DO PATENT POOLS ENCOURAGE INNOVATION? EVIDENCE FROM 20 U.S. INDUSTRIES UNDER THE NEW DEAL

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Patent pools, which allow firms to combine separately owned patents, are expected to strengthen incentives for R&D by reducing litigation risks and license fees. But pools may also weaken incentives by creating high levels of effective concentration in an industry. This paper takes advantage of a window of regulatory tolerance under the New Deal to examine the effects of pools that would form in the absence of effective antitrust. Difference-in-differences comparisons for pools in 20 industries indicate that pool technologies produced 16 percent fewer patents per year after the formation of a pool compared with a control group of closely related technologies in the same industry. The data also indicate that the decline in patenting was driven by technologies for which the pool combined patents for substitute technologies by competing inventors.

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Patent pools, which allow competing firms to combine (or "pool") their patents, have been proposed as a mechanism to ensure the production of patented inventions in tablet computers, smart phones, video compression technologies, and diagnostic test kits for breast cancer. Pools are expected to strengthen incentives to invest in R&D by reducing litigation risks (Gilbert 2004; Shapiro 2001) and by lowering the costs of licensing when multiple firms own "blocking" patents for complementary technologies (Merges 1999; Shapiro 2001; Gilbert 2004).[1]

Pools may, however, also discourage innovation if they encourage members to free ride on the research investments of other members. For example, Vaughan (1956, p. 67) observes that the 1917 aircraft pool, which resolved blocking patents for airplanes discouraged innovation 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…revolutionary changes in aviation have come from outside the pool - for example, the jet engine from an independent inventor in another country."[2]

Data on patenting and alternative measures of improvements in the performance of sewing machines indicate that the creation of a pool (1856-1877) discouraged innovation by members and other firms (Lampe and Moser 2010), and shifted innovation towards technologically inferior substitutes (Lampe and Moser 2011).

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[1] Specifically, pools may prevent double-marginalization (or "royalty stacking"), which occurs when multiple firms charge license fees for parts of the same technology (Merges 1999; Shapiro 2001, p. 134). Data for the U.S. sewing machine industry confirms this empirically – the sewing machine pool combined nine complementary patents that were required to build a commercially successful sewing machine in 1856. As a result of the creation of this pool, licensing fees increased from $25 before to $5 for members and $15 for non-member licensees after the creation of the pool.

[2] Also see Aoki and Nagaoka (2004) and Lerner, Strojwas, and Tirole (2007, p. 613).

Qualitative evidence indicates an increase in innovation for CDs, but a decline for optical disk drives (Flamm 2012). In open source software, technologies for which IBM contributed patents to the Patent Commons Pool after 2005 experienced a modest increase in entry (Ceccagnoli, Forman, and Wen 2012).

This paper extends existing empirical tests by systematically examining the effects of patent pools across a broad range of industries, and by investigating the mechanism through which unregulated pools may discourage innovation. A systematic analysis of pools in 20 industries indicates that patenting declined by 16 percent after the creation of a pool. This decline was driven by technologies for which the pool members had competed to improve substitute technologies before the pool had formed. Results are robust to controlling for the quality of patents, using a new data set of patent citations since 1921, and to alternative controls for differential changes in patenting across technologies and across industries.

Since the Sherman Act of 1890, antitrust regulation has been in place to prevent anti-competitive practices, making it impossible to observe the effects of patent pools that would form in the absence of effective regulation. After the Great Depression, however, the New Deal program, which was aimed at encouraging economic recovery, created a unique window of regulatory tolerance towards pools. New Deal policies, such as the National Industrial Recovery Act (NIRA, 1933-35) exempted the large majority of U.S. industries from antitrust regulation (Haley 2001, p. 8).[3] Regulators were tolerant of patent pools even if they may have reduced the intensity of competition. In 1931, for example, the U.S. Supreme Court upheld the Standard Oil pool for gasoline cracking even though it controlled 44 percent of the market. Its line of reasoning anticipates arguments for patent pools today:

> "An interchange of patent rights and a division of royalties according to the value attributed by the parties to their respective patent claims are frequently necessary if technical advancement is not to be blocked by threatened litigation" (*Standard Oil Co. of New Jersey v. United States* 283 U.S. 163, 167-168, (1931)).

