instrument Corp.*, 87 F. Supp. 157 (D.N.J. 1949)) and ready-made furniture slip covers (*United States v. Krasnov*, 143 F. Supp 184 (E.D. Pa 1956)).

effects on outside firms as well as members, and investigate changes in innovation at the industry level – including outsiders as well as member firms.[12]

Baseline estimates indicate a 16 percent decline in industry-level patent applications in pool subclasses compared with cross-reference subclasses after the creation of a pool. This result is robust to the inclusion of subclass and year fixed effects, separate linear and quadratic time trends for pool technologies, and interactions between year and industry fixed effects, which flexibly control for industry-specific changes in patenting over time (e.g., as a result of changes in innovation and patenting over the life-cycle of an industry).

Regressions that expand the control group to include all subclasses in the same USPTO class yield slightly larger estimates, confirming that regressions with cross-reference subclasses as the control may underestimate the true decline. Conditional fixed-effects Poisson regressions, which address the count data characteristics of patents and allow for correlation in the error term over time, suggest a smaller, albeit large and statistically significant decline. Estimates are also robust to restricting the sample to pools that formed before the NIRA became unconstitutional in 1935, and to dropping any individual pool, or all patents by pool members from the sample.

Another potential concern with the basic difference-in-differences estimate is that the creation of a pool may be an endogenous response to changes in the speed of innovation that precede the creation of a pool. To investigate this issue, we estimate annual coefficients, allowing estimates for the pool "effect" to be different from zero before the creation of a pool. This analysis reveals no significant decline for the pre-pool

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[12] Existing analyses have focused almost exclusively on predicting effects on pool members. Desquiedt and Versaevel (2012) examine the effects of anticipating a patent pool on firm's incentives to patent. Llanes and Trento (2012) show that innovators are less likely to join a pool with more members because revenue would be shared with more firms. Jeitschko and Zhang (2012) demonstrate that pools of complementary patents may weaken the incentive of downstream firms to invest in R&D if they create knowledge spillovers that lead to a decline in product differentiation and thereby reduce firms' profits. Lerner and Tirole (2004) focus on differential welfare effects of pools that combine complementary compared with substitute patents; their model does not include outside firms and includes only a brief discussion on innovation. Brenner's (2009) model implies that predictions in Lerner and Tirole (2004) depend on members' ability to prevent entry into the pool.

period; annual coefficients gradually become more negative after a pool forms, and are consistently negative and statistically significant six years after the creation of a pool.

We also investigate whether part of the observed decline may be driven by a reduction in lower-quality or "strategic" patents. For example, the creation of a pool may reduce the need for member firms to create patent thickets by reducing the threat of litigation (e.g., Shapiro 2001; Gilbert 2004).[13] The prospect of a pool may also provoke a wasteful race to patent before the creation of a pool (e.g., Baron and Pohlmann 2011; Dequiedt and Versaevel 2012), so that patent applications that firms submit leading up to the creation of a pool may be of lower quality.[14] The creation of a pool may also increase the quality of patents by pool members if pool members coordinate their research efforts and avoid duplicative R&D (e.g. Kamien, Muller, and Zang 1992).

To control for the quality of patented inventions, we extend the NBER data set on patent citations after 1975 (Hall, Jaffe, and Trajtenberg 2001) to include patent citations between 1921 and 1975. Previous research has shown that the size of the innovation that is covered by a patent is highly correlated with the number of citations to that patent by later patents (e.g., Trajtenberg 1990; Moser, Ohmstedt and Rhode 2011). Our data collection yields 322,998 citations to 61,694 unique patents between 1921 and 2002, which we use to construct citation-weighted patents to control for patent quality.

Analyses of citation-weighted patents indicate a large, but substantially smaller decline in quality-adjusted patents, implying a differential increase in the quality of patented inventions for pool technologies after the creation of a pool. Subclasses with one additional pool patent produced 8 percent fewer citation-weighted patents after the creation of a pool, compared with a 16 percent decline in the main specifications. The

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[13] Surveys of research labs indicate that many firms value patents for strategic reasons (Levin et al. 1987; Cohen, Nelson, and Walsh 2000). In a sample of 95 publicly traded semiconductor firms, firms with large capital investments increased their propensity to patent between 1979 and 1995 as a strategic response to the threat of patent litigation and hold-up (Hall and Ziedonis 2001).

[14] Loury's (1979) model of investment in R&D under uncertainty about the date when a rival will introduce the technology implies that more firms enter than is socially optimal because they do not take account of the parallel nature of R&D. A continuous time model of pools (Dequiedt and Versaevel 2012) implies that the prospect of a pool may induce firms to overinvest in R&D.

analysis, however, also indicates a substantial differential decline in patenting for pool technologies after the creation of a pool, even controlling for the quality of patents.

Were these changes limited to patenting or did they reflect a decline in the rate of innovation? Archival evidence for the movie industry indicates that the creation of a pool lead to a significant delay in the adoption of a cost-saving method to shoot movies in color. In the early 1930s, Eastman Kodak and Technicolor pursued independent research to produce the cost-effective monopack method of shooting movies in color, which was to replace the expensive three-strip technology that had allowed Technicolor to dominate the market. After Kodak and Technicolor pooled their patents in 1934, however, efforts slowed to develop the monopack technology. When consent decrees dissolved the pool in 1948 and 1950, Eastman Kodak introduced its monopack film *Eastmancolor* in 1950, and a broad range of color processes emerged using *Eastmancolor* film. Fuelled by substantial cost savings, the share of color movies increased from 19 percent in 1950 to 33 percent in 1952 and 58 percent in 1954.

What are the mechanisms by which the creation of a patent pool may discourage innovation? Intuitively, complementarities across pool patents should encourage innovation, as the creation of a pool resolves blocking patents, mitigates litigation risks for members, and reduces license fees and transaction costs for outside firms (e.g., Shapiro 2001; Lerner and Tirole 2004). The creation of a pool may, however, also discourage innovation as it reduces competition among members to improve substitute technologies.[15] Regulators are particularly concerned that pools, which combine patents for substitute technologies "are more likely to harm social welfare and than are pools of complementary patents" (Department of Justice and Federal Trade Commission 2007). In practice, however, it is extremely difficult to identify pools of substitute patents.[16]

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[15] At low levels of competition, an increase in competition may strengthen firms' incentives to invent as a means to avoid neck-and-neck competition (Aghion et al. 2001). Consistent with this prediction, an analysis of U.K. patents by 311 firms between 1973 and 1994 suggests an inverted-U shape relationship between competition and innovation (Aghion et al. 2005).

[16] E.g, Lerner, Strojwas, and Tirole (2007, p. 619) exploit the fact that regulators may be more likely to litigate pools of substitute patents (which allow member firms to avoid Bertrand price competition) to use the existence of litigation as an indicator for pools of substitute patents, but caution that litigation could be

This paper addresses the problem empirically by exploiting the USPTO's system of classifying inventions into subclasses according to the function that they perform. If technologies that perform the same function can act as substitutes for each other, variation in the number of pool members across subclasses can be used to identify technologies for which the creation of a pool combines patents for substitutes: In subclasses with patents by one single member, all pool patents are owned by one firm and the pool does not combine patents for substitutes. In these subclasses, the pool technology benefits only from complementarities with other pool technologies, which may increase incentives to invent after the creation of a pool. By comparison, in subclasses with two or more firms, the creation of a pool combines patents for substitute technologies by competing firms. In these subclasses, the pool technology benefits from complementarities with other pool technologies, but is also affected by a decline in competition to improve substitutes.

Comparisons across pool subclasses with one versus more pool members indicates that the differential decline in patenting is driven almost entirely by pool subclasses in which the creation of a pool combines patents by competing firms. Results are robust to controlling for the inclusion of year-industry interactions and for the quality of patents. This suggests that pools, which form in the absence of effective antitrust, would discourage innovation by weakening competition.

I. DATA

To examine changes in patenting after the creation of a pool, we have collected a new data set of 75,396 patent applications between 1921 and 1948, covering 10 years before the first pool formed and 10 years after the last pool formed. These data include 433 pool subclasses and 828 control (cross-reference) subclasses without pool patents in the same industry. To construct measures for the quality of patented inventions, we have also collected information on 322,998 citations to these patents after 1921.

These data extend existing data sets in three important ways. First, they include

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triggered by other behaviors of pools, such as price-fixing.

application years in addition to grant years to more accurately measure the timing of invention. The distinction between application and grant years is important because grants can occur several years after application, depending on the workload of examiners (e.g., Popp, Juhl, and Johnson 2004; Gans, Stern, and Hsu 2008). We extract application years between 1921 and 1948 through a key word search, which yields application years for 97.7 percent of 1,069,414 patents issued between 1921 and 1948.[17] The mean lag between application and grant is 2.5 years with a standard deviation of 1.9 years (Appendix Figure A1).[18]

Our data also include information on cross-reference subclasses (subsection B), while standard data sets report only primary subclasses.[19] The data also include information on the number of pool members per subclass (subsection C), and extend existing data to include citations from 1921 to 1975 (subsection D).

