PATENT POOLS, COMPETITION, AND INNOVATION - EVIDENCE FROM 20 U.S. INDUSTRIES UNDER THE NEW DEAL*

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Patent pools, which allow competing firms to combine their patents, have emerged as a prominent tool to resolve crippling risks of 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 that would form in the absence of effective antitrust. Difference-in-differences regressions of a new data set of patents and patent citations across 20 industries imply a 14 percent decline in patenting for each additional patent that is included in a pool. This decline is driven by technologies, which pool members competed to improve before the creation of the pool, suggesting that pools may discourage innovation by weakening competition. An alternative data set on innovation in the movie industry confirms that the creation of a patent pool discouraged technological progress in color cinematography.

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Patent pools, which allow a group of 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 technology. 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 facilitate the commercialization of smart phones, tablet computers, video compression technologies, malaria and HIV drugs, and diagnostic test kits for breast cancer.

Whether pools encourage or discourage future improvements in a technology, however, is difficult to predict. 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 facilitate cumulative innovation by encouraging the adoption of new technologies as they prevent 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 reduce innovation by discouraging investments in R&D by pool members, because returns to R&D will be shared, and members may choose to free ride on the research efforts of other members (Vaughan 1956; Lerner, Strojwas, and Tirole 2007).[2]

Regulators also 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,

[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 to 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."

marketing, or R&D information through the mechanism of the pool" (Department of Justice and Federal Trade Commission 2007).

Existing empirical analyses have been limited to less than a handful of individual industries, which deliver no direct evidence on the role of competition. 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 (Lampe and Moser 2012).[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 patent pools and their potentially anti-competitive effects in 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 (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 facilitate economic recovery from the Great Depression. In fact, arguments in favor of patent pools in the 1930s bear a striking resemblance to arguments for patent

[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 2012).

[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.

pools today. For example, the U.S. Supreme Court argued in 1931, when it upheld the Standard Oil pool for gasoline cracking, 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 effects 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 level of individual industries. Technologies are defined at the level of

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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).

United States Patent and Trademark Office (USPTO) subclasses. Pool technologies are subclasses with at least one patent that was included in a pool; counts of pool patents in a given subclass quantify the technology's exposure to a pool.

Methodologically, our analysis extends existing analyses of patent data by introducing cross-reference subclasses as a conservative control group.[10] One benefit of cross-reference subclasses is that patent examiners – rather than researchers – define them as technologies that are closely related to the affected technology. In the current setting, cross-reference subclasses also help to address a common concern with difference-in-difference estimates, which is that observed effects might be due to differential pre-trends. Until a pool forms, cross-reference and pool subclasses exhibit similar trends in patenting. After a pool has formed, patenting in cross-reference subclasses declines after a small initial increase, which is suggestive of negative spillovers that would lead us to underestimate the true effects of a pool.[11] 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.[12] Regressions also include subclass and year fixed effects to control for variation in the correspondence between patents and innovations across technologies and over time (e.g., Moser 2012).

The main data for this analysis 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

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[10] Benner and Waldfogel's (2008) analysis of 118,350 photography patents between 1980 and 2002 has identified cross-reference subclasses as a useful proxy for technology space that is covered by a patent. Although the NBER U.S. Patent Citations Data File (Hall, Jaffe, and Trajtenberg 2001) does not include cross-reference subclasses, the data can be easily obtained from the USPTO Patent Full-Text Database. For example, Moser and Voena (2012) include cross-reference subclasses along with primary subclasses to measure research fields that are affected by compulsory licensing.

[11] Robustness checks, which we describe in more detail below, repeat the analysis with alternative definitions of the control. These tests yield larger estimates, confirming that cross-reference subclasses are a conservative control.

[12] 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.

pool members account for more than 60 percent of output in some industries.[13] This suggests that, to capture their full effects on innovation, analyses of patent pools must consider effects on outside firms as well as members, and investigate changes in innovation at the industry level – including outsiders as well as member firms.[14]

Baseline estimates indicate that, after the creation of a pool, pool subclasses produced 14 percent fewer industry-level patent applications for each additional patent that was included in a pool. This result is robust to the inclusion of separate linear and quadratic time trends for pool technologies in addition to subclass and year fixed effects, and to the inclusion of 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). 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 decline that is only slightly smaller than the main estimates. Estimates are also robust to excluding pool subclasses with a large number of patents, 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 pools may form in 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 period; annual coefficients

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

[14] Existing analyses have focused almost exclusively on predicting effects on pool members. Dequiedt 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. Brenner's (2009) model implies that predictions in Lerner and Tirole (2004) depend on members' ability to prevent entry into the pool.

gradually become more negative after a pool forms, and are consistently negative and statistically significant six years after the creation of a pool. Consistent with the idea of a patent race (Baron and Pohlmann 2011; Dequiedt and Versaevel 2012), patent applications experience a small spike in year *t*-1 before a pool forms, but this spike is too small to explain the substantial decline in patenting in the post-pool period, and omitting data for year *t*-1 causes no substantive decline in the estimates.

What is the mechanism by which the creation of a pool may discourage innovation? To explore this question, we exploit the fact that technologies experienced a differential decline in competition depending on the state of competition *before* the creation of a pool. All pool technologies were affected by complementarities across pool technologies, as well as lower litigation risks and license fees, but only technologies for which the pool combined patents by competing firms, experienced a decline in competition. Comparisons of changes in patenting across pool technologies indicate that the observed decline in patenting was driven almost entirely by technologies that experienced a decline in competition as a result of the pool. Estimates are robust to alternative tests, which exclude cross-reference subclasses from the sample and instead use pool subclasses with a single pool patent as an alternative control.

Archival evidence suggests two mechanisms by which the creation of a pool may limit competition and discourage innovation to improve the pool technology. First, a pool may increase litigation risks for outside firms – even as it reduces such risks for members – because outside firms now have to face the entire group of pool member in court. This threat is particularly severe for pools that combine patents by a group of large firms, which agree to jointly defend their patents. Second, an agreement to pool patents may be accompanied by agreements to divide markets, which eliminate competition among pool members and make it difficult for new firms to enter the industry. This feature poses a particular risk in the absence of effective antitrust.

We also investigate whether the observed decline may be driven by a decline in lower quality or "strategic" patents.[15] For example, the creation of a pool may reduce the need for pool members to create patent thickets by reducing the threat of litigation (e.g., Shapiro 2001; Gilbert 2004), and increase the quality of member patents by allowing members to coordinate research efforts and avoid duplicative R&D.[16] To control for the quality of patented inventions, we extend the NBER U.S. Patent Citations Data File, which includes citations from patents issued after 1975 (Hall, Jaffe, and Trajtenberg 2001) to include citations from patents issued 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 2012). Our new data set identifies 322,998 citations to 61,694 unique patents between 1921 and 2002, which we use to construct citation-weighted patent counts as a control for patent quality.

Analyses of citation-weighted patents indicate a moderate, albeit significant decline in quality-adjusted patents, implying a moderate increase in the quality of patents for pool technologies after the creation of a pool. Subclasses with one additional pool patent produced 11 percent fewer citation-weighted patents after the creation of a pool, compared with a 14 percent decline in the main specifications. Comparisons across pool subclasses with one versus more pool members confirm that the differential decline in quality-adjusted patenting is driven by technologies for which the creation of a pool combines patents by competing firms.

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[15] 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).

[16] For example, Spencer and Grindley (1993, p. 15) note that a principal benefit of the Semiconductor Manufacturing Technology (Sematech) consortium, a research joint venture formed in 1987 between leading U.S. semiconductor firms, was that "central funding and testing can lower the costs of equipment development and introduction by reducing the duplication of firms' efforts to develop and qualify new tools." Consistent with the elimination of duplicative R&D, Irwin and Klenow (1996) find that Sematech caused its members to reduce their overall R&D spending by $300 million per year. Loury's (1979) model of investment in R&D under uncertainty implies that more firms enter than is socially optimal because they do not take account of the parallel nature of R&D.

Another potential issue with using patents as a measure of innovation is that firms may decide not to patent important innovations, and instead protect them through alternative mechanisms, such as secrecy (e.g., Cohen, Nelson, and Walsh 2000; Anton and Yao 2004; Moser 2012). To address this issue, we examine alternative measures of innovation for the movie industry, which accounts for a large number of pool patents in our data.