The regulatory climate became less favorable after 1935, when Congressional hearings began to scrutinize patent pools.[4] On May 27, 1935, the U.S. Supreme Court ruled in *Schechter Poultry Corp. vs. United States* that price and wage-fixing in the poultry industry, which were sanctioned under the NIRA were

[3] By 1934, NRA codes covered over 500 industries, which accounted for nearly 80 percent of private non-agricultural employment. Excluded sectors were steam railroads, nonprofit organizations, domestic services, and professional services (Cole and Ohanian 2004, p. 784). Alchian (1970) conjectures that New Deal policies, which limited competition and increased the bargaining power of unions, kept the economy depressed after 1933. Consistent with this idea, 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. An analysis of 128,953 chemical patents between 1869 and 1938 suggests that some of these advances may have been due to the ability of U.S. firms to produce foreign-owned inventions under the *Trading-with-the-Enemy Act* of 1919 (Moser and Voena 2012). In the context of recovery from the Great Depression, patent pools may have helped to trigger the relative decline in productivity gains after a period of rapid gains in the 1930s. Specifically, our analysis suggests that many of the industries that witnessed the largest gains in productivity in the 1930s - such as railroads, radios, automobiles, and textiles (Field 2011) - experienced a decline in patenting after the creation of a pool.

[4] *Pooling of Patents, Hearings before House Committee on Patents on House Resolution 4523*, Parts I-IV, 74 Cong (February 11 to March 7 1935),

unconstitutional.[5] Regulators, however, continued to tolerate collusion and price fixing in many industries (Hawley 1966).

The Department of Justice began to enforce antitrust regulation more aggressively after March 11, 1938, when President Roosevelt appointed Thurman Arnold to reorganize its Antitrust Division. From 1940 to 1949, Justice bought 38 criminal antitrust cases per year, compared with 8.7 per year between 1930 and 1939 (Posner 1970, p. 376). In 1941, Congressional hearings investigated antitrust violations through cartels and pools.[6] In 1942, the Senate's "Bone Hearings" investigated patents and patent licensing.[7]

The 1942 decision to break up the *Hartford Empire* pool marked a turning point for pools.[8] Having grown to include more than 600 patents, which machinery to produce 94 percent of U.S. glass containers, the Hartford Empire pool had imposed production quotas and prevented licensees from adopting competing technologies. Supreme Court 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…."[9]

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[5] *A.L.A. Schechter Poultry Corp. v. United States*, 295 U.S. 495 (1935).
[6] June 16, 1938 to April 3, 1941, *Investigation of Concentration of Economic Power, Final Report and Recommendations of the Temporary National Economic Committee.* Washington, DC: U.S. G.P.O., March 31, 1941.
[7] *Patents, Hearings before Senate Committee on Patents on Senate Resolutions 2303 and 2491, Parts 1-9*, 77 Cong., 2 sess. (Bone).
[8] *Hartford-Empire Co. v. United States*, 46 F. Supp. 541 (1942), *modified*, 323 U.S. 386 (1945).
[9] *Hartford Empire Co. v. U.S.* 323 U.S. 386, 436-37 (Jan., 1945). In 1942 the Northern District of Ohio found the pool guilty of antitrust violations and ordered royalty-free licensing. The case was appealed to the Supreme Court, which agreed with the district court in 1945, but modified licensing to be at standard royalties Vaughan (1956, pp. 82-83).

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 in 1997 and 1999.[10]

This paper presents a systematic analysis of changes in U.S. patent applications per year for patent pools that formed in 20 industries between 1930 and 1938. Specifically, we compare changes in patent applications per year across technologies that were differentially affected by the creation of a pool. Technologies are defined at the level of United States Patent Office (USPTO) subclasses. Pool subclasses are technologies that include at least one patent that was included in a pool; counts of pool patents in a given pool subclass measure the intensity of exposure to a pool. Cross-reference subclasses, which patent examiners identify as closely related technologies for pool patents, serve as the comparison group.

This basic difference-in-differences regression allows us to control for unobservable factors, such as changes in the speed of patenting over the life-cycle of an industry, which may influence patenting irrespective of the creation of a pool. Examiner-added cross-reference subclasses exhibit similar pre-trends in patenting before the creation of a pool; this helps to address a common concern with difference-in-difference estimates, which is that observed effects may be a reflection of differential pre-trends. Our empirical approach of investigating pools across 20 industries also allows us to measure changes in patenting relative

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[10] 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, p. 14-15).

to a pool-specific year of pool creation, which mitigates bias as a result of an unobservable policy change, such as the variation in spending or work relief programs under the New Deal (e.g., Wright 1974) that may have triggered differential changes in patenting in a given calendar year. Regressions also include subclass and year fixed effects, as well as linear and quadratic time trends at the subclass level, to control for variation in the correspondence between patents and innovations across technologies and over time.