A. Pool Patents in 20 Industries, 1930-1938

To construct the data, we first collected all mentions of patent pools from Vaughan (1956), Gilbert (2004), and Lerner, Tirole, and Strojwas (2007), and then searched the records of the National Archives in Chicago, Kansas City, New York, and Riverside for lists of all patents that were included in these pools. For 13 pools, pool patents are available from consent decrees at the National Archives; for 5 pools, pool patents are included in licensing agreements; for 3 pools, patents are listed in written complaints, and for another 3 pools, patents are included in the final judgments.[20]

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[17] For example, we search the full text of patent grants for the words “iling” (for “Filing”) and “Ser.” (for “Serial Number”) to recover the year associated with this block of text. In a random sample of 300 patents, the algorithm correctly records application years for 296 patents.

[18] In comparison, Popp, Juhl, and Johnson (2004) find that the average U.S. patent between 1976 and 1996 was granted 28 months after the application (with a standard deviation of 20 months).

[19] An analysis of 118,350 patents in photography between 1980 and 2002 indicates that cross-reference subclasses are useful proxy for technology space (Benner and Waldfogel 2008).

[20] For pools in railroad springs, Phillips screws, film, and eyeglasses, patents are listed in more than one source. In comparison with Lerner, Strojwas, and Tirole (2007), our sample includes 8 additional pools between 1930 and 1938 and omits 15 pools for which pool patents are not available. We also exclude a pool for television and radio apparatus because it did not include any U.S. firms, a pool for male hormones (1937-1941) because it was short-lived, and a “pool” for grinding hobs (1931-1943) because it combined two patents by the Barber-Colman Company.

Pools covered a broad range of industries (Table 1) ranging from hydraulic pumps (1933-52), machine tools (1933-55), Philips screws (1933-49), variable condensers to select radio stations (1934-53), wrinkle finishes, enamels and paints (1937-55), fuse cutouts (1938-48), and furniture slip covers (1938-49). Years of pool formation were spread relatively evenly between 1931 and 1938, with 9 pools before 1934 and 11 pools between 1934 and 1938. The average pool was active for 16 years and included pool patents that were 4.2 years old when the pool formed, counting from the year of the patent application.[21]

B. Patents per Year in Pool and Cross-reference Subclasses

The main specifications compare changes in the number of patent applications per year in 433 pool subclasses with changes in 828 cross-reference subclasses of related technologies. For example, U.S. patent 1,908,080 (issued May 9, 1933) for a cross-recessed (Phillips) "screw" belongs to the primary subclass 411/403 for "externally threaded fastener elements," which we define as a "pool subclass."[22] U.S. patent 1,908,080 is also assigned to three cross-reference subclasses: 411/919 ("screw having driving contact"), 470/60 ("apparatus for making externally threaded fastener"), 470/9 ("threaded, headed fastener, or washer making: process-screw"), which form the control in the main specifications.[23] The average pool patent is assigned to 2.0 cross-reference subclasses.

Alternative specifications limit the control to cross-reference subclasses within the

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[21] Sixteen pools included grant-back provisions, which required pool members to contribute new patents for related technologies to the pool, and may have exacerbated pool members' incentives to free ride on R&D by other members (e.g., Aoki and Nagaoka 2004).

[22] Seven subclasses include patents by more than one pool; for them, we define the year of pool formation using the earliest pool. One subclass (352/225) is listed as a pool subclass for two pools. Four subclasses (340/524, 62/056, 524/594, and 174/152R) are pool and cross-reference subclasses; two subclasses (417/426 and 200/56R) are cross-reference subclasses for two pools. We assign them to the pool that formed first. For five pools (fuel injection, pharmaceuticals, railroad springs, lecithin, and aircraft instruments), the *pool* years include a small number of years after the pool had dissolved. To be conservative we include these years as pool years.

[23] A class-specific digest subclass (16/DIG.39), which "relates to a class but not to any particular subclass" (http://www.uspto.gov/web/offices/ac/ido/oeip/taf/c_index/explan.htm) is dropped from the sample, along with 14 other digest classes.

same main class, and expand the control to include all subclasses in the main class (e.g. class 411 “fasteners”).

For 38 subclasses, the creation of a pool combined patents by two or more firms. For example, a pool for wrinkle finishes combined Kay and Ess’ U.S. patent 2,077,112 for “imitation leather paper” with the Chadeloid Chemical Company’s patent 1,689,892 for “wrinkle finishes.” Both patents are assigned to USPTO subclass 427/257, which covers inventions to produce an “irregular surface…by intentionally employing coating materials which dry to a wrinkled appearance or which crack on drying to produce a ‘crackled’ finish.”

C. Citations by Patents after 1921 as a Control for Patent Quality

Citations have emerged as the standard measure for the quality of patents. Unlike references in academic journals, patent citations are checked by professional examiners who remove false citations and add relevant citations that inventors may have missed.[24] Trajtenberg (1990) shows that citation-weighted patent counts – calculated by adding the number of citations that a patent receives to the count for each patent (i.e. each patent is weighted as 1 + the number of citations it receives) – are correlated with the estimated surplus of improvements in computed tomography (CT) scanners. Hall, Jaffe, and Trajtenberg (2005) establish a positive correlation between the ratio of citations to a firm’s patents and that firm’s stock market value. An analysis of field trial data for patented inventions in hybrid corn reveals that citations are positively correlated with the size of patented improvements in plants, measured as improvements in yields and other characteristics of hybrid corn (Moser, Ohmstedt and Rhode 2011).

To construct the citations data for this study, we searched the full text of patent grants between January 4, 1921 and December 31, 1974 for mentions of 75,396 unique patent numbers in our data. Until February 4, 1947, USPTO patent grants recorded citations anywhere in the text of the patent document; to extract these citations, we search

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[24] For U.S. patent grants between January 2001 and December 2002, patent examiners added between 21 and 32 percent of missing citations (Lampe 2012).

the full text of patent grants. After February 4, 1947, the USPTO began to organize citations in separate sections at the beginning or at the end of patent documents; we extract citations directly from these sections.[25] This search yields a total of 238,874 citations between January 4, 1921 and December 31, 1974, to which we add 84,124 citations between January 7, 1975 and December 31, 2002 from the NBER data set.

A total of 61,694 patents (82 percent) are cited by at least one patent between 1921 and 2002. Conditional on being cited at least once, the average patent was cited 5.2 times. In comparison, 2,034,737 patents between 1975 and 2002 in the NBER data (77 percent) were cited by at least one other patent in the NBER data; conditional on being cited, the average patent was cited 7.7 times.[26]

II. RESULTS

For pool technologies, patent applications declined after the creation of a pool, both in absolute terms and relative to alternative definitions of the control. In pool subclasses, patent applications declined from 2.54 per subclass and year before the creation of a pool to 2.40 afterwards (Table 2), and from 2.80 to 2.48 within a 10-year window before and after the creation of a pool (Figure 1). In cross-reference subclasses, patent applications increased from 2.70 before the creation of a pool to 2.94 afterwards (Table 2), and from 2.94 to 3.02 within a 10-year window (Figure 1). In the broader control group that includes all subclasses in the same class, patent applications increased from 1.00 per year before the creation of a pool to 1.11 afterwards (Table 2).

A. Baseline estimates

Baseline difference-in-differences regressions compare changes in the number of

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[25] To evaluate the quality of these data, we examine page scans for 150 randomly chosen patents between 1947 and 1974 on Google Patents (www.google.com/patents). This check indicates that the algorithm correctly identifies 636 of 741 (86 percent) of citations; 5 of 105 citations that the algorithm missed were misread numbers (i.e. false positives) as a result of errors in the optical character recognition (OCR).

[26] 68.2 percent of 4,524 randomly chosen patents grants in 1930 are cited in patent grants between 1947 and 2008 (Nicholas 2010, p. 63). Linking patents to citations with a long lag may, however, miss many important citations. For example, Mehta, Rysman, and Simcoe (2010) find that patent citations in the NBER are highly skewed and peak one year after the original grant.

patent applications per subclass and year in pool subclasses with an additional pool patent with cross-reference subclasses, controlling for differential time trends for pool subclasses, as well as subclass and year fixed effects:

$$(1)\ Patents_{ct} = \alpha + \beta_1\, pool_{ct} * pool\ patents_c \\ + \beta_2\, t * pool\ subclass_c + \beta_3\, t^2 * pool\ subclass_c + f_c + \delta_t + \varepsilon_{ct}$$

where *pool patents*$_c$ counts the number of pool patents in subclass *c*, and *pool*$_{ct}$ equals 1 if subclass *c* includes at least one pool patent and year *t* is after the creation of a pool. Under the assumption that changes in patent applications per year would be comparable in pool and cross-reference subclasses if the pool had not formed, the coefficient for the difference-in-differences estimator $pool_{ct} * pool\ patents_c$ measures the causal effect of the creation of a pool. (We will investigate this assumption in the following section.) Year fixed effects δ_t and subclass-fixed effects f_c, as well as separate linear and quadratic trends $t * pool\ subclass_c$ and $t^2 * pool\ subclass_c$ control for differential changes in patenting between pool subclasses and the control that are independent of the creation of a pool. The variable *pool subclass*$_c$ equals 1 if subclass *c* includes at least one pool patent.