Archival evidence for the movie industry confirms that the creation of a pool lead to a decline in the speed of innovation. In the early 1930s, Eastman Kodak and Technicolor pursued independent research to produce the cost-effective monopack method of shooting movies in color to replace the expensive three-strip technology that had allowed Technicolor to dominate the market. After Kodak and Technicolor pooled their patents in 1934 – creating a virtual monopoly for Technicolor in high-quality color cinematography – efforts to develop the monopack technology slowed.[17] Soon after consent decrees dissolved the pool in 1948 and 1950, however, Eastman Kodak introduced its monopack film *Eastmancolor*, and a broad range of color processes emerged using *Eastmancolor* film. Fuelled by substantial cost savings, the share of color movies increased from 20 percent in 1950 to 33 percent in 1952 and 58 percent in 1954, suggesting that the creation of a pool may have led to a substantial delay in the adoption of color film.

I. DATA

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

[17] Anscocolor, Cinecolor, and Trucolor offered processes in the 1930s and 1940s that were of substantially lower quality, with diluted images and without vibrant hues (Young 2002, p. 187).

These data extend existing data sets in three important ways. First, they include 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.[18] The mean lag between application and grant is 2.5 years with a standard deviation of 1.9 years (Appendix Figure A.1).[19]

In addition, our data include information on cross-reference subclasses (subsection B), while standard data sets, such as the NBER U.S. Patent Citations Data File (Hall, Jaffe, and Trajtenberg 2001) report only primary subclasses. The data also include information on the number of pool members per subclass (subsection B), and extend existing data to include citations from 1921 to 1975 (subsection C).

A. Pool patents in 20 industries, 1930-1938

To construct data on patents that were included in a pool, 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.[20] Pools covered a broad range of industries (Table I) ranging from hydraulic

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[18] 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.

[19] 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).

[20] 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. For four 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,

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. 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 same main class,

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and a "pool" for grinding hobs (1931-1943) because it combined two patents by the Barber-Colman Company.

[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.

and expand the control to include all subclasses in the main class (e.g. class 411 "fasteners").

Of 433 pool subclasses, 327 include one pool patent, and 106 include multiple pool patents (Table II). Thirty-eight subclasses with multiple pool patents include patents by multiple 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

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 (Moser, Ohmstedt and Rhode 2012).[24]

To construct historical citations data, 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 the full text of patent grants. After February 4, 1947, the USPTO began to organize citations in

[24] Patent citations are checked by professional examiners who remove false citations and add relevant citations that inventors may have missed. For U.S. patent grants between January 2001 and December 2002, patent examiners added between 21 and 32 percent of missing citations (Lampe 2012).

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 added 84,124 citations between January 7, 1975 and December 31, 2002 from the NBER Data File.

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 U.S. Data File (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 II), and from 2.80 to 2.48 within a 10-year window before and after the creation of a pool (Figure I). For cross-reference subclasses, comparisons of means indicate a slight increase in patenting: patent applications in cross-reference subclasses increased from 2.70 before the creation of a pool to 2.94 afterwards (Table II).

Data on changes in patenting, however, indicate that, after a small initial increase, patenting began to decline in cross-reference subclasses, following changes for pool subclasses, albeit at a smaller rate (Figure I). These patterns are suggestive of negative spillover effects from pool subclasses to cross-references subclasses, which will lead tests with cross-reference subclasses as a control to underestimate a decline in patenting as a

[25] To evaluate the quality of these data, we examined 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] 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 U.S. Patent Citations Data File peak one year after the original grant.

result of the pool. Until the creation of a pool, counts of patent applications per year follow similar trends for pool subclasses and cross-reference subclasses.

A. Baseline estimates

Baseline difference-in-differences regressions compare changes in the number of patent applications per subclass and year in pool subclasses with an additional pool patent with changes in the number of patent applications in cross-reference subclasses, controlling for subclass and year fixed effects:

(1) $Patents_{ct} = \alpha + \beta_1\, pool_{ct} * pool\ patents_c + f_c + \delta_t + \varepsilon_{ct}$

where the variable $pool\ patents_c$ 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 in the absence of a pool, 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 control for differential changes in patenting between pool subclasses and the control that are independent of the creation of a pool. Standard errors are clustered at the subclass level.[27]

Baseline estimates indicate that subclasses with one additional pool patent produce 0.36 fewer patents per year after the creation of a pool (significant at 1 percent, Table III, column 1). Compared with a mean of 2.47 patents per year in pool subclasses (Table II), this represents a 14.37 percent decline in patenting after the creation of a pool. Alternative specifications define exposure to a pool more flexibly through a binary

[27] Estimates remain statistically significant at the 1 percent level, if we cluster standard errors at the industry (rather than the subclass) level to control for unobservable industry-level variation that may affect both pool subclasses and the control, with a standard error for $pool_{ct} * pool\ patents_c$ of 0.11, compared with 0.10 if we cluster at the subclass level.

variable for *pool subclasses*$_c$, which equals 1 for any subclass that includes at least one pool patent. Estimates indicate that pool subclasses produce 0.40 fewer patents after the creation of a pool (significant at 1 percent, Table III, column 2), implying a decline of 16.32 percent.

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 changes in patenting across the life-cycle of an industry), indicate that subclasses with one additional pool patent produce 0.32 fewer patents per year after the creation of a pool (significant at 1 percent, Table III, column 3), implying a decline of 12.83 percent. Results are also robust to alternative specifications, which allow for separate linear and quadratic trends for each of the 433 pool subclasses. Estimates with quadratic trends indicate that pool subclasses with one additional pool patent produce 0.39 fewer patents per year after the creation of a pool (significant at 1 percent, Table III, column 4), implying a decline of 15.59 percent.

Consistent with the fact that outside firms produce more than 97 percent of all patents in the average industry, excluding all patents by pool members does not change the size of the estimates. In regressions that exclude all 2,058 patents by pool members, pool subclasses with an additional pool patent produce 0.34 fewer patents per year after the creation of a pool (significant at 1 percent, Table III, column 5), implying a 14.46 percent decline compared with a mean of 2.33 patents per year in pool subclasses.

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 difference-in-differences estimator, and to investigate the timing of effects, we estimate coefficients separately for each year, allowing the estimated effect 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 creation of a pool (e.g., Baron and Pohlmann 2011; Dequiedt and Versaevel 2012). Excluding data for year t-1, however, leads only to a moderate reduction in the size of the estimate to -0.34 for the baseline specification (significant at the 1 percent level, not reported), which implies a 13.93 percent decline compared with a mean of 2.44 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 II).[28]

C. Controlling for patent quality through citations

A potential shortcoming with patents as a proxy for innovation is that patented inventions "differ greatly in 'quality,' in the magnitude of inventive output associated with them" (Griliches 1990, p. 1669). To address this issue, we use data on patent citations as a measure for the quality of patented inventions. Following Trajtenberg (1990) we repeat the main specifications using citation-weighted patents:

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

[28] Regressions with industry-year interactions confirm these results. 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 A.2).

Citation-weighted patents increase for both pool and cross-reference subclasses over time, because more recent patents are more likely to be cited (Hall, Jaffe, and Trajtenberg 2001; Mehta, Rysman, and Simcoe 2010), 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 II).

Estimates with citation-weighted patents are statistically significant and large, albeit slightly smaller than the main estimates. Subclasses with an additional pool patent produce 1.42 fewer citation-weighted patents after the creation of a pool (significant at 1 percent, Table IV, column 1), implying an 11.33 percent decline.[29] Analyses that exclude member patents from the sample indicate that subclasses with an additional pool patent produce 1.42 fewer citation-weighted patents (significant at 1 percent, Table IV, column 5), implying an 11.97 percent decline in quality-adjusted patents, compared with a mean of 11.84 non-member citation-weighted patents per year in pool subclasses. Although the difference between an 11.33 percent decline with citation-weighted patents and a 14.37 percent decline with raw patent counts is relatively small, it is consistent with a decline in the share of strategic patenting after the creation of a pool.

Annual coefficients with citation-weighted patents confirm that the decline in patenting begins after the creation of a pool and intensifies over time, even when controlling for the quality of patents. Annual coefficients become statistically significant in year 6 and range from -1.02 to -2.93, with an average of 1.66 (significant at 5 percent, Figure III) implying a decline of 13.29 percent.

D. Additional robustness checks

Additional robustness checks estimate the main specifications with alternative definitions of the control, as Poisson regressions, and excluding pools that formed after

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[29] 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.