Changes in patenting are measured as patent applications per year between 1921 and 1948 across 1,261 subclasses, including 433 pool subclasses and 828 cross-reference subclasses in the control. These data include a total of 75,396 patents and 322,998 citations to these patents, which we collected from the full text of all U.S. patent grants after 1921. Information on 698 patents that were included in pooling agreements is drawn from primary records on patent pools, which we accessed at regional depositories of the National Archives.

Difference-in-differences regressions of these data imply that subclasses with one additional pool patent experience a 16 percent decline in patenting after the creation of a pool compared with cross-reference subclasses that examiners identify as related technologies.

A potential concern with this difference-in-differences estimate is that the creation of a pool may be an endogenous response to changes in the nature of innovation that precede the creation of a pool. To address this issue, we estimate annual coefficients, allowing estimates for pool technologies to be different from zero before the creation of a pool. Annual coefficients increase after the creation of a pool and become consistently negative and statistically significant six years after the creation of a pool. Results are also robust to the inclusion of interaction terms between year and industry fixed effects, to flexibly control for industry-specific changes in patenting over time irrespective of the creation of a pool.

What are the mechanisms by which patent pools may discourage innovation? Specifically, do patent pools create differential effects on innovation for complementary patents and for substitutes? Complementary patents cover technologies that can be used together to build a new product – such as patents on wings and landing gears for a plane – while substitute patents cover technologies that fulfill the same function – such as two patents for alternative designs of the landing gear. Pools of complementary patents are predicted to improve welfare (e.g., by reducing license fees and overcoming blocking patents, Shapiro 2001 and Gilbert 2004), while pools of substitute patents are predicted to *reduce* welfare (e.g., by increasing license fees, Lerner and Tirole 2004).[11] In practice, however, pools of complementary patents are inherently difficult to separate from pools of substitute patents (e.g., Lerner, Strojwas, and Tirole 2007, p. 619).[12]

[11] Alternative models predicted that pools are welfare-enhancing if a subset of firms is vertically integrated: If upstream firms issue separate licenses or a single license for the bundle of components to downstream firms, vertical integration may lead to lower prices by eliminating double marginalization for firms that are vertically integrated (Kim 2004). Without a pool, vertically integrated firms have an incentive to raise prices enough to eliminate non-integrated downstream firms (e.g. to raise rivals' costs Ordover, Saloner, and Salop 1990, Salop and Scheffman 1983). The existence of a pool allows upstream firms to coordinate their input prices; pool members internalize the impact of higher prices on the demand for other inputs in the pool and on the profits of vertically integrated downstream members.

[12] Exploiting the fact that pools of substitute patents (which allow member firms to avoid Bertrand competition) may be more likely to be subject to antitrust litigation than pools of complementary patents (which avoid n-marginalization and thereby reduce license fees), Lerner, Strojwas, and Tirole (2007) use the existence of litigation as an indicator for pools of substitute patents. The authors, however, caution that litigation may be triggered by other behaviors of pools, such as price-fixing (Lerner, Strojwas, and Tirole 2007, p. 619), and pools that are litigated are more likely

This paper investigates whether a differential impact of pool creation on competition to improve complements and substitute technologies may drive the observed decline in innovation. Specifically, pooling patents for complementary technologies may encourage innovation as a result of spillovers across complementary technologies (as the expected payoffs from improving a part of a technology increases as other pool members improve complementary parts of the technology), while pooling patents for substitute technologies may discourage innovation by reducing competition across firms.

In contrast to previous analyses, we investigate the effects of patent pools at the level of individual technologies *within* industries. Specifically, we take advantage of the USPTO's system of classifying inventions based on the function that they perform to identify technologies for which a pool combines patents for substitutes. Innovation in all subclasses with pool patents may benefit from complementarities with other pool technologies, but only subclasses with more than one pool patent can combine patents for substitutes by competing firms.

This analysis reveals that the decline in patenting is strongest for technologies where the pool combines patents by two or more competing firms. Patenting stays relatively flat for subclasses in which only one pool member was active before the creation of a pool, but declines substantially for subclasses in which a pool combines patents by competing firms.

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to enter Lerner et al.'s (2007) sample as well as ours. Lerner, Strojwas, and Tirole (2007) are able to collect pooling agreements for 63 of 125 pools that formed between 1856 and 2001; 37 of these pools were litigated.