Baseline estimates indicate that subclasses with one additional pool patent produced 0.39 fewer patents per year after the creation of a pool (significant at 1 percent, Table 3, column 2). Compared with a mean of 2.47 patents per year in pool subclasses, this represents a 15.79 percent decline in patenting after the creation of a pool.

Regressions with interactions between year and industry dummies to flexibly control for differential changes in patenting across industries and over time (e.g., as a result of the industry life cycle) indicate that subclasses with one additional pool patent produced 0.36 fewer patent applications per year after the creation of a pool (significant at 1 percent, Table 3, column 3), implying a decline of 14.57 percent.

Consistent with the low share of pool members in industry-level patents, excluding all 2,058 patents by pool members leaves the estimates substantially unchanged. Pool subclasses with an additional pool patent produced -0.36 fewer patents per year after the creation of a pool (significant at 1 percent, Table 3, column 4), equivalent to a 15.45 percent decline.

B. Time varying estimates for the pre- and post pool period

To test for differential pre-trends, which would violate the identifying assumption of the baseline regressions, and more generally to investigate the timing of effects, we estimate the effects of the creation of a pool separately for each year, allowing them to begin *before* the creation of a pool:

$$(2)\ Patents_{ct} = \alpha + \beta_k * pool\ patents_c + f_c + \delta_t + \varepsilon_{ct}$$

where $pool\ patents_c$ is defined as above, and k =-17,-16….17, 18 denotes years before and after the creation of a pool forms; k=0 is the excluded period.

Annual coefficients are not statistically significant in any year except t-1, when estimates imply a 9.31 percent increase in patenting. This is consistent with the idea of a (potentially wasteful) patent race leading up to the pool (e.g.,Baron and Pohlmann 2011; Dequiedt and Versaevel 2012). We examine this in more detail in tests that control for the quality of patents.

Most importantly, however, estimates imply a decline in patenting that begins after the creation of a pool and intensifies over time. Annual coefficients range from -0.17 to -0.30, with an average -0.23 for the first five years, implying a decline of 9.31 percent, and from -0.34 to -0.69, with an average of -0.43 for years six and above, implying a decline of 17.41 percent (significant at 5 percent in years one, three, four and all years above five, Figure 2).[27]

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[27] In regressions with industry-year interactions, annual coefficients are not statistically significant before the creation of a pool. Estimates become statistically significant, with an estimate of -0.32 three years after the creation of a pool, implying a decline of 12.96 percent, and remain significant through the sample, with an estimate of -0.40 ten years after the creation of a pool, implying a decline of 16.19 percent (significant at 5 percent, Appendix Figure A2). Sanders' (1962, p. 71) *Patent Use Survey* of a random 2 percent sample of U.S. patents in 1938, 1948 and 1952 suggests that the average patent application occurs 9 months after a firm has invested in related R&D. By comparison, Hall, Griliches, and Hausman's (1986) find that patent

B. Controlling for Patent Quality through Citations

To control for the quality of patented inventions, we repeat the main specifications using citation-weighted patents (Trajtenberg 1990):

(3) $\textit{Citation-weighted patents}_{ct} = \textit{patents by application year 1921-1948}_{ct}$
$+ \textit{ citations in patent grants 1921-2002 to patent applications 1921-1948}_{ct}$

Because later patents are more likely to be cited, citation-weighted patents increase for both pool and cross-reference subclasses over time, but the increase is substantially smaller for pool subclasses. After the creation of a pool, the average pool subclass produced 15.12 citation-weighted patents, compared with 9.89 before. By comparison, the average cross-reference subclass produced 19.40 citation-weighted patents after the creation of a pool, compared with 11.61 before (Table 2).

Estimates with citation-weighted patents are large and statistically significant. But they are also substantially smaller than the main estimates, which is consistent with the idea that the creation of a pool may lead to a differential increase in the quality of patented inventions for technologies that are covered by a pool. Subclasses with an additional pool patent produced 1.03 fewer citation-weighted patents after the creation of a pool (significant at 1 percent, Table 4, column 2), equivalent to an 8.25 percent decline.[28] Analyses that exclude member patents from the sample indicates that subclasses with an additional pool patent produced 1.02 fewer citation-weighted patents (significant at 1 percent, Table 4, column 4), implying an 8.61 percent decline in quality-adjusted patents, which is slightly above the estimated decline for the full data set.

C. Investigating a Mechanism: Less Competition to Improve Substitutes

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applications for 642 U.S. firms between 1972 and 1979 are most highly correlated with contemporaneous R&D.

[28] Results are robust to alternative tests that remove patents that were not cited, and weight citation counts by the average number of citations to patents issued in the same year.

Variation in the number of pool members across pool subclasses allows us to investigate the mechanism by which the creation of a pool may discourage innovation. In pool subclasses, which include pool patents by one single member, the pool technology may benefit from complementarities with other pool technologies, but there is no change in the intensity of competition, because pool patents were owned by a single firm before the pool had formed. In pool subclasses, which include pool patents by two or more members, the pool technology may benefit from complementarities, but it is also subject to a decline in competition because the pool allows several firms to bundle their patents for substitute technologies. 38 of 435 pool subclasses include patents by multiple members.

Summary statistics indicate that the decline in patenting is driven by subclasses in which the creation of a pool combined patents by multiple members, with a mean of 4.20 patents per year before the creation of a pool, compared with 2.60 afterwards (Table 2), and 4.43 within a 10-year window before the creation of a pool, compared with 2.73 patents afterwards (Figure 3). By comparison, subclasses with only one pool member experienced a much smaller decline from 2.64 to 2.45 patents per year.

Difference-in-differences analyses estimate interaction terms between the pool variables (as defined above) and an indicator variable to measure variation across pool subclasses in the number of member firms

$$
\begin{aligned}
(4)\ Patents_{ct} = {} & \alpha + \beta_1\, pool_{ct} * pool\ patents_c * 1\ firm_c \\
& + \beta_2\, pool_{ct} * pool\ patents_c * > 1\ firm_c \\
& + \beta_3\, t * pool\ subclass_c + \beta_4\, t^2 * pool\ subclass_c + f_c + \delta_t + \varepsilon_{ct}
\end{aligned}
$$

where $1\ firm_c$ equals 1 if subclass c includes patents by a single pool member, and $> 1\ firm_c$ equals 1 if the creation of a pool combines patents by multiple firms.

Difference-in-differences estimates indicate that each additional pool patent in subclasses with multiple pool patents is associated with 0.44 fewer patents after the creation of a pool (significant at 1 percent, Table 5, column 1), implying a 13.02 percent decline relative to a mean of 3.38. By comparison, each pool patent in subclasses with a single pool member is associated with 0.30 fewer patents, and the effect is not statistically significant (Table 5, column 1).

Citation-weighted counts confirm the differential decline for subclasses with multiple member firms. Subclasses with pool patents by more than one member produced 1.37 fewer citation-weighted patents after the creation of a pool (significant at 1 percent, Table 5, column 3), implying a decline of 9.15 percent relative to a mean of 14.98 patents per year. By comparison, subclasses with a single member produced only 0.49 fewer citation-weighted patents, and the effect is not statistically significant.

D. Robustness checks

Robustness checks estimate the main specifications with alternative definitions of the control, as Poisson regressions, and exclude pools that formed after 1935, as well as any individual pool.

The first test restricts the control group to 631 cross-reference classes in the same 108 main classes that include at least one of 433 pool subclasses; the restricted sample includes 62,898 patents. Compared with cross-reference subclasses in the same main class, pool subclasses with an additional pool patent produced 0.39 fewer patents per year after the creation of a pool, implying a 15.79 percent decline, and 1.08 fewer citation-weighted patents, implying a 8.65 percent decline (significant at 1 percent, Table 6, columns 1 and 2).

An alternative specification expands the control to include all 69,316 subclasses without pool patents in 108 (main) classes with at least one pool subclass and in 61 classes with at least one cross-reference subclasses; this expands the sample to 807,326 patents.[29] Estimates suggest that pool subclasses with an additional pool patent produced 0.41 fewer patents per year after the creation of a pool, implying a decline of 16.60

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[29] In this test, 285 subclasses that did not produce any patents between 1921 and 1948 are dropped. In the main specifications, these subclasses are excluded by construction, because only subclasses that at least one patent lists as a primary or a cross-reference subclass are included in the sample.

percent, and 0.89 fewer citation-weighed patents per year, implying a 7.13 percent decline (significant at 1 percent, Table 6, columns 3 and 4).