1935, as well as individual pools. 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 produce 0.37 fewer patents per year after the creation of a pool, implying a 14.78 percent decline, and 1.47 fewer citation-weighted patents, implying an 11.76 percent decline (significant at 1 percent, Table V, columns 1 and 2).[30]

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.[31] Poisson estimates imply that subclasses with one additional pool patent produce 8.70 percent fewer patents and 7.41 percent fewer citation-weighted patents after the creation of a pool (significant at 1 percent, Table V, columns 3 and 4).[32]

An additional robustness check excludes two subclasses with exceptionally many patents: aircraft instruments (12 pool patents) and stamped metal wheels (10 pool patents).[33] Estimates with the restricted sample indicate that subclasses with an additional pool patents produce 0.29 fewer patents per year after the creation of a pool, implying a 11.80 percent decline, and 1.43 fewer citation-weighted patents, implying an 11.52 percent decline (significant at 1 percent, Table V, columns 5 and 6). Annual coefficients display less volatility in the pre-pool period and confirm the timing of the baseline estimates. For example, the estimate for *t*-5 is 0.07 (Figure IV, compared with

[30] Results are also robust to expanding 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. Estimates suggest that pool subclasses with an additional pool patent produce 0.30 fewer patents per year after the creation of a pool, implying a decline of 12.11 percent (significant at 1 percent, not reported). In this control group, patent applications increased from 1.00 per year before the creation of a pool to 1.11 afterwards.

[31] 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.

[32] Percentage changes are calculated as (exp(-0.091)-1)*100=-8.70 and (exp(-0.077)-1)*100=-7.41.

[33] 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.

0.26 in the full sample), and the estimate for *t*-1 is not statistically significant.[34] After a pool forms, estimates range from -0.19 to -0.36, with an average of -0.26 in the first five years, implying a decline of 10.66 percent, and from -0.31 to -0.73, with an average of -0.43 for years six and above, implying a decline of 17.62 percent.

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.[35] Regressions with the restricted sample indicate that subclasses with an additional pool patent produce 0.38 fewer patents per year after the creation of a pool, implying a 14.71 percent decline, and 1.36 fewer citation-weighted patents, implying a 10.32 percent decline (significant at 1 percent, Table V, columns 7 and 8). 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.[36]

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. Estimates remain large and statistically significant when excluding any remaining industry. Excluding aircraft instruments has the largest effect; estimates remain at -0.27 (significant at 1 percent, Table VI), implying a 12.23 percent decline, compared with an average of 2.24. Excluding a pool for variable condensers has the second largest effect, but coefficients remain large at -0.31, implying a 12.38 percent decline (significant at 1 percent, Table VI), compared with an average of 2.48. Section III provides narrative evidence on mechanisms by which these two pools discouraged innovation.

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[34] Excluding data for year *t*-1 leads to a moderate reduction in the size of the estimate to -0.27 (significant at 1 percent), implying an 11.07 percent decline compared with a mean of 2.44 patents in this sample.

[35] *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)).

[36] "By 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). Also see (Hawley 1966, p. 418).

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 -0.41 for *pool*pool patents* (significant at 1 percent, Table VI). Below we investigate this pool in more detail using alternative (non-patent) measures of innovation.

III. MECHANISM: DIFFERENTIAL CHANGES IN THE INTENSITY OF COMPETITION

How may the creation of a pool lead to a decline in innovation, despite the many ways in which a pool might encourage innovation? Regulators' biggest concern is that pools may reduce overall welfare by weakening competition (e.g., Department of Justice and Federal Trade Commission 2007), but there is little empirical evidence.

To investigate this issue, we exploit variation in the intensity of competition across pool technologies (i.e., within industries and patent pools). Complementarities across pool technologies and other factors that may encourage innovation (e.g., Shapiro 2001; Lerner and Tirole 2004) benefit all technologies for which pool members contribute patents to a pool. Changes in the intensity of competition, however, only influence technologies for which the creation of a pool allows competing firms to combine their patents.

A. Differential changes in the intensity of competition

Summary statistics indicate that the observed decline in patenting for pool technologies is driven almost entirely by technologies for which the pool combines patents by competing firms. In subclasses with multiple members, patents per year decline from 4.20 patents per year before the creation of a pool to 2.60 afterwards (Table II). Restricting the data to a 10-year window before and after the creation of a pool, patents per year decline from 4.43 patents before the creation of a pool to 2.73 patents afterwards (Figure V). By comparison, technologies in which a single pool member owned all patents experienced a much smaller decline from 2.93 to 2.80 patents per year, and subclasses with a single pool patent (and one pool member by definition) experienced a slight rise from 2.27 to 2.29 patents.

To evaluate these differences more systematically we estimate:

$$(4)\ Patents_{ct} = \alpha + \beta_1\, pool_{ct} * 1\ pool\ patent_c + \beta_2\, pool_{ct} * > 1\ pool\ patent_c * 1\ firm_c + \beta_3\, pool_{ct} * > 1\ pool\ patent_c * > 1\ firm_c + f_c + \delta_t + \varepsilon_{ct}$$

where $1\ pool\ patent_c$ equals 1 if subclass *c* includes a single pool patent (327 subclasses), *>1 pool patent*1 firm* equals 1 if subclass *c* includes multiple pool patents by a single firm (68 subclasses), and *>1 pool patent*>1 firm* equals 1 if subclass *c* includes pool patents by multiple firms (38 subclasses).

Estimates indicate that subclasses in which the pool combined patents by multiple pool members produce 1.89 fewer patents per year after the creation of a pool (significant at 1 percent, Table VII, column 1), implying a 55.92 percent decline relative to a mean of 3.38 patents per year. By comparison, estimates are small and not statistically significant for subclasses in which all pool patents were owned by a single firm, and for subclasses with a single pool patent (owned by a single firm). A Wald test statistic of 4.65 with a *p*-value of 0.03 rejects the hypothesis that estimates are equal for technologies (with multiple pool patents) owned by a single versus multiple pool members.

Citation-weighted counts confirm the differential decline in patenting for subclasses in which the pool combined patents by competing firms. Subclasses with pool patents by multiple members produce 7.23 fewer citation-weighted patents after the creation of a pool (significant at 1 percent, Table VII, column 3), implying a decline of 48.27 percent relative to a mean of 14.98 citation-weighted patents per year. Mirroring results for raw patent counts, estimates are not statistically significant for subclasses with multiple patents by a single firm and for subclasses with a single pool patent by a single firm.

B. Subclasses with a single pool patent as an alternative control

We also examine whether the use of cross-reference subclasses as a control may overstate the decline in patenting for pool technologies – despite similar pre-trends in patenting – because the creation of a pool encouraged patenting in cross-reference subclasses. For example, the creation of a pool that resolves blocking patents may stimulate invention in technologies that are complementary to pool technologies; if these technologies are included in cross-reference subclasses, patenting may increase in cross-reference subclasses after the creation of a pool.

A long-term decline in patenting in cross-reference subclasses, however, is suggestive of negative spillover effects from pool subclasses to cross-references subclasses (Figure I), suggesting that additional patents in cross-reference subclasses are unlikely to drive the differential decline in patenting for pool technologies. To be conservative, however, we exclude cross-reference subclasses from the sample in an additional test and instead use subclasses with a single pool patent – in which the creation of a pool did not affect the intensity of competition – as a control for changes in subclasses with multiple pool patents and multiple firms.

This test indicates that cross-reference subclasses are a conservative control and also confirms that subclasses, in which the pool combines patents by multiple members, drive the observed decline. Subclasses in which the creation of a pool combines patents by multiple firms produce 1.66 fewer patents per year after the creation of a pool compared with subclasses with a single pool patent (significant at 1 percent, Table VIII, column 1). Compared with an average of 3.38 patents per year in this sample, this estimate implies a 49.20 percent decline in patenting after the creation of a pool. As above, estimated effects of the pool on subclasses with a single pool member are substantially smaller and not statistically significant (Table VIII, column 1). A Wald test statistic of 4.82 with a p-value of 0.03 rejects the hypothesis that estimates are equal for technologies with a single versus multiple pool members.

Results are also robust to controlling for the quality of patents (Table VIII, column 3). Difference-in-differences estimates with citation-weighted patents indicate that subclasses with multiple pool firms are associated with 5.18 fewer citation-weighted patents after the creation of a pool (significant at 1 percent, Table VIII, column 3), implying a 34.58 percent decline relative to a mean of 14.98.