We also investigate whether the decline in patenting may reflect a decline in strategic patenting or in important inventions.[13] To perform this test, we collect citations to the 75,396 patents in our data set by U.S. patents after 1921. This search yields a total of 322,998 citations, which we use to control for the quality of patents. Analyses of citations-weighted patents indicate a slightly smaller increase in invention, suggesting that the creation of a pool may have reduced the need for strategic patenting: Subclasses with an additional pool patent produce eight percent fewer patents after the creation of a pool.

Estimates are robust to alternative specifications, including regressions with a broader set of control technologies that consist of all subclasses in the same main class, as well as conditional fixed-effects Poisson regressions to address the count data characteristics of patents. Excluding patents by pool members leave the estimates essentially unchanged; estimates are also robust to restricting the sample to pools that formed before the NIRA became unconstitutional in 1935, and to dropping individual pools from the sample.

I. DATA

To examine changes in innovation after the creation of a pool, we compare changes in U.S. patent applications per subclass and year in 433 subclasses that included at least one pool patent with 828 cross-reference subclasses without pool

[13] Using hedonic estimates of social value, Trajtenberg (1990) shows that patents for socially valuable improvements in CAT scanners are more heavily cited. Analyzing field trial data for patented inventions in hybrid corn, Moser, Ohmstedt, and Rhode 2011 find that citations are positively correlated with the size of patented improvements in plants, measured as improvements in yields and other characteristics of hybrid corn.

patents that patent examiners identified as related technologies. These data cover a total of 75,396 patent applications between 1921 and 1948, and 322,998 citations to these patents after 1921.

A. Pool Patents in 20 Industries, 1931-1938

In the first step of the data collection, we collected all mentions of patent pools from Vaughan (1956), Gilbert (2004), and Lerner, Tirole, and Strojwas (2007) and searched the records of the National Archives in Chicago, Kansas City, New York, and Riverside for lists of pool patents. Patents numbers are obtained from written complaints (3 pools), consent decrees which required the pools to license their patents to outside firms (13 pools), final judgments (3 pools), and license agreements (4 pools).[14]

Pools cover a broad range of industries (Table 1) including hydraulic pumps for oil wells (1933-52), machine tools (1933-55), Philips screws (1933-49), variable condensers for radios (1934-53), wrinkle finishes, enamels and paints (1937-55), fuse cutouts (1938-48), and furniture slip covers (1938-49).[15]

B. Patent Applications in Pool and Control Technologies

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[14] Courts grant consent decrees in lieu of a decision based on an agreement between the defendant and the Department of Justice; consent decrees typically present the minimum conditions that Justice is willing to accept in lieu of a court decision (Vaughan 1956, p. 47). In comparison with Lerner, Strojwas, and Tirole (2007), our sample includes 8 additional pools between 1930 and 1938 and omits 13 pools that were not included in records of the National Archives. Our sample also exclude a pool for television and radio apparatus because it included no U.S. firms, a pool for male hormones (1937-1941) because it only lasted four years, a pool for railroad joint bars (1928-1944) because it formed before 1930, and the Barber-Colman's Company "pool" for grinding hobs (1931-1943) because it combined two patents by the same firm.

[15] The average pool was active for 16 years. The average pool patent was 4.2 years old when the pool formed, counting from the year of the patent application.

The main specifications compare changes in patent applications per year in 433 pool subclasses with changes in patent applications in 828 cross-reference subclasses as a control. For example, U.S. patent 1,908,080 (issued May 9, 1933) for a "screw" was included in a patent pool for Philips screws (1933-1949). Patent examiners assigned the U.S. patent 1,908,080 to the USPTO class 411 "fastener" the USPTO subclass 411/403 for "externally threaded fastener elements," which we define as a "pool subclass."[16]

Patent counts are an imperfect measure for changes in innovation, because the match between patents and innovation varies across technologies and over time (Moser 2005, 2012) and because the size of patented improvements is far from uniform (e.g., Griliches 1999; Moser, Ohmstedt and Rhode 2011).[17] The systematic classification of patented technologies by the USPTO, however, offers important benefits for empirical analyses of changes in innovation across technologies and over time.