We also repeat the main specifications as conditional fixed-effects Poisson regressions to control for the count data characteristics of patents, allowing for correlation over time.[30] Poisson estimates imply that subclasses with one additional pool patent produced 8.42 percent fewer patents and 7.22 percent fewer citation-weighted patents after the creation of a pool (significant at 1 percent, Table 6, columns 5 and 6).[31]

An additional robustness check excludes two subclasses for aircraft instruments and stamped metal wheels, with 12 and 10 pool patents, respectively.[32] Estimates with the restricted sample indicate that subclasses with an additional pool patents produced 0.30 fewer patents per year after the creation of a pool, implying a 12.30 percent decline, and 0.99 fewer citation-weighted patents, implying a 7.99 percent decline (significant at 1 percent, Table 7, columns 1 and 2).

Estimated effects are also robust to restricting the sample to pools that formed before May 27, 1935, when the U.S. Supreme Court ruled that price and wage-fixing in the poultry industry, which had been sanctioned under the NIRA, were unconstitutional.[33] Regressions with the restricted sample indicate that pool subclasses with an additional pool patent produced 0.40 fewer patents per year after the creation of a pool, implying a 15.67 percent decline, and 0.92 fewer citation-weighted patents, implying a 6.96 percent decline (significant at 1 percent, Table 7, columns 3 and 4). These results are consistent with historical analyses, which suggest that regulators continued to tolerate collusion and price fixing in many industries until the late 1930s (Hawley 1966, p. 418). “By

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[30] The Poisson model is robust to misspecifications of the distribution and to a disproportionate share of zeros in the dependent variable. Wooldridge (1999) develops a quasi-maximum-likelihood estimator for the fixed effects Poisson model that is also robust to correlation over time; Rysman and Simcoe (2008) implement the estimator.

[31] Percentage changes are calculated as exp(-0.088)-1=-0.08 and exp(-0.075)-1=-0.07.

[32] USPTO subclass 261/41.5 for gas and liquid contact aircraft instruments produced 21.7 patents per year before the creation of a pool and 8.4 afterwards. USPTO subclass 301/35.59 produced 3.8 patents per year between 1927 and 1936, and no patents after a pool had formed in 1937.

[33] *A.L.A. Schechter Poultry Corp. v. United States*, 295 U.S. 495 (1935). Congressional hearings began to scrutinize patent pools in 1935 (*Pooling of Patents, Hearings before House Committee on Patents on House Resolution 4523*, Parts I-IV, 74 Cong (February 11 to March 7 1935)).

1939…well after the demise of the New Deal's initial experiment with an 'industrial policy' of cartelization under the National Industrial Recovery Act (NIRA) — an estimated 47.4 percent by value of all agricultural products and 86.9 percent of all minerals produced are estimated to have been subject to cartel restrictions" (Haley 2001, p. 8).

A final robustness check estimates 20 separate regressions, excluding one of the 20 industries in each regression, to check whether the decline in patenting may be driven by a single industry. Most importantly, the pool for color cinematography, which included 143 pool patents, accounts for 263 of 1,261 (20.86 percent) subclasses in the data. Results are robust to excluding this pool, with a coefficient of -0.42 for *pool*pool patents* (significant at 1 percent, Table 8). Below we investigate alternative (non-patent) measures of innovation for this pool.

Estimates remain large and statistically significant when excluding any remaining industry. Excluding aircraft instruments has the largest effect; estimates remain at -0.31 (significant at 1 percent, Table 8), implying a 13.84 percent decline, compared with an average of 2.24. A government complaint of 1942 suggests that this pool was particularly aggressive in curtailing competition. For example, a January 31, 1935 pooling agreement between Bendix and four European firms stipulated that Bendix would not sell carburetors in Europe; in return, European firms would not sell carburetors in the United States and Canada.[34] By 1940, such agreements included 17 foreign producers.

Excluding a pool for variable condensers has the second largest effect, but coefficients remain large at -0.34, implying a 13.71 percent decline (significant at 5 percent, Table 8), compared with an average of 2.48. This pool combined patents by the General Instrument Corporation, the Radio Condenser Company, and the Dejur-Amsco Corporation, which jointly produced more than 75 percent of variable condensers for American radios. Their agreement combined eight patents by two firms each in two

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[34] *United States v. Bendix Aviation Corporation*, CCH 1946-47 Trade Cases ¶57,444 (D.C.N.J. Civil No. 2531; Complaint, 1942, Consent Decree, 1946).

subclasses (361/299.1 and 361/298.5). It also included a joint defense provision, which authorized members to use any pool patent to countersue non-members; this provision was supported by a litigation fund.[35]

E. A Pool Delays the Adoption of Color Film

Archival records for the movie industry – which accounts for the largest number of patents in our sample – suggest that the creation of a pool delayed technical progress and the transition from black-and-white to color film. In the early 1930s, Technicolor had dominated the market for professional color cinematography with a method that simultaneously ran three separate strips of film, which covered different parts of the color spectrum, through a specialized camera. Technicolor's three-strip process produced an exceptionally vivid color scheme but was expensive to rent, with Technicolor in complete control of the market.

At the time, Technicolor and its competitor Kodak pursued parallel and independent research to develop an alternative method to produce color film, which ran a single strip of celluloid on regular black-and-white cameras.[36] Less cumbersome and costly than the three-strip process, the "monopack" technology threatened Technicolor's monopoly.

On June 25, 1934, Technicolor and Eastman Kodak agreed to pool their patents. In 1941, Technicolor introduced a monopack film, which, however, was too grainy for studio work, and was only used for outdoor shots that the company's bulky 3-strip cameras could not reach (Haines 1993, p. 28; Basten 2005, p. 127). On December 14, 1945, Technicolor and Eastman Kodak amended their agreement to remove a covenant that Kodak "refrain from engaging in the commercial processing of wide 'monopack' film." A government complaint in 1947, however, observed that Kodak "continued to refrain from the commercial processing of wide 'monopack' film, from licensing others

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[35] $9,000, roughly $150,000 dollars in 2011, using the Consumer Price Index (Williamson 2011). *United States v. General Instrument Corp*., 87 F. Supp. 157, 194 (D.N.J. 1949); *United States v. General Instrument Corp*., 115 F. Supp. 582 (D.N.J. 1953).

[36] *United States v. Technicolor, Inc.* (Civil No. 7507-M, S.D. Calif., 1947).

to engage in such processing, and, with minor exceptions, from selling such film with the right to process to customers other than Technicolor…the development of the art of professional color cinematography by others than Technicolor has been retarded, to the detriment of the general public, the motion picture industry, and the film manufacturing industry.[37]

Data on patent applications confirm a decline in the speed of innovation in film-making. An estimate of -0.14 for the baseline specification (significant at 5 percent, Table 7, column 5) implies an 8.43 percent decline compared with a mean of 1.66 patents per pool subclass in the film industry. Regressions that control for the quality of patented inventions yield an estimate of -0.99 (with a p-value of 5.6, Table 7 column 6), implying a 10.86 percent decline compared with a mean of 9.12.

To investigate the shift from black-and-white to color movies, we collect data on the color scheme of 1,900 feature-length movies from the catalogues of the American Film Institute (AFI) between 1930 and 1960.[38] These data indicate that, for as long as the pool was active, the majority of movies continued to be filmed in black-and-white (Figure 4). Exceptional movies that were shot in color – such as "Gone with the Wind" and "The Wizard of Oz" (both 1939) – were produced at high costs because they continued to depend on Technicolor's cumbersome and expensive three-strip method.

Rates of innovation recovered after the Department of Justice filed a complaint against Technicolor and Eastman Kodak on August 18, 1947. In 1948 alone, Eastman Kodak invested more than $3 million in R&D to improve its offerings of color film. By comparison, the company had spent a total of $15 million to improve color film between 1921 and 1948 (Frost and Oppenheim 1960, p. 124).

On November 24, 1948, a consent decree made Kodak's patents available for compulsory licensing to outside firms. A second consent decree on February 28, 1950

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[37] *United States v. Technicolor, Inc.* (Civil No. 7507-M, S.D. Calif., 1947, paras. 18 and 27). *United States v. Technicolor, Inc.*, CCH 1950-51 Trade Cases ¶2,586 (S.D. Calif. Civil No. 7507-M; Complaint, 1947; Consent Judgments, 1948 and 1950).

[38] The AFI catalogues include information on the cast, crew, genre, and technical characteristics of nearly 60,000 feature-length movies that were produced in the U.S. or financed by U.S. production companies between 1893 and 2012 (www.afi.com).

required Technicolor to license its patents to outside firms and terminate arrangements that forced producers to use Technicolor's three-strip cameras.

In the same year, Eastman Kodak introduced *Eastmancolor*, a monopack film that was fine-grained enough for commercial filmmakers.[39] In December 1951, Canada's National Film Board released its documentary "Royal Journey," the first professional-quality film in *Eastmancolor.* In 1952, Kodak introduced an improved monopack technology with higher emulsion speed and better grain structure that allowed its technology to meet the standards of the major Hollywood studios.[40] Based on *Eastmancolor* film a spade of new color processes emerged in the 1950s (Basten 2005, p. 128).