C. Archival evidence on mechanisms to limit competition

Archival evidence illustrates alternative mechanisms by which a pool may limit competition and discourage innovation. Most directly, the creation of a pool may discourage investments in improving the pool technology by increasing litigation risks for outside firms. For example, a pool between two major producers of furniture slip covers, Surefit and Comfy, filed its first suit just nine days after it formed on October 4, 1938; by 1941, the pool had instigated law suits against four competitors.[37] A 1933 pool for hydraulic oil pumps between Old Kobe and the Rodless Pump Company similarly sued the Dempsey Pump Company in 1948 when Dempsey tried to enter with a cheaper and better pump.[38] A 1934 pool for lecithin sued firms that tried to enter after 1939, if they refused to purchase a license from the pool.[39] These patterns are also confirmed in archival evidence for the 19th-century sewing machine industry, when the creation of a pool, which increased litigation risks for member firms, discouraged new firms from patenting and producing the pool technology while the pool was active (Lampe and Moser 2010; 2012).

Another mechanism by which pools may weaken competition is through explicit market sharing agreements that accompany agreements to pool patents. For example, a January 31, 1935 pooling agreement between the U.S. manufacturer of aircraft instruments Bendix and four European firms stipulated that Bendix would not sell its carburetors in Europe, and in return, European firms would not sell carburetors in the United States and Canada.[40] By 1940, these agreements had expanded to include 17 foreign firms. A pool for high-tension cables similarly prohibited the U.S. General Cable

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[37] *United States v. Krasnov*, 143 F. Supp. 184 (E.D. Pa. 1956).
[38] *Kobe v. Dempsey Pump Co.*, 198 F.2d 416 (10th Cir. 1952).
[39] *United States v. American Lecithin Co.* (N.D. Ohio Civil No. 24115; Complaint, 1946). A pool between General Instrument Corporation, the Radio Condenser Company, and the Dejur-Amsco Corporation, which jointly produced more than 75 percent of variable condensers for U.S. radios in 1934 included a joint defense provision that was supported by a litigation fund of $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 (D.N.J. 1949), and License Agreement (August 7, 1934, pp. 13-14).
[40] *United States v. Bendix Aviation Corporation* (D.C.N.J. Civil No. 2531; Complaint, 1942).

Corporation and General Electric from selling cables in Europe, and in return stipulated that the Italian Societa Pirelli would not offer its cables in the United States.[41] A pooling agreement among five dominant machine tool manufacturers on August 3, 1933 divided the domestic U.S. market into products, assigning "the manufacture, use and sale of Combined Horizontal Boring, Drilling and Milling Machines and Jig Boring Machines" to the Lucas Machine Tool Company, and "the manufacture, use and sale of milling machines and broaching machines" to the DeVileg Engineering Company.[42]

IV. Non-Patent Measures of Innovation

Archival records for the movie industry – which accounts for the largest number of patents in our sample – suggest that 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. Technicolor was in complete control of the market and charged high rental fees for his camera equipment and for the use of its film.

Technicolor and its competitor Kodak began to pursue 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.[43] This "monopack" technology would have been substantially less cumbersome and costly than Technicolor's three-strip process, and it posed a substantial threat to Technicolor's monopoly for high-quality color film.

On June 25, 1934, Technicolor and Eastman Kodak agreed to pool their patents, and research on the monopack technology slowed. In 1941, Technicolor introduced a monopack film, which, however, was no threat to its three-strip technology because it

[41] *United States v. General Cable Corp.* (S.D.N.Y. Civil No. 40-76; Complaint, 1947).
[42] *United States v. Associated Patents, Inc.*, 134 F. Supp. 74 (E.D. Mich. 1955), and License Agreement (August 3, 1933, p. 11).
[43] *United States v. Technicolor, Inc.* (S.D. Calif. Civil No. 7507-M; Complaint, 1947).

was too grainy for studio work, and was only used for outdoor shots that the company's bulky three-strip cameras could not reach (Haines 1993, p. 28; Basten 2005, p. 127). Until 1945, their pooling agreement included a covenant that Kodak "refrain from engaging in the commercial processing of wide 'monopack' film." On December 14, 1945, Technicolor and Eastman Kodak amended their agreement to remove the covenant, but a government complaint in 1947 observed that Kodak

> "continued to refrain from the commercial processing of wide 'monopack' film, from licensing others 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."[44]

To investigate whether the creation of a pool may have delayed the "art of professional color cinematography," we collected data on the color scheme of 1,912 feature-length movies from the catalogues of the American Film Institute (AFI) between 1930 and 1960.[45] 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 VI). Exceptional movies that were shot in color – such as "The Wizard of Oz" and "Gone with the Wind" (both 1939) – were extremely costly to produce, with production costs of $2,777,000, equivalent to $45,000,000 year 2011 U.S. dollars, and $3,957,000, equivalent to $64,100,000 year 2011 U.S. dollars (based on percentage changes in the CPI, Officer and Williamson 2011). In 1935, shooting a movie using Technicolor's cumbersome and expensive three-strip method increased production costs by 30 percent relative to average production costs of $300,000 per feature (Kindem 1979, p. 34).

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[44] *United States v. Technicolor, Inc.* (Civil No. 7507-M, S.D. Calif.; Complaint, 1947, paras. 18 and 27). An estimate of -0.07 for the baseline specification implies a 4.52 percent decline compared with a mean of 1.66 patents per pool subclass in the film industry. Regressions with citation-weighted patents yield an estimate of -0.96 (significant at 5 percent), implying a 10.52 percent decline compared with a mean of 9.12.

[45] 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).

Data on R&D investments indicate a delay in investments as a result of the pool. Between 1921 and 1948, Eastman Kodak spent a total of $15 million to improve color film. After the Department of Justice filed a complaint against Technicolor and Eastman Kodak on August 18, 1947, Eastman Kodak invested more than $3 million in R&D to improve color film in 1948 alone (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 required Technicolor to license its patents to outside firms and terminate arrangements that forced producers to use Technicolor's three-strip cameras.[46] In the same year, Eastman Kodak introduced *Eastmancolor*, a monopack film that was fine-grained enough for commercial filmmakers.[47] In December 1951, Canada's National Film Board released the documentary "Royal Journey," one of the first professional-quality films 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.[48] In the 1950s, many studios created new color processes using *Eastmancolor* film (Basten 2005, p. 128).

Buoyed by substantial costs savings, the number of U.S. color movies increased from 121 in 1952 to 174 in 1954 (Figure VI). 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.

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[46] *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).

[47] 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).

[48] 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.

Universal Pictures' "Foxfire," released in 1955, was the last live-action American film that used the three-strip method (Basten 2005, p. 129).[49]

V. 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. Although public opinion is typically favorable of pools, there is some concern 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).

This paper has taken advantage of a unique window of regulatory tolerance under the New Deal to investigate the effects of patent pools that would form in the absence of effective antitrust. Difference-in-differences regressions of changes in patenting across 20 industries indicate that the creation of a pool led to a 14 percent decline in patent applications for each additional patent that was included in a pool. Results are robust to a broad range of specifications, including alternative definitions of the control, flexible controls for unrelated changes in patenting over time (e.g., as a result of the industry life-cycle), count data analyses, to dropping subclasses with many pool patents, and to dropping individual pools, or all pools after 1935 from the sample. Analyses, which use patent citations as a control for the quality of patented inventions, yield slightly smaller estimates, with an estimated 11 percent decline in citation-weighted patenting. These results are consistent with a moderate increase in the quality of patents for the pool technology after the pool had formed, possibly as a result of a reduction in duplicative research efforts, but the difference is relatively small.

An analysis of alternative (non-patent) measures of innovation in the movie industry confirms that the creation of a pool discouraged innovation. Until Technicolor

[49] An analysis of color usage by studios that were differentially affected by the 1948 *Paramount* decree, which forced studios to divest from movie theaters, reveals no direct link between the decree and the use of color (*United States v. Paramount Pictures, Inc. et al.,* 334 U.S. 131 (1948), Gil and Lampe 2012).

and Eastman Kodak formed a pool in 1934, both companies had tried to develop the monopack technology, a cheaper and less cumbersome technology to shoot movies in color. After the pool formed created a virtual monopoly for Technicolor three-strip method, R&D investments and progress to improve monopack slowed, and only the most high-budget films, like *Gone with the Wind* and the *Wizard or Oz* could be shot in color. When consent degrees threatened to dissolve the pool, pool members resumed their research to improve the monopack technology and, soon after the pool dissolved, both pool members and outside firms began to offer a variety of high-quality versions of color film, which sped up the switch to producing movies in color.