These data extend existing data sets in three important ways. First, they include information on cross-reference subclasses, while existing data sets, such as the NBER data set of patents (Hall, Jaffe, and Trajtenberg 2001) are limited to

[16] Only one subclass (352/225 for color cinematography and aircraft instruments) is listed as a pool subclass for two pools. Four subclasses (340/524 for water conditioning apparatuses, 62/056 for dry ice, 524/594 for wrinkle finishes, and 174/152R for fuel injection equipment) are listed both in the "treatment" and "control." We assign the subclass to the pool that formed first. An additional two subclasses are listed as control technologies for two pools: 417/426 for the fuel injection equipment and aircraft instruments pools, and 200/56R for the high-tension cables and aircraft instruments pools.

[17] The size of patented improvements is typically difficult to measure. Recent patents for biological innovations, however, offer a unique opportunity to measure the size of patented inventions because applicants report the results of field trials on their patent applications. These data indicate that many patents do not constitute significant improvements over prior art (Moser, Ohmstedt, and Rhode 2011).

primary subclasses.[18] Second, our data 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 an automated search of patent grants between 1920 and 1974.[19] This search yields application years for 97.7 percent of 1,069,414 patents issued between 1921 and 1948.[20] With a mean lag between application and grant of 2.7 years and a standard deviation of 1.9 years (Figure 1).[21] Third, we have constructed a new data set of patent citations to the patents in our data set by all patents after 1921. (Citations data are described in subsection D.)

C. Cross-reference Subclasses as a Control

A key benefit of the USPTO's classification system is that patent examiners in the 1930s have assigned pool patents to related technologies in "cross-reference" subclasses, which we can use as a control group for pool technologies. Each pool patent is assigned to one primary (pool) subclass, which covers the key

[18] Benner and Waldfogel's (2008) analysis of 118,350 patents by 64 firms in the photographic industry between 1980 and 2002 suggests that incorporating information on cross-reference subclasses improves the measurement of firms' locations in technology space, especially for firms with few patents that cover a narrow range of technologies.
[19] 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.
[20] In a random sample of 300 patents, application years were correctly recorded for 296 patents.
[21] 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).

technology areas of each pool patent.[22] For example, U.S. patent 1,908,080 for the (Phillips) "screw" falls into primary subclass 411/403 ("externally threaded fastener element") within the main class 411 ("expanded…locked-threaded fastener"). In addition to the primary subclass, the patent examiner may also assign a patent to one or more secondary, cross-reference subclasses. For example, U.S. patent 1,908,080 for the Phillips screw is assigned to 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"), and 16/DIG.39 ("miscellaneous hardware-adjustment means").

In the main specifications, cross-reference subclasses form the control for the pool subclass 411/403.[23] The average pool patent is assigned to 2.0 cross-reference subclasses in addition to its primary class.[24] Alternative specifications with a more narrow control limit the control to cross-subclasses within the same main class (e.g., 411/919); alternative specifications with a broader control expand the control group to include all other subclasses in the main class 411 "fasteners."

Pool and cross-reference subclasses exhibit comparable time trends in

[22] The Patent Office calls these technology areas "claims" which "define the invention and are what aspects are legally enforceable" (http://www.uspto.gov/main/glossary). The primary (or "original") subclass classification is the subclass "which receives the most intensive claimed disclosure, and in which the patent is indexed in the official classification indexes" (USPTO 1915, p. 21). Cross-reference subclasses cover related aspects of the invention. For example, if "a patent discloses an internal combustion engine associated with a specific form of carburetor [and] the claims relate to the engine parts only [then] the class of Internal-Combustion Engines should receive the patent, and a cross-reference should be placed in Carburetors" (USPTO 1915, p. 32).
[23] Patents that cannot be assigned to a unique subclass are assigned to class-specific digest subclasses, which we drop from the data; 15 digest subclasses are listed on pool patents.
[24] The average patent pool covers 21.7 primary subclasses and 41.4 cross-reference subclasses.

patent applications before the creation of a pool (Figure 2). Both pool and cross-reference subclasses produce more patents compared with other technologies before a pool forms, with 2.54 and 2.70 patents per year, respectively, compared with 1.00 for other subclasses in the same class (Table 2). Consistent with the idea of a patent race (e.g., Dequiedt and Versaevel 2007), patent application peak in year *t*-1 before the creation of a pool.

After a pools form, pool subclasses produce fewer patents, both in absolute terms and relative to cross-reference technologies (Figure 2). Patenting in pool subclasses declines from 2.54 to 2.40 patents per year, while patenting in cross-reference subclasses increases from 2.70 to 2.94, and patenting in other subclasses in the same main class increases from 1.00 to 1.11.