Buoyed by substantial costs savings, the number of U.S. color movies increased from 122 in 1952 to 174 in 1954 (Figure 4). As a share of all U.S. movies, color films increased from 2 percent in the 1930s to 33 percent in 1952 and 58 percent in 1954. Universal Pictures' "Foxfire," released in 1955, was the last live-action American film that used the three-strip method (Basten 2005, p. 129).

III. CONCLUSIONS

Patent pools have emerged as a prominent policy tool to mitigate threats of crippling litigation and ensure the production of new technologies for which competing firms own overlapping patents. Regulators, however, caution that pools, which form in the absence of effective antitrust, may harm competition and discourage innovation (e.g., Department of Justice and Federal Trade Commission 2007).

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[39] Haines (1993, p. 28) describes the monopack technology: "The Monopack stock contained silver halides which were exposed through thin layers of filters during principal photography. The filters allowed light to pass through each layer to generate black and white latent image of the red, green and blue records. During development, the film went through three bleaches that contained 'dye couplers.' Dye couplers were tiny color globules, which replicated the latent silver image of each record. After the dyes were "coupled" with the latent image of each layer, the silver was washed away. The end result was a three color positive image with each hue represented by a think layer of dye couplers." The principle of colored dye couplers (U.S. patents 2,428,054 and 2,449,054) was made operational in *Eastmancolor* (Frost and Oppenheim 1960, p. 115-116).

[40] Records of the Eastman Kodak Company, accessed on May 25, 2012 at http://motion.kodak.com/motion/Products/Chronology_Of_Film/1940-1959/index.htm.

This paper has taken advantage of a unique window of regulatory tolerance under the New Deal, which effectively suspended antitrust, to investigate how pools that would form in the absence of effective antitrust might affect innovation. Baseline difference-in-differences regressions indicate that the creation of a pool caused a 16 percent decline in patent applications. Results are robust to alternative definitions of the control group, various controls for differential changes in patenting across technologies and at the industry level, Poisson regressions, and to dropping individual pools, subclasses, pool member patents, or groups of pools from the sample.

Archival evidence for the movie industry indicates that the creation of a pool for the monopack technology served to protect its costly and cumbersome predecessor, the three-strip technology, for which one of the pool members was a monopolist. Innovation slowed during the pool and only increased again after the pool had dissolved, delaying the switch from black-and-white to color film.

Analyses, which use citations by later patents to control for the quality of patents, confirm the differential decline in patenting for pool technologies. Estimates with citation-weighted patents are, however, noticeably smaller, indicating that firms produced fewer low quality or strategic patents in pool technologies after the creation of a pool. This decline may be due to a welfare-improving reduction in duplicative research efforts as a result of the pool (e.g., Kamien, Muller, and Zang 1992), or it may reflect a socially wasteful race to patent technologies *before* the creation of a pool (e.g., Baron and Pohlmann 2011; Dequiedt and Versaevel 2012). A temporary spike in patent applications immediately before the creation of the pool is consistent with the idea of a patent race.

What are the mechanisms by which the creation of a pool may discourage innovation? Regulators are concerned that pools, which combine patents for substitute technologies, may harm competition and discourage innovation. It has, however, proven exceedingly difficult to identify pools that combine substitutes. This paper has used a simple test, which exploits the USPTO classification system to identify substitutes at the level of technologies, rather than industries. Patent examiners classify inventions into subclasses based on the function that they perform, so that, by definition, patents in the same subclass are more likely to act as substitutes for each other. For subclasses in which a single pool member owns all pool patents before the creation of a pool, the pool has no direct effect on competition. By comparison, for subclasses in which two or more pool members patent before the creation of a pool, the pool reduces competition by combining patents for substitute technologies.

Difference-in-differences comparisons reveal that the observed decline in patenting was driven almost exclusively by subclasses in which a pool combined patents by two or more member firms. This result lends empirical support to theoretical predictions that pools, which combine patents for substitute technologies are likely to harm competition and discourage innovation.

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TABLE 1 - 20 PATENT POOLS FORMED BETWEEN 1930 AND 1938

Industry	Year Formed-Year Dissolved	Member Firms	Pool Patents
High Tension Cables	1930-48	2	73
Water Conditioning	1930-51	3	4
Fuel Injection	1931-42	4	22
Pharmaceuticals	1932-45	2	5
Railroad Springs	1932-47	2	8
Textile Machines	1932-50	2	40
Hydraulic Oil Pumps	1933-52	2	3
Machine Tools	1933-55	5	3
Phillips Screws	1933-49	2	2
Color Cinematography	1934-50	2	143
Dry Ice	1934-52	4	37
Electric Generators	1934-53	2	30
Lecithin	1934-47	4	36
Variable Condensers	1934-53	3	60
Aircraft Instruments	1935-46	2	94
Stamped Metal Wheels	1937-55	3	90
Wrinkle Paint Finishes	1937-55	2	20
Fuse Cutouts	1938-48	2	3
Ophthalmic Frames	1938-48	4	23
Furniture Slip Covers	1938-49	2	2

Notes: Data from license agreements, written complaints, and court opinions from regional depositories of the National Archives in Chicago (railroad springs, machine tools, Phillips screws, lecithin, stamped metal wheels, wrinkle finishes, and fuse cutouts), Kansas City (ophthalmic frames), New York City (high tension cables, water conditioning, fuel injection, pharmaceuticals, textile machinery, dry ice, electric equipment, variable condensers, aircraft instruments), and Riverside (color film). Member firms and pool patents are measured at the time of the initial pooling agreement.

TABLE 2: MEAN PATENT APPLICATIONS PER SUBCLASS AND YEAR

	Pre-pool	Post-pool	All years
<u>Raw patents</u>			
Pool subclasses (N=433)	2.54	2.40	2.47
One pool firm (N=395)	2.38	2.38	2.38
Two or more pool firms (N=38)	4.20	2.60	3.38
Control			
Cross-reference subclasses (N=828)	2.70	2.94	2.81
In the same main class (N=631)	2.69	2.95	2.82
All other subclasses in the same class (N=68,055)	1.00	1.11	1.06
<u>Citation-weighted patents</u>			
Pool subclasses (N=433)	9.89	15.12	12.49
One pool firm (N=395)	9.48	15.07	12.25
Two or more pool firms (N=38)	14.23	15.69	14.98
Control			
Cross-reference subclasses (N=828)	11.61	19.40	15.50
In the same main class (N=631)	11.45	19.63	15.51
All other subclasses in same class (N=68,055)	4.14	7.57	5.99

Notes: Pool subclasses include at least one pool patent that lists this subclass as the primary subclass. *Cross-reference subclasses* are subclasses without pool patents that patent examiners have identified as related technologies. *All other subclasses in the same class* are subclasses in the same main class as a pool or cross-reference subclass. *Citation-weighted patents* are constructed as 1+ # of citations by later patents (Trajtenberg 1990). We collect citations by searching the full text of patent grants 1921-1974 for all patent numbers in our data, adding citations from patent grants 1975-2002 from (Jaffe, Hall, Trajtenberg 2001).

TABLE 3: OLS – DEPENDENT VARIABLE IS PATENTS PER SUBCLASS AND YEAR

	Full sample (1)	Full sample (2)	Full sample (3)	Without pool members (4)
Pool * pool patents	-0.355**	-0.385**	-0.358**	-0.361**
	(0.096)	(0.117)	(0.132)	(0.115)
Constant	1.975**	1.975**	2.452**	1.925**
	(0.073)	(0.072)	(0.081)	(0.071)
Subclass fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	-	Yes
Linear and quadratic trends	-	Yes	Yes	Yes
Industry - year interactions	-	-	Yes	-
Standard errors clustered at the subclass level; ** significant at 1 percent, * significant at 5 percent.				
N (# subclasses * 28 years)	35,308	35,308	35,308	35,308
R-squared	0.554	0.554	0.581	0.557

Notes: The dependent variable counts patents per subclass and year. The timing of invention is measured by the application year for granted patents. The variable *pool* equals 1 after a pool forms. *Pool patents* counts patents that were included in the initial pooling agreement and list subclass *c* as their primary subclass. 433 pool subclasses include one or more pool patents; 828 cross-reference subclasses, which patent examiners have identified as related technologies, form the control

TABLE 4: OLS – DEPENDENT VARIABLE IS CITATION-WEIGHTED PATENTS

	Full sample (1)	Full sample (2)	Full sample (3)	Without pool members (4)
Pool * pool patents	-1.415**	-1.030**	-0.867**	-1.018**
	(0.289)	(0.280)	(0.312)	(0.272)
Constant	6.608**	6.608**	12.593**	6.437**
	(0.397)	(0.397)	(0.528)	(0.390)
Subclass fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	-	Yes
Linear and quadratic trends	-	Yes	Yes	Yes
Industry - year interactions	-	-	Yes	-
Standard errors clustered at the subclass level; ** significant at 1 percent, * significant at 5 percent.				
N (# subclasses * 28 years)	35,308	35,308	35,308	35,308
R-squared	0.474	0.474	0.496	0.475