The analysis also indicates that changes in the intensity of competition are a key mechanism by which a patent pool may discourage innovation. Patent data show that the observed decline in patenting was driven almost entirely by pool technologies for which the pool combined patents by competing firm. By comparison, the data indicate no significant change in patenting for pool technologies in which a single pool member owned all pool patents before the pool had formed.

Archival evidence suggests two main mechanisms by which the creation of a pool may weaken competition and discourage innovation. First, the creation of a pool may increase litigation risks for outside firms, even as it lowers risks for members, because outside firms must now expect to face all pool members jointly as a group in court. This threat is particularly severe if a pool combines patents by a group of dominant firms, and if the pool includes joint defense agreements and dedicated litigation funds. Second, pooling agreements may be accompanied by market sharing agreements, which discourage innovation by eliminating competition among members and by discouraging entry. This threat is particularly severe in the absence of effective regulation.

More generally, findings of a positive link between competition and innovation are consistent with theoretical models which predict that – starting from low levels of competition – shifts towards competition may encourage innovation as they encourage firms to invest in R&D to avoid neck-and-neck competition (Aghion et al. 2001; Aghion et al. 2005). Similar to today, many of the industries that formed patent pools in the

1930s were relatively concentrated. For example, pool members accounted for 75 percent of the market in the dry ice and variable condensers industry, respectively.[50] When patent pools further weaken competition in such industries, the apparent benefits of cooperation (instead of litigation), may be offset by a loss in innovation.

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[50] Market share data for dry ice is from a written complaint by the Department of Justice in 1948 (*United States v. The Liquid Carbonic Corp.* (E.D.N.Y. Civil No. 9179; Complaint, 1948)). Market share data for variable condensers is from *United States v. General Instrument Corp.*, 87 F. Supp. 157 (D.N.J. 1949).

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TABLE I: 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 II: MEAN PATENT APPLICATIONS PER SUBCLASS AND YEAR

	Pre-pool	Post-pool	All years
Raw patents			
Pool subclasses (N=433)	2.54	2.40	2.47
1 pool patent (N=327)	2.27	2.29	2.28
> 1 pool patent & 1 pool firm (N=68)	2.93	2.80	2.87
> 1 pool patent & >1 pool firm (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
Citation-weighted patents			
Pool subclasses (N=433)	9.89	15.12	12.49
1 pool patent (N=327)	9.12	14.91	12.00
> 1 pool patent & 1 pool firm (N=68)	11.19	15.81	13.44
> 1 pool patent & >1 pool firm (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

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. Subclasses *in the same main 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 Hall, Jaffe and Trajtenberg (2001).

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

	Full sample (1)	Full Sample (2)	Full sample (3)	Full sample (4)	Without pool members (5)
Pool * # pool patents	-0.355**		-0.317**	-0.385**	-0.337**
	(0.096)		(0.107)	(0.117)	(0.094)
Pool * any pool patents		-0.403**			
		(0.137)			
Constant	1.975**	1.975**	2.591**	1.975**	1.925**
	(0.073)	(0.072)	(0.102)	(0.072)	(0.071)
Subclass fixed effects	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	-	Yes
Industry*year fixed effects	-	-	Yes	-	-
Linear and quadratic trends	-	-	-	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	35,308
R-squared	0.554	0.551	0.557	0.554	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. *Any pool patents* equals 1 if subclass *c* contains at least one pool patent. 433 pool subclasses include one or more pool patents; 828 cross-reference subclasses, which patent examiners have identified as related technologies, form the control. Bootstrap standard errors reported in column (3).

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

	Full sample (1)	Full Sample (2)	Full sample (3)	Full sample (4)	Without pool members (5)
Pool * # pool patents	-1.415**		-1.124**	-1.030**	-1.417**
	(0.289)		(0.293)	(0.280)	(0.285)
Pool * any pool patents		-2.625**			
		(0.801)			
Constant	6.608**	6.608**	16.978**	6.608**	6.437**
	(0.397)	(0.396)	(0.528)	(0.397)	(0.390)
Subclass fixed effects	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	-	Yes	Yes
Industry*year fixed effects	-	-	Yes	-	-
Linear and quadratic trends	-	-	-	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	35,308
R-squared	0.474	0.474	0.496	0.474	0.474

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. *Any pool patents* equals 1 if subclass *c* contains at least one pool patent. 433 pool subclasses include one or more pool patents; 828 cross-reference subclasses, which patent examiners have identified as related technologies, form the control. Bootstrap standard errors reported in column (3).

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

	Control is cross-reference subclasses in same class as pool subclasses		Conditional fixed-effects Poisson; control is all cross-reference subclasses		Excluding subclasses with many (10 and 12) pool patents from the sample		Excluding pools that formed after NIRA 1935	
	Raw patents (1)	Citation-weighted (2)	Raw patents (3)	Citation-weighted (4)	Raw patents (5)	Citation-weighted (6)	Raw patents (7)	Citation-weighted (8)
Pool * # pool patents	-0.365**	-1.469**	-0.091**	-0.077**	-0.288**	-1.427**	-0.375**	-1.364**
	(0.097)	(0.297)	(0.017)	(0.017)	(0.080)	(0.332)	(0.112)	(0.330)
Constant	1.945**	6.516**			1.964**	6.587**	1.959**	6.825**
	(0.079)	(0.433)			(0.072)	(0.398)	(0.077)	(0.446)
Subclass fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	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	35,308	35,308	35,252	35,252	29,848	29,848
R-squared / Log-likelihood	0.533	0.455	-62,707	-246,691	0.551	0.473	0.562	0.473

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. Columns (7) and (8) 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 VI: EXCLUDING INDIVIDUAL POOLS
OLS – DEPENDENT VARIABLE IS PATENTS PER SUBCLASS AND YEAR

	Cables	Water Cond.	Fuel Inject.	Pharma.	Railroad Springs	Textile Mach.	Oil Pumps
Pool*# pool patents	-0.389**	-0.356**	-0.371**	-0.354**	-0.349**	-0.382**	-0.356**
	-0.107	-0.096	-0.099	-0.096	-0.097	-0.098	-0.096
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	0.551	0.554	0.553	0.553	0.558	0.556	0.554

	Machine Tools	Phillips Screws	Color Cinema.	Dry Ice	Electric Gen.	Lecithin	Variable Cond.
Pool*# pool patents	-0.356**	-0.355**	-0.406**	-0.350**	-0.341**	-0.362**	-0.307**
	-0.096	-0.096	-0.108	-0.099	-0.097	-0.097	-0.108
Constant	1.977**	1.977**	2.092**	1.968**	1.975**	2.051**	1.943**
	-0.073	-0.073	-0.087	-0.075	-0.073	-0.077	-0.074
Subclasses* years	35,084	35,168	27,944	33,012	32,564	32,844	33,852
R-squared	0.553	0.554	0.550	0.549	0.550	0.556	0.554

	Aircraft Instr.	Metal Wheels	Wrinkle Finishes	Fuse Cutouts	Ophth. Frames	Slip Covers
Pool*# pool patents	-0.274**	-0.345**	-0.365**	-0.356**	-0.369**	-0.356**
	-0.075	-0.106	-0.098	-0.096	-0.098	-0.096
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	0.545	0.560	0.555	0.554	0.553	0.553

Including year fixed effects and subclass fixed effects. 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.