Although patenting increases on average for cross-reference technologies, comparisons of patent applications over time suggest that cross-reference subclasses experience a (substantially smaller) decline in patent applications six to ten years after the creation of a pool. This is consistent with spillovers from narrowly defined USPTO subclasses of pool technologies to the control group of related technologies in USPTO cross-reference subclasses, which will attenuate the estimates.

D. Patents in the same Subclass as a Proxy for Substitutes

Another advantage of the USPTO data is that its system of classifying inventions by their function offers a straightforward way – and to the best of our knowledge thus far un-exploited – mechanism to identify substitutes. For example, the wrinkle finishes pool combined U.S. patent 2,077,112 for "imitation leather paper" by Kay and Ess with U.S. Patent 1,689,892 for "wrinkle finishes" by the Chadeloid Chemical Company. Patent examiners assigned both patents to the primary subclass 427/257 for 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." A total of 106 subclasses include two or more pool patents, 53 pool of the 433 pool subclasses in our sample (12 percent) include 2 pool patents, and another 53 pool subclasses (12 percent) include more than 2 pool patents.[25]

This allows us to investigate the differential effect of a pool on technologies for which a pool combined patents for substitute technologies by more than one firm. Eleven of 53 subclasses with 2 pool patents (21 percent) include pool patents by more than 1 firm; 27 of 53 subclasses with more than 2 pool patents (51 percent) include pool patents by more than 1 firm.[26]

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

A potential shortcoming with patent counts as a measure of innovation is the substantial variation in the quality of patents (e.g., Griliches 1990, p. 1669). Most importantly for the current analysis, firms may patent low quality inventions

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[25] Two pool subclasses, for aircraft instruments, and stamped metal wheels include 10 and 12 pool patents, respectively. We drop these pool patents from our sample in a robustness check below.

[26] To collect firm-level data, we identify pool members from license agreements, written complaints, and final judgments at the National Archives and match pool members to patent owners and assignees in patent documents. The Patent Office refers to owners who are not the original inventors as assignees. Beginning in the early 20th century, "employers increasingly required that all employees who were likely to invent sign agreements to assign to the employer any inventions they might make" (Fisk 1998, p. 1185).

to protect themselves from litigation (Hall and Ziedonis 2001). To address this issue, we collect citations to the patents in our data set and construct citations-weighted patent counts to control for the quality of patents.

Citations have emerged as the standard measure for the quality of patents. Trajtenberg (1990) shows that citations-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) – are correlated with the estimated surplus of improvements in computed tomography (CT) scanners.[27] Hall, Jaffe, and Trajtenberg (2005) establish a positive correlation between the ratio of citations to patents owned by a firm and that firm's stock market value, and Moser, Ohmstedt and Rhode (2011) find that counts of citations are positively correlated with the size of patented improvements in biological innovations. Citations are checked by examiners who eliminate false citations and add relevant citations that patentees may have missed or strategically withheld (Lampe 2012).[28]

We collect citations from patent grants between January 4, 1921 and December 31, 1974 by searching the full text of patent documents for mentions of the unique 75,396 patent numbers in our data. Until February 4, 1947, USPTO patent grants recorded citations anywhere in the text of the patent document; we

[27] Trajtenberg (1990) counts citations from patents in the same field (CT scanners) only. Since we are also interested in value derived from spillovers to other technological areas, we include citations from patents in outside fields as well. Our results are robust to alternative weighting schemes that (1) scale by the expected number of citations to patents issued in the same year, and (2) remove patents that were not cited.

[28] For U.S. patent grants between January 2001 and December 2002, patent examiners added between 21 and 32 percent of relevant citations that inventors missed or withheld for strategic reasons (Lampe 2012).

search the full text of patent documents to extract these citations. After February 4, 1947, USPTO patents listed citations in separate sections at the beginning or at the end of patent documents; we extract citations directly from these sections.[29] This yields a total of 238,874 citations from patents between January 4, 1921 and December 31, 1974. To these data, we add 84,124 citations by patent grants between January 7, 1975 and December 31, 2002 from the NBER data (Hall, Jaffe, and Trajtenberg 2001).

In sum, a total of 61,694 patents (82 percent) are cited by at least one patent between 1921 and 2002. The average patent with at least one citation was cited 5.2 times.[30]

II. Results

Descriptive statistics indicate a decline in patenting after the creation of a pool, both in absolute terms and relative to the control. The average pool subclass produces 2.54 patents per year before a pool formed and 2.40 patents per year afterwards (Table 2). In comparison, cross-reference subclasses produce 2.70 patents per year before a pool formed and 2.94 afterwards. Restricting the sample to patent applications within 10 years of the creation of a pool strengthens this

[29] 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 data 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) mechanism.