Notes: The dependent variable counts patents per subclass and year. *Citation-weighted patents* are constructed as 1+ # of citations by later patents (following Trajtenberg 1990). The timing of invention is measured by the application year for granted patents. The variable *pool* equals 1 after a pool forms. *Pool patents* counts patents that were included in the initial pooling agreement and list subclass *c* as their primary subclass. 433 pool subclasses include one or more pool patents; 828 cross-reference subclasses, which patent examiners have identified as related technologies, form the control

TABLE 5: OLS – SUBCLASSES WITH ONE VERSUS MORE THAN ONE POOL MEMBER; DEPENDENT VARIABLE IS PATENTS PER SUBCLASS AND YEAR

	Raw patents		Citation-weighted	
	(1)	(2)	(3)	(4)
Pool * pool patents * 1 firm	-0.296	-0.306	-0.485	-0.474
	(0.219)	(0.246)	(0.496)	(0.586)
Pool * pool patents * > 1 firm	-0.440**	-0.390**	-1.365**	-1.105**
	(0.115)	(0.117)	(0.328)	(0.336)
Constant	1.975**	2.462**	6.608**	13.605**
	(0.073)	(0.081)	(0.397)	(0.541)
Subclass fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	-	Yes	-
Linear and quadratic trends	Yes	Yes	Yes	Yes
Industry - year interactions	-	Yes	-	Yes
Standard errors clustered at the subclass level; ** significant at 1 percent, * significant at 5 percent.				
N (# subclasses * 28 years)	35,308	35,308	35,308	35,308
R-squared	0.554	0.581	0.475	0.496

Notes: The dependent variable counts patents per subclass and year. *Citation-weighted patents* are constructed as 1+ # of citations by later patents (following Trajtenberg 1990). The variable *1 firm* equals 1 if subclass *c* includes pool patents by a single firm; the variable > *1 firm* equals 1 if subclass *c* includes pool patents by multiple member firms. The variable *pool* equals 1 after a pool forms. *Pool patents* counts patents that were included in the initial pooling agreement and list subclass *c* as their primary subclass. 433 pool subclasses include one or more pool patents; 828 cross-reference subclasses, which patent examiners have identified as related technologies, form the control.

TABLE 6: ROBUSTNESS CHECKS – DEPENDENT VARIABLE IS PATENTS PER SUBCLASS AND YEAR

	Control is cross-reference subclasses in same class as pool subclasses		Control is all subclasses in classes with at least 1 pool or cross-reference subclass		Conditional fixed-effects Poisson; control is all cross-reference subclasses	
	Raw patents (1)	Citation-weighted (2)	Raw patents (3)	Citation-weighted (4)	Raw patents (5)	Citation-weighted (6)
Pool*pool patents	-0.389**	-1.076**	-0.409**	-0.890**	-0.088**	-0.075**
	(0.117)	(0.281)	(0.112)	(0.280)	(0.017)	(0.017)
Constant	1.945**	6.516**	0.954**	3.110**		
	(0.079)	(0.432)	(0.006)	(0.031)		
Subclass fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Linear and quadratic trends	Yes	Yes	Yes	Yes	Yes	Yes
Standard errors clustered at the subclass level; ** significant at 1 percent, * significant at 5 percent.						
N (# subclasses * 28 years)	29,792	29,792	1,940,848	1,940,848	35,308	35,308
R-squared / Log-likelihood	0.533	0.455	0.514	0.392	-62,693	-246,547

Notes: The dependent variable counts patents per subclass and year. Cross-reference subclasses are subclasses that patent examiners have identified as related technologies for pool patents. *Citation-weighted patents* are constructed as 1+ # of citations by later patents (e.g., Trajtenberg 1990). The timing of invention is measured by the application year for granted patents. The variable *pool* equals 1 after a pool forms. *Pool patents* counts patents that were included in the initial pooling agreement and list subclass *c* as their primary subclass.

TABLE 7: ROBUSTNESS CHECKS – DEPENDENT VARIABLE IS PATENTS PER SUBCLASS AND YEAR

	Excluding subclasses with many (10 and 12) pool patents from the sample		Excluding pools that formed after NIRA 1935		Color Cinematography Sub-sample	
	Raw patents (1)	Citation-weighted (2)	Raw patents (3)	Citation-weighted (4)	Raw patents (5)	Citation-weighted (6)
Pool*pool patents	-0.295**	-0.987**	-0.399**	-0.924**	-0.139*	-0.993
	(0.095)	(0.336)	(0.141)	(0.312)	(0.069)	(0.517)
Constant	1.964**	6.587**	1.959**	6.825**	1.529**	6.011**
	(0.072)	(0.397)	(0.077)	(0.446)	(0.104)	(0.601)
Subclass fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Linear and quadratic trends	Yes	Yes	Yes	Yes	Yes	Yes
Standard errors clustered at the subclass level; ** significant at 1 percent, * significant at 5 percent.						
N (# subclasses * 28 years)	35,252	35,252	29,848	29,848	7,364	7,364
R-squared	0.551	0.473	0.562	0.473	0.500	0.349

Notes: The dependent variable counts patents per subclass and year. Cross-reference subclasses are subclasses that patent examiners have identified as related technologies for pool patents. *Citation-weighted patents* are constructed as 1+ # of citations by later patents (following Trajtenberg 1990). The timing of invention is measured by the application year for granted patents. The variable *pool* equals 1 after a pool forms. *Pool patents* counts patents that were included in the initial pooling agreement and list subclass *c* as their primary subclass. There are 433 (pool) subclasses with one or more pool patents. Columns (3) and (4) exclude five pools for stamped metal wheels, wrinkle finishes, dropout cutouts, ophthalmic frames, and slip covers that were formed after the National Industrial Recovery Act (NIRA) was ruled unconstitutional on May 27, 1935 in *A.L.A. Schechter Poultry Corp. v. United States*, 295 U.S. 495 (1935).

Table 8: Excluding Individual Pools
OLS– Dependent Variable is Patents per Subclass and Year

	Cables	Water Cond.	Fuel Injection	Pharma.	Railroad Springs	Textile Mach.	Oil Pumps
Pool*pool patents	-0.428**	-0.385**	-0.393**	-0.383**	-0.382**	-0.418**	-0.385**
	(0.131)	(0.117)	(0.122)	(0.117)	(0.118)	(0.118)	(0.117)
Constant	1.988**	1.982**	1.926**	1.988**	1.970**	1.983**	1.974**
	(0.076)	(0.073)	(0.072)	(0.073)	(0.073)	(0.074)	(0.073)
Subclasses* years	32,480	34,916	33,824	34,944	35,000	33,992	35,112
R-squared	0.55	0.55	0.55	0.55	0.56	0.56	0.55

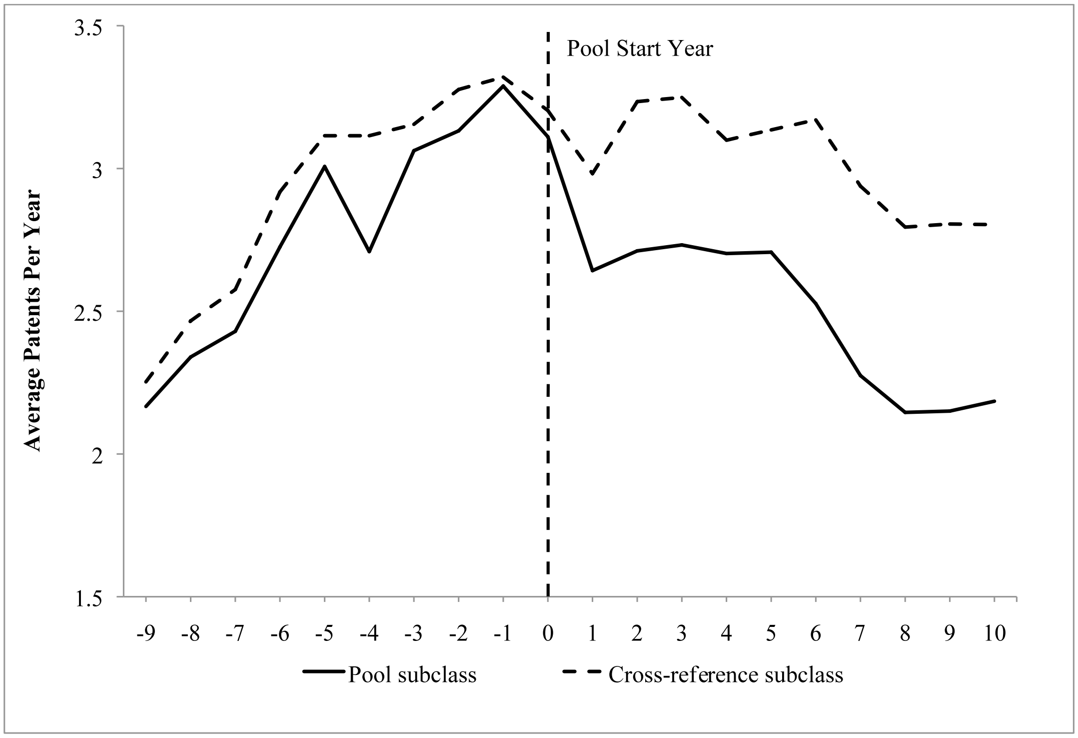
	Machine Tools	Phillips Screws	Color Cinema.	Dry Ice	Electric Gen.	Lecithin	Variable Cond.
Pool*pool patents	-0.385**	-0.384**	-0.423**	-0.378**	-0.379**	-0.388**	-0.340*
	(0.117)	(0.117)	(0.129)	(0.121)	(0.118)	(0.118)	(0.136)
Constant	1.977**	1.977**	2.092**	1.968**	1.975**	2.051**	1.943**
	(0.073)	(0.073)	(0.087)	(0.075)	(0.072)	(0.077)	(0.074)
Subclasses* years	35,084	35,168	27,944	33,012	32,564	32,844	33,852
R-squared	0.55	0.55	0.55	0.55	0.55	0.56	0.55