TABLE VII: OLS – SUBCLASSES WITH 1 VERSUS MORE POOL MEMBER; DEPENDENT VARIABLE IS PATENTS PER SUBCLASS AND YEAR

	Raw patents		Citation-weighted	
	(1)	(2)	(3)	(4)
Pool * 1 pool patent	-0.235	-0.245	-2.080	-1.918*
	(0.137)	(0.153)	(0.840)	(0.858)
Pool * > 1 pool patent * 1 firm	-0.388	-0.275	-2.694	-1.619
	(0.379)	(0.371)	(1.994)	(1.898)
Pool * > 1 pool patent * > 1 firm	-1.890**	-1.601**	-7.231**	-5.445*
	(0.589)	(0.585)	(2.521)	(2.219)
Constant	1.975**	2.544**	6.608**	17.111**
	(0.073)	(0.106)	(0.397)	(0.769)
Subclass fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	-	Yes	-
Industry*year fixed effects	-	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	0.553	0.580	0.474	0.496

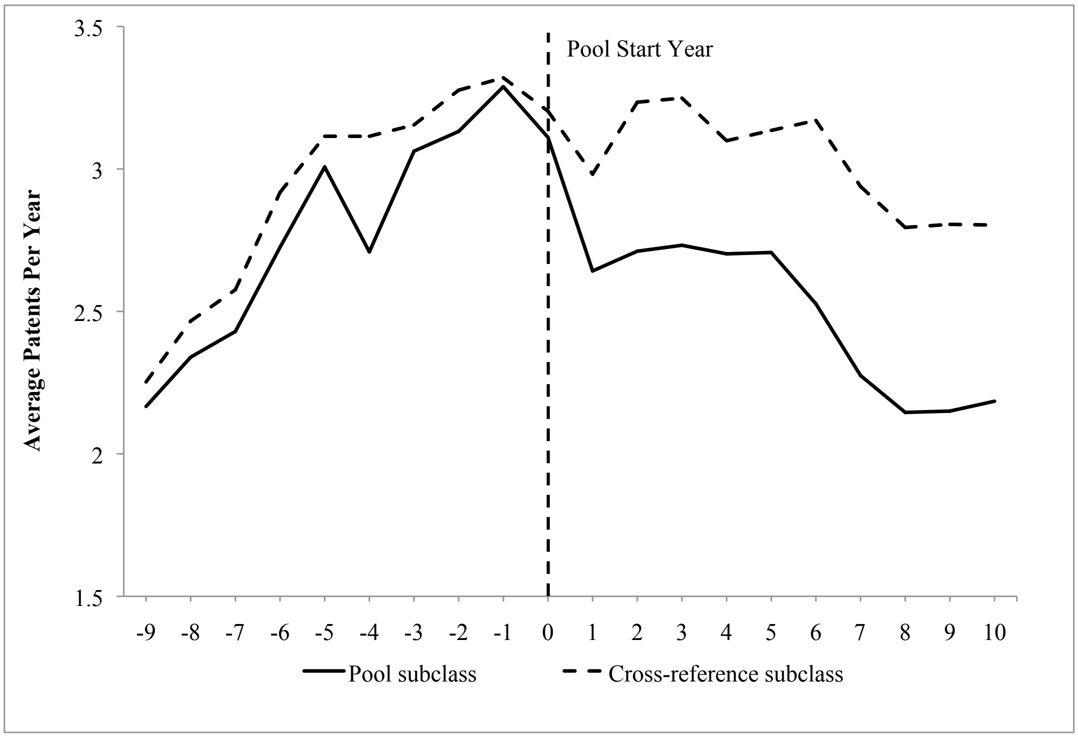
Notes: The dependent variable counts patents per subclass and year. *Citation-weighted patents* are constructed as 1+ # of citations by later patents (following Trajtenberg 1990). *1 pool patent* equals 1 if there was exactly *1 pool patent* that was included in the initial pooling agreement and listed subclass *c* as their primary subclass in subclass *c* (327 subclasses). *>1 pool patent*1 firm* equals 1 if subclass *c* includes more than 1 pool patent owned by a single member firm (68 subclasses). *>1 pool patent*>1 firm* equals 1 if subclass *c* includes patents owned by multiple member firms (38 subclasses). 433 pool subclasses include one or more pool patents; 828 cross-reference subclasses, which patent examiners have identified as related technologies, form the control. Bootstrap standard errors reported in columns (2) and (4).

TABLE VIII: OLS – ALTERNATIVE CONTROL IS SUBCLASSES WITH 1 POOL PATENT
DEPENDENT VARIABLE IS PATENTS PER SUBCLASS AND YEAR

	Raw patents		Citation-weighted	
	(1)	(2)	(3)	(4)
Pool * > 1 pool patent * 1 firm	-0.132	-0.040	-0.531	-0.273
	(0.386)	(0.352)	(2.019)	(2.000)
Pool * > 1 pool patent * > 1 firm	-1.663**	-1.412*	-5.180*	-3.758
	(0.592)	(0.601)	(2.515)	(2.261)
Constant	1.730**	2.269**	5.427**	13.453**
	(0.116)	(0.147)	(0.560)	(0.987)
Subclass fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	-	Yes	-
Industry*year fixed effects	-	Yes	-	Yes
Standard errors clustered at the subclass level; ** significant at 1 percent, * significant at 5 percent.				
N (# subclasses * 28 years)	12,124	12,124	12,124	12,124
R-squared	0.480	0.530	0.405	0.443

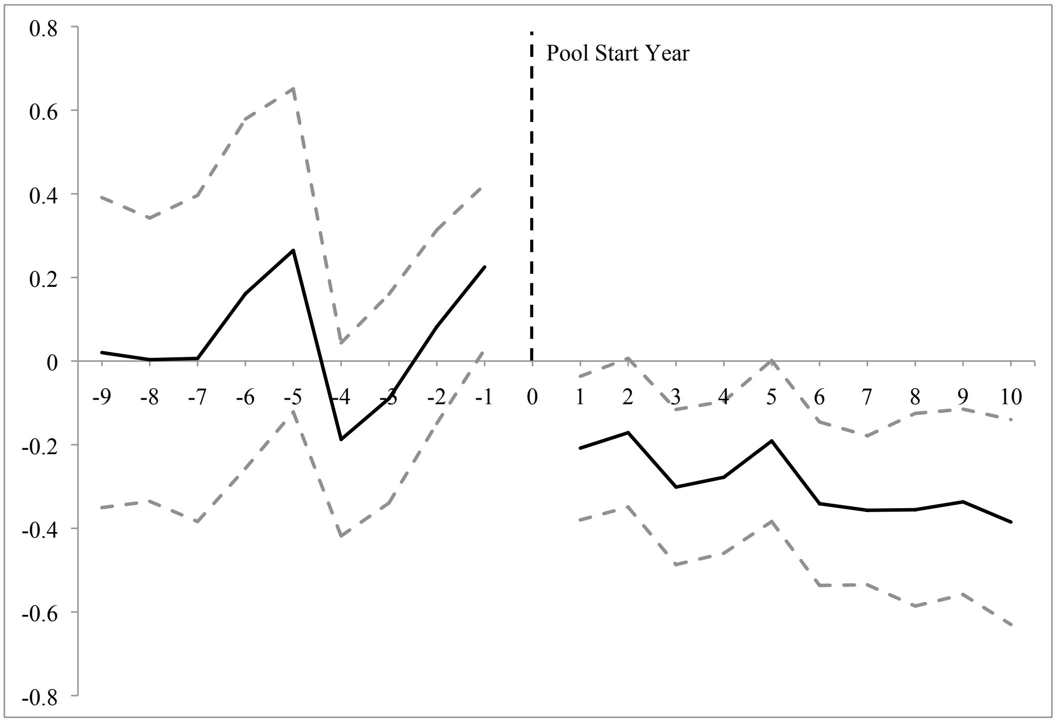
Notes: The dependent variable counts patents per subclass and year. *Citation-weighted patents* are constructed as 1+ # of citations by later patents (following Trajtenberg 1990). Excluded group is subclasses with exactly 1 pool patent. *>1 pool patent*1 firm* equals 1 if subclass *c* includes more than 1 pool patent owned by a single member firm (68 subclasses). *>1 pool patent*>1 firm* equals 1 if subclass *c* includes patents owned by multiple member firms (38 subclasses). 433 pool subclasses include one or more pool patents. 327 subclass with 1 pool patent form the control. Bootstrap standard errors reported in columns (2) and (4).