[30] In comparison, 2,034,737 patent grants between 1975 and 2002 in the NBER patent data set were cited at least once; conditional on being cited, the average patent was cited 7.70 times. Nicholas (2010, p. 63) finds that 68.2 percent of 4,524 randomly chosen patents grants in 1930 are cited in patent grants between 1947 and 2008. Linking patents to citations with a long lag may however miss many important citations. Thus, an analysis of patent citations in the NBER data set indicates that citation peak one year after the grant (Mehta, Rysman, and Simcoe 2010).

difference. Within a 20-year window, the average pool subclass produces 2.80 patents per year before a pool formed and 2.48 afterwards; in comparison, cross-reference subclasses produce 2.94 patents per year before a pool formed and 3.02 afterwards (Figure 2).

A. Baseline estimates

Difference-in-difference regressions take advantage of variation in the number of pool patents per subclass and year to investigate the effects of a pool. Baseline estimates compare changes in patents per subclass and year in pool subclasses that include an additional pool patent with changes in cross-reference subclasses, controlling for subclass and year fixed effects, as well as subclass-specific linear and quadratic time trends:

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

where *pool patents*$_c$ counts the number of pool patents that list subclass c as their primary subclass, and $pool_{ct}$ equals 1 for subclasses with pool patents for all years after the creation of a pool.[31] The variable *pool subclass*$_c$ equals 1 for subclasses that include one or more pool patents. Cross-reference subclasses listed on pool patents form the control. For example, *pool subclass*$_c$ equals 1 for the Philips

[31] Seven subclasses include patents from more than one pool; to measure the timing of the pool in these subclasses, we use the start year for the first pool. 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 been dissolved. We include these years as pool years to estimate the pool effects in the most conservative way.

screw pool subclass 411/403; cross-reference subclasses 411/919, 470/60, and 470/9 form the control.[32]

Under the assumption that changes in patents 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 a pool. 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 changes in patents per year across pool and cross-reference subclasses that are independent of the creation of a pool.

OLS estimates indicate that subclasses with one additional pool patent produce 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 implies a 15.79 percent decline in invention after the creation of a pool.

Results are robust to including interaction terms between year fixed effects and indicator variables for each of the 20 industries. These regressions flexibly control for differential changes in patenting across industries and over time, which may, for example, result from differences in the maturity of pool technologies across industries. In regressions with year-industry interactions, the estimated coefficient is -0.36, which implies a 14.57 percent decline in patents per year (significant at 1 percent, Table 3, column 3).

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[32] The screw patent is also assigned to a "digest" subclass" (16/DIG.39), which we exclude from the sample along with 14 other digest subclasses. Digest subclasses cover technologies based on "a concept which relates to a class but not to any particular subclass of that class" (http://www.uspto.gov/web/offices/ac/ido/oeip/taf/c_index/explan.htm).

Alternative specifications estimate coefficients separately for each year, allowing the estimated effects of additional *pool patents* to be different from zero *before* the creation of a pool:

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

where k =-17,-16….17, 18, counts years before and after a pool forms, and k=0 forms the excluded time period. This approach makes it possible to investigate differential changes in patenting before a pool, which would violate the identifying assumption of the baseline estimates. Most importantly, firms may be more likely to create pools as a means to mitigate competition after the rate of technical progress in an industry has declined; then the timing of the pool creation may be an endogenous response to a decline in innovation.

Annual coefficients indicate that, for the average pool across 20 industries, patenting declined in response to the creation of a pool, rather than the opposite. In the pre-pool period estimates are not statistically significant in any year except *t*-1. In year *t*-1 estimates imply a 9.31 percent increase in patent applications. This spike in patenting immediately before the creation of a pool is consistent with the idea of a potentially wasteful race to patent the pool technology (e.g. Dequiedt and Versaevel 2007), as well as the idea that pools form in response to an increase in the threat of litigation, which encourages socially wasteful strategic patenting (Loury 1979; Hall and Ziedonis 2001).[33] We examine these issues below by estimating changes in citations-weighted patents.