	Aircraft Instr.	Metal Wheels	Wrinkle Finishes	Fuse Cutouts	Ophth. Frames	Slip Covers
Pool*pool patents	-0.314**	-0.378**	-0.390**	-0.387**	-0.395**	-0.385**
	(0.087)	(0.134)	(0.120)	(0.117)	(0.119)	(0.117)
Constant	1.844**	1.942**	1.977**	1.980**	1.980**	1.978**
	(0.077)	(0.074)	(0.074)	(0.073)	(0.074)	(0.073)
Subclasses* years	29,036	32,312	33,992	35,084	34,440	35,252
R-squared	0.55	0.56	0.56	0.55	0.55	0.55

Including year fixed effects, subclass fixed effects, and linear and quadratic time trends for pool subclasses. Standard errors clustered at the level of subclasses in parentheses.
** significant at 1 percent, * significant at 5 percent.

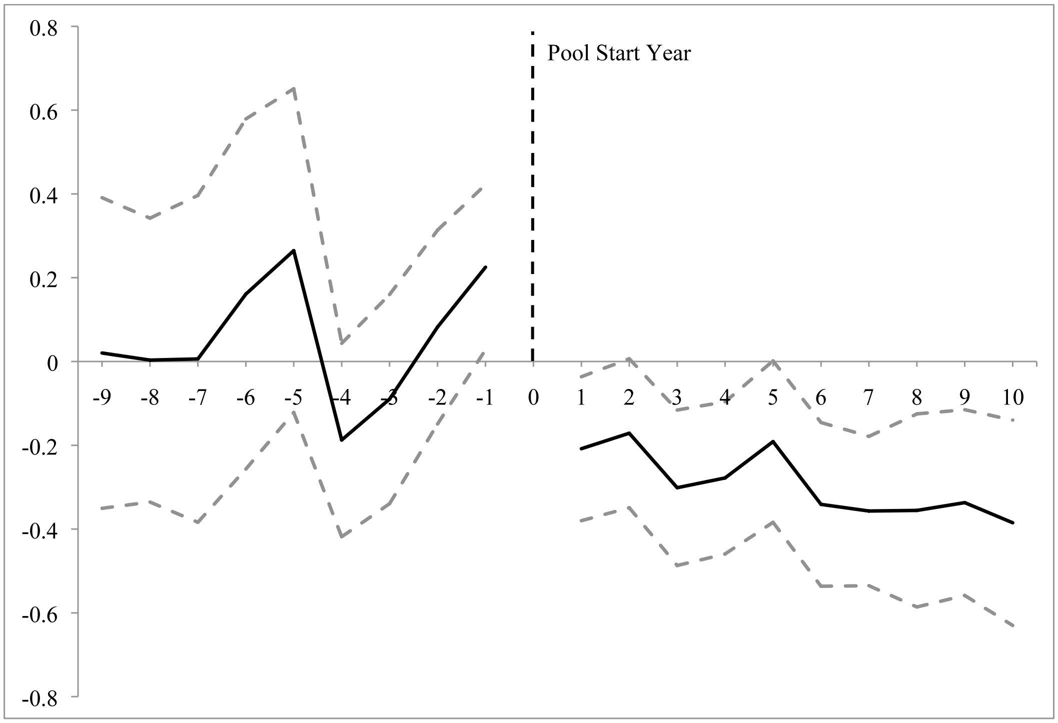
Notes: The dependent variable counts patents per subclass and year. The timing of invention is measured by the application year for granted patents. The variable *pool* equals 1 after a pool forms. *Pool patents* counts patents that were included in the initial pooling agreement and list subclass *c* as their primary subclass. 433 pool subclasses include one or more pool patents; 828 cross-reference subclasses, which patent examiners have identified as related technologies, form the control.

FIGURE 1 – PATENTS PER SUBCLASS AND YEAR: POOL VERSUS CROSS-REFERENCE SUBCLASSES



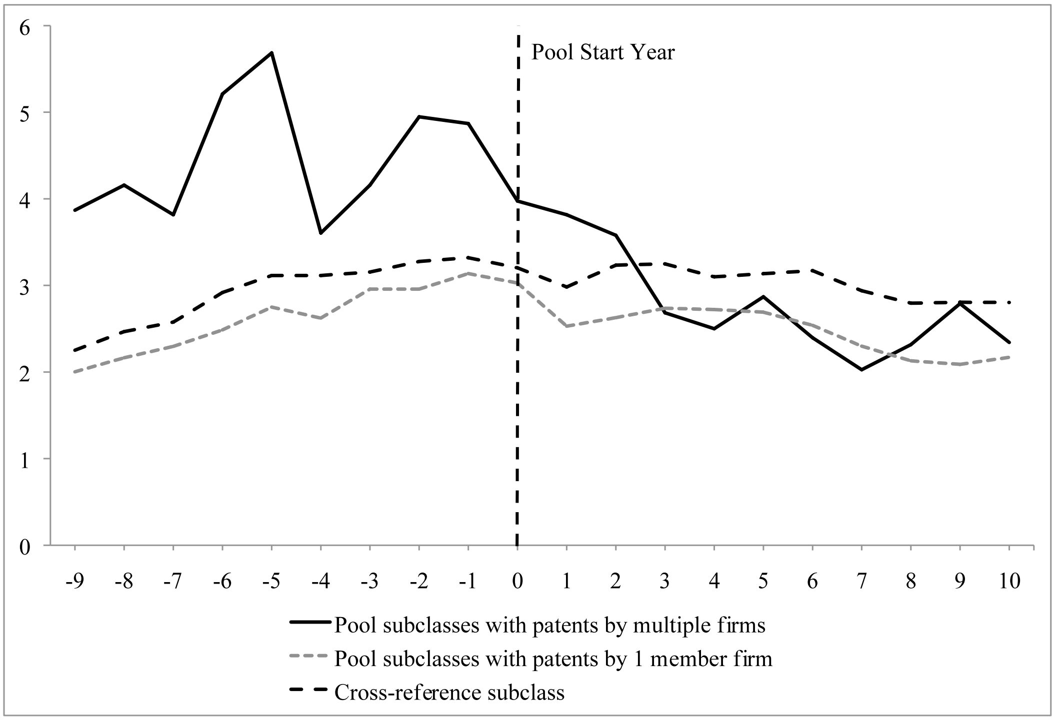
Notes: t =0 denotes the year when a pool forms; the timing of invention is measured at the year of the patent application. Data include patent counts for 433 *pool subclasses* that include at least one pool patent and 828 *cross-reference subclasses* that patent examiners have identified as related technologies.