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



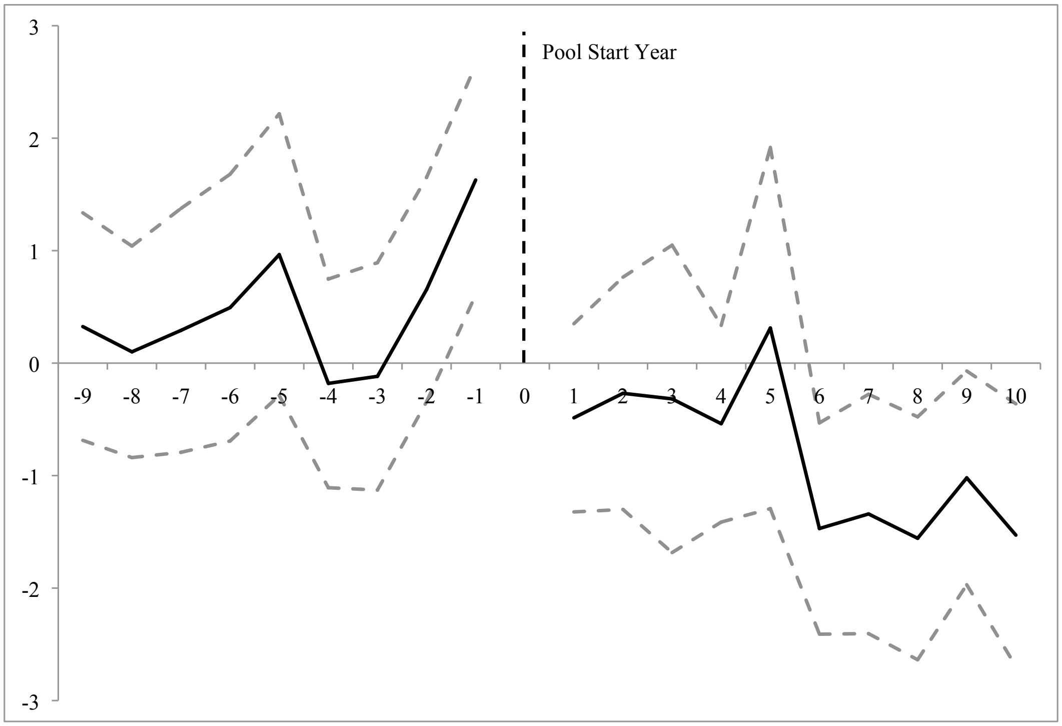
Notes: t=0 denotes the year when a pool forms; the timing of invention is measured at the year of the patent application. Data include patent counts for 433 *pool subclasses* that include at least one pool patent and 828 *cross-reference subclasses* that patent examiners have identified as related technologies.

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



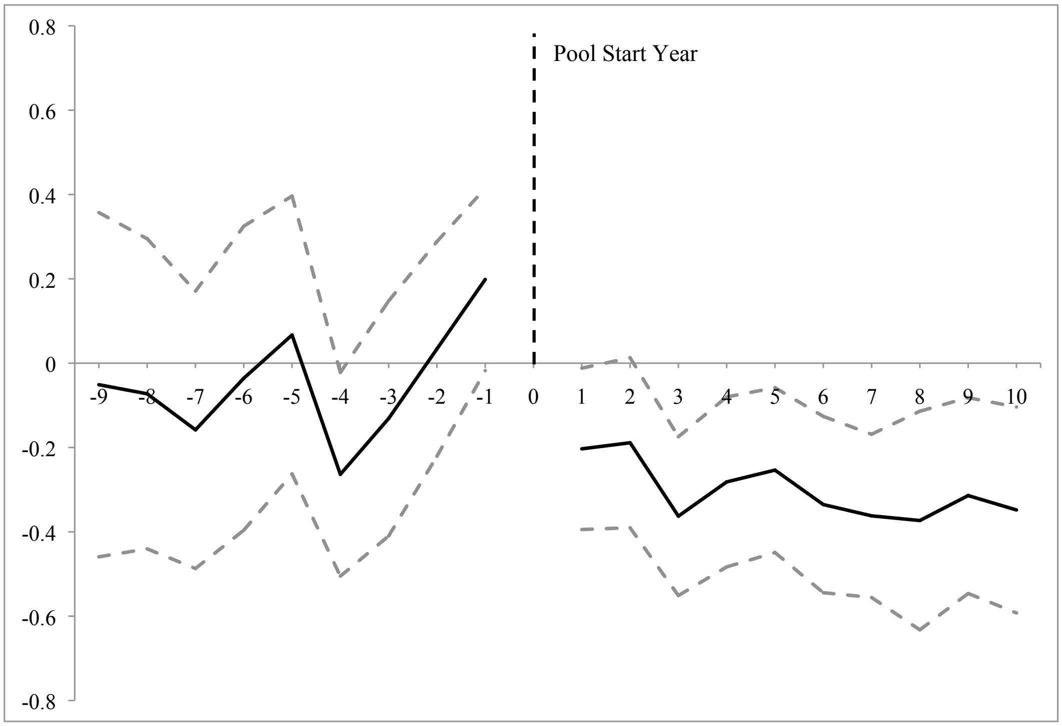
Notes: t=0 denotes the year when a pool forms; the timing of invention is measured at the year of the patent application. Estimates for β_k in the regression $Patents_{ct} = \alpha + \beta_k * pool\ patents_c + f_c + \delta_t + \varepsilon_{ct}$ where k =-17,…,17, 18, counts years before and after a 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 III – ANNUAL COEFFICIENTS, OLS,
DEPENDENT VARIABLE IS CITATIONS-WEIGHTED PATENTS PER SUBCLASS AND YEAR



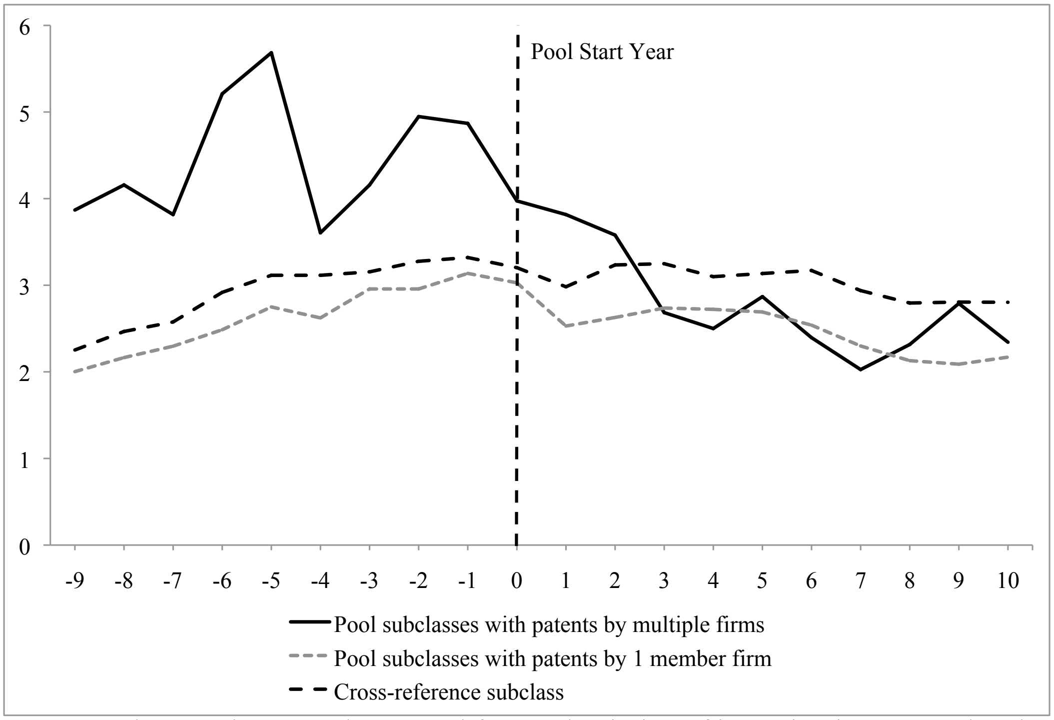
Notes: t=0 denotes the year when a pool forms; the timing of invention is measured at the year of the patent application. Estimates for β_k in the regression $Patents_{ct} = \alpha + \beta_k * pool\ patents_c + f_c + \delta_t + \varepsilon_{ct}$ where k =-17,…,17, 18, counts years before and after a 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. *Citations-weighted patents* are constructed as 1+ # of citations by later patents (following Trajtenberg 1990).