FIGURE 2 – ANNUAL COEFFICIENTS, OLS,
DEPENDENT VARIABLE IS PATENTS PER SUBCLASS AND YEAR



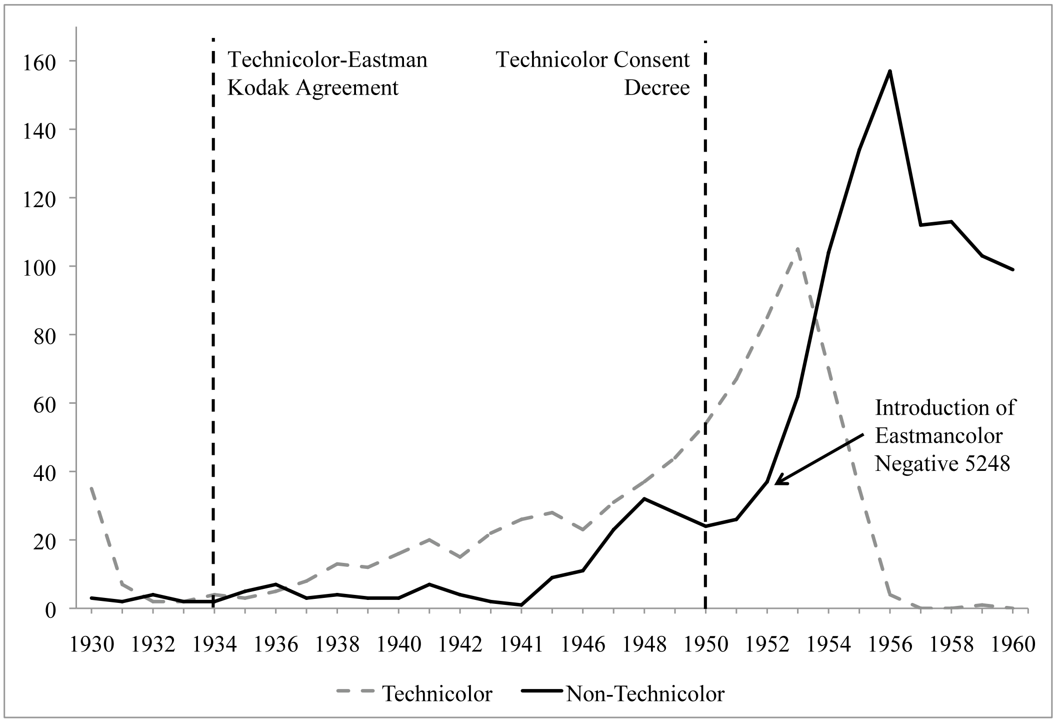
Notes: t =0 denotes the year when a pool forms; the timing of invention is measured at the year of the patent application. Estimates for β_k in the regression $Patents_{ct} = \alpha + \beta_k * Pool\ Patents_c + f_c + \delta_t + \varepsilon_{ct}$ where k =-17,…,17, 18, counts years before and after a pool forms. The variable *Pool Patents*$_c$ counts patents that were included in the initial pooling agreement and that list subclass *c* as their primary subclass.

FIGURE 3 – PATENTS PER SUBCLASS AND YEAR:
ACROSS POOL SUBCLASSES WITH 1 AND MULTIPLE POOL MEMBERS



Notes: t =0 denotes the year when a pool forms; the timing of invention is measured at the year of the patent application. Data include 433 *pool subclasses* that include at least one pool patent and 828 *cross-reference subclasses* that patent examiners have identified as related technologies. For 38 pool subclasses, the creation of a pool combines patents by multiple members.

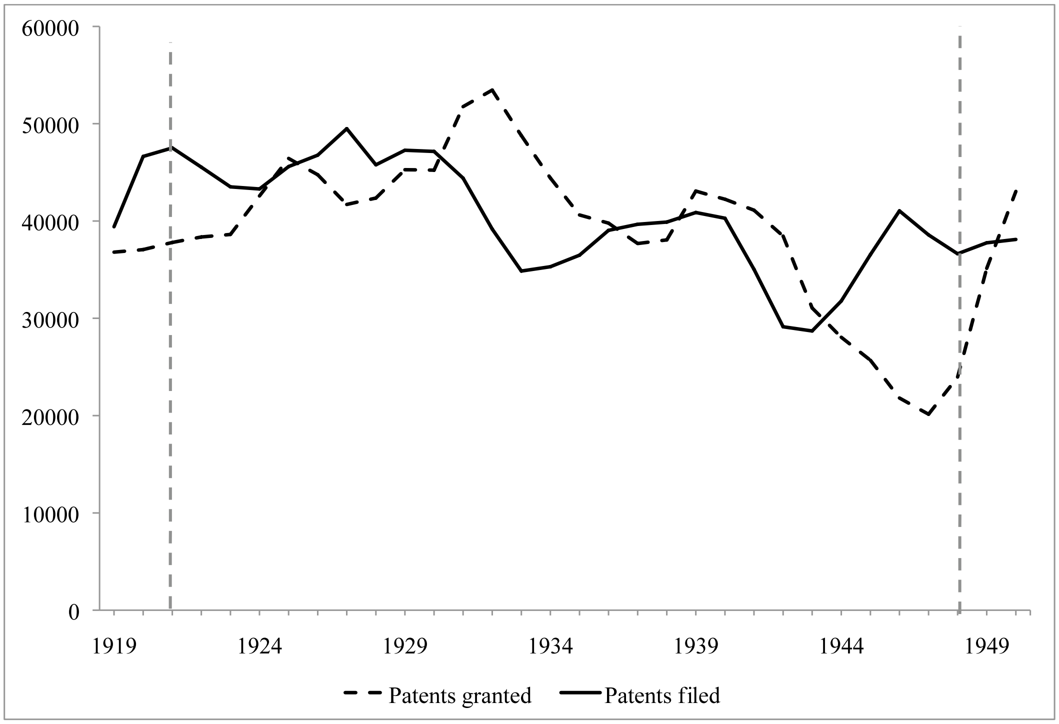
FIGURE 4 – RELEASES OF U.S. COLOR MOVIES PER YEAR, 1930-1960



Notes: Kodak and Technicolor pooled their patents for the monopack method on June 25, 1934. Consent decrees made pool patents available in 1948 and 1950. Eastman introduced *Eastmancolor,* the first monopack film suitable for studio work, in 1952. Data cover 1,900 U.S. movies from the American Film Institute (www.afi.com, accessed on July 9, 2011). Data on Technicolor films from Haines (2003).

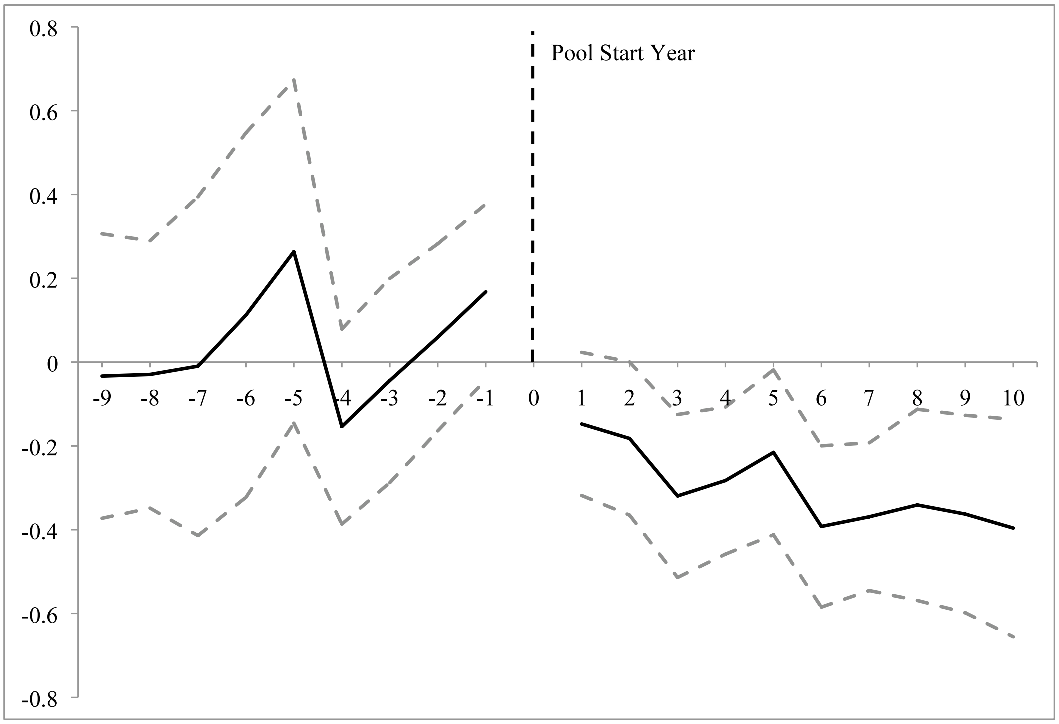
ONLINE APPENDIX
(NOT FOR PUBLICATION)

FIGURE A1 – PATENT COUNTS PER YEAR OF APPLICATION AND GRANT



Notes: Patents per year of application and grant for granted U.S. patents. We collected data on filing years through a key word search of the full text of patent grants between 1920 and 1975, available at www.google.com/patents. This graph reveals truncation bias for patent applications before 1921; to avoid truncation bias, the empirical tests use data on applications between 1921 and 1948. The average lag between applications and grants is 2.5 years with a standard deviation of 1.9.

FIGURE A2 – ANNUAL COEFFICIENTS, OLS WITH INDUSTRY-YEAR INTERACTIONS
DEPENDENT VARIABLE IS PATENTS PER SUBCLASS AND YEAR



Notes: t =0 denotes the year when a pool forms; the timing of invention is measured at the year of the patent application. Estimates for β_k in the regression $Patents_{cit} = \alpha + \beta_k * Pool\ Patents_c + f_c + i_c{*}\delta_t$ where k =-17, ….17, 18, counts years before and after a pool forms, and $i_c{*}\delta_t$ represents interactions between industry and year fixed effects. The variable $Pool\ Patents_c$ counts patents that were included in the initial pooling agreement and that list subclass c as their primary subclass.