FIGURE IV – ANNUAL COEFFICIENTS, OLS,
DEPENDENT VARIABLE IS PATENTS PER SUBCLASS AND YEAR EXCLUDING POOL SUBCLASSES WITH 10 AND 12 POOL PATENTS



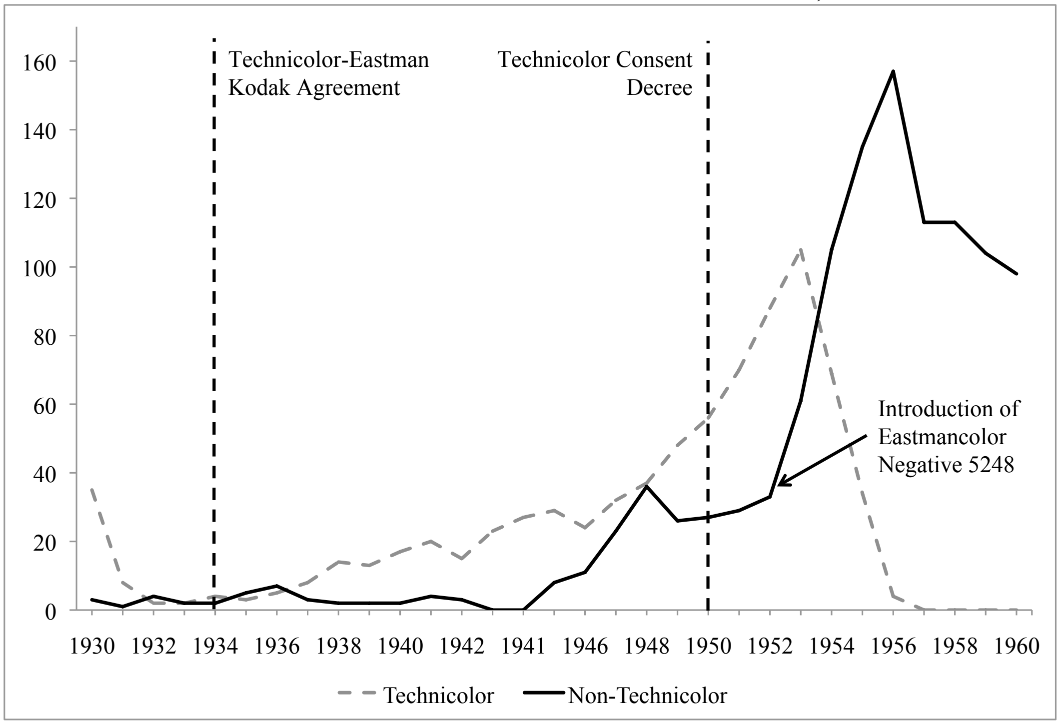
Notes: t=0 denotes the year when a pool forms; the timing of invention is measured at the year of the patent application. Estimates for β_k in the regression $Patents_{ct} = \alpha + \beta_k * pool\ patents_c + f_c + \delta_t + \varepsilon_{ct}$ where k =-17,…,17, 18, counts years before and after a 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. Excludes subclasses exceptionally many patents: aircraft instruments (subclass 261/41.5 with 12 pool patents) and stamped metal wheels (subclass 301/35.59 with 10 pool patents).

FIGURE V – PATENTS PER SUBCLASS AND YEAR:
POOL SUBCLASSES WITH 1 VERSUS >1 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.

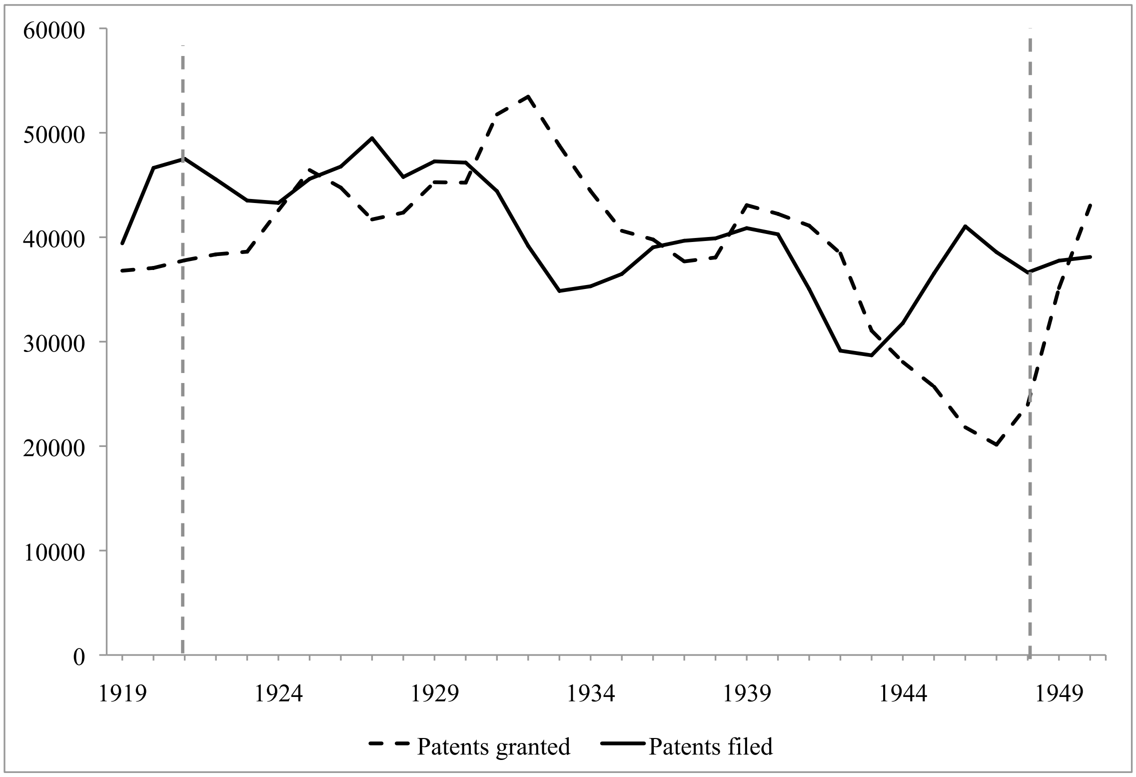
FIGURE VI – RELEASES OF U.S. COLOR MOVIES PER YEAR, 1930-1960



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 1,912 color U.S. movies from the American Film Institute (www.afi.com, accessed on July 9, 2011). Data on color processes from Haines (2003), IMDB (www.imdb.com, accessed January 24, 2013), and Limbacher (1968).

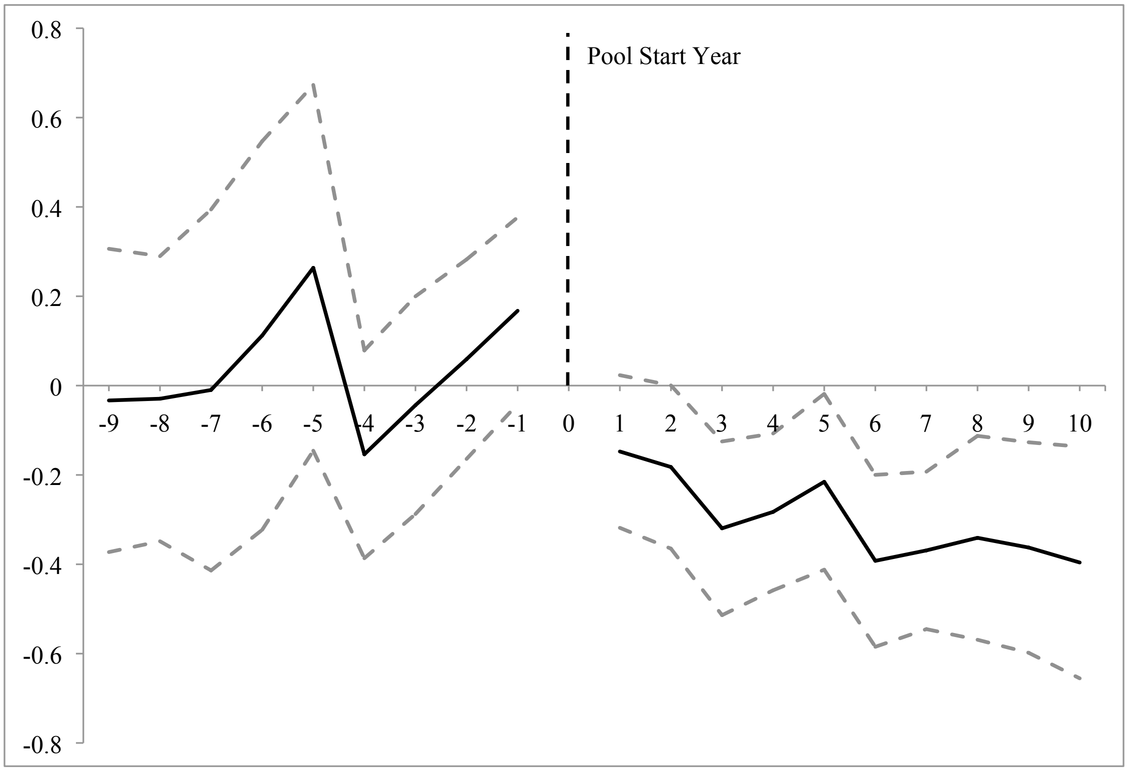
APPENDIX
(NOT FOR PUBLICATION)

FIGURE A.1 – 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 1919 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 A.2 – 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 list subclass c as their primary subclass.