Most importantly, however, annual coefficients imply a decline in patenting after the creation of a pool that intensifies over time and becomes consistently significant six years after the creation of the pool. Annual coefficients range from -0.17 to -0.30 with an average -0.23, implying a decline of 9.31 percent for the first five years, and from -0.34 to -0.69 with an average of -0.43 implying a decline of 17.41 percent for years six and above (significant at the 5 percent level in years one, three, four and all years above five, Figure 3).[34]

Regressions with industry-year interactions indicate that changes over time cannot be explained by differential changes in patent applications across industries over time. Annual coefficients are not statistically significantly different from zero before the creation of a pool, and become statistically significant with an estimate of -0.32 at the 5 percent level in year 3 (Figure 4). Estimates remain significant through the end of the sample, with an estimate of -0.40 in year 10.

[33] Loury's (1979) model of investment in R&D under technological and market uncertainty (about the date when a rival will introduce the technology) implies that, in any market structure, more firms enter the industry than is socially optimal because individual firms do not take account of the parallel nature of their efforts. Hall and Ziedonis (2001) find that in a sample of 95 publicly traded semiconductor firms, those 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.

[34] These results are consistent with a relatively long lag between research decisions and patenting. Sanders' (1962, p. 71) *Patent Use Survey* of a random 2 percent sample of U.S. patents issued in 1938, 1948 and 1952 (with 600 in 1,220) suggests that the average patent application occurred nine months after firms incurred research expenses for related products. Hall, Griliches, and Hausman (1986), however, find that the correlation between patents and research expenditures is strongest for contemporaneous expenditures: OLS regressions of patent applications for 642 U.S. firms between 1972 and 1979 on current R&D and lagged R&D expenditure yield significant estimates only for contemporaneous R&D.

B. Controlling for Patent Quality through Citations-weighting

Even though patent data suggest that the creation of a pool discourages innovation, observed declines in patenting may reflect declines in the share of innovations that are patented rather than a decline in innovation.[35] To mitigate this concern, all estimates include subclass and year fixed effects along with subclass-specific linear and quadratic trends. Neither fixed effects nor time trends can, however, control for changes in strategic patenting as a result of a pool. For example, the creation of a pool may reduce the number of patents per innovation, by reducing the need for strategic patenting (Merges 1999; Shapiro 2002).

To explore this effect we repeat the main specifications controlling for the quality of patents by constructing citations-weighted patents (Trajtenberg 1990):

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

Controls for linear and quadratic trends are particularly important in this analysis because patents that are more recent are more likely to be cited (Hall, Jaffe, and Trajtenberg 2001) and because the majority of citations in this sample originate from patent grants after 1947. Citations-weighted patents, however, increase less in pool subclasses compared with cross-reference subclasses. The average pool subclass produces 9.89 citations-weighted patents per year before a pool has formed and 15.12 citations-weighted patents per year afterwards. In

[35] In 19-century data, the share of innovations that are patented varies between 5 and 45 percent across industries (Moser 2012), and increases with declines in the effectiveness of secrecy, as an alternative mechanism to protect intellectual property. Late 20th century surveys indicate that the need for strategic patenting is a key determinant of the patenting decisions of U.S. firms (Levin et al. 1987; Cohen, Nelson, and Walsh 2000).

comparison, cross-reference subclasses produce 11.61 patents per year before a pool has formed and 19.40 afterwards (Table 2).

Difference-in-differences estimates confirm that the creation of a pool reduced patenting, even when controlling for the quality of patents. Estimates with citations-weighted patents are, however, slightly smaller, suggesting that the creation of a pool may in fact reduce the need for strategic patenting. Subclasses with an additional pool patent produce 1.03 fewer citations-weighted patents after a pool has formed (significant at 1 percent, Table 4, column 2), implying an 8.25 percent decline in citations-weighted patents after the creation of a pool.

Regressions with industry-year interactions for each of the 20 industries yield only slightly smaller estimates. Controlling for industry-year interactions, subclasses with an additional pool patent produce 0.87 fewer patents per year after the creation of a pool, implying a 6.97 percent decline in citations-weighted patents (significant at 5 percent, Table 4, column 3).[36]

C. Subclasses in which Pools Combine Patents by Competing Firms

How may patent pools discourage innovation? Theoretical predictions about the effects of patent pools on innovation are ambiguous. Complementarities across pool patents encourage innovation, as pools combine blocking patents and lower litigation risks for members, and reduce license fees

[36] Citations-weighted estimates also confirm that the decline in patenting intensifies over time. In the first five years after a pool forms, annual coefficients range from 0.31 to -0.54 with an average of -0.26, implying a decline of 2.08 percent (not statistically significant). In years six and above, annual coefficients range from -1.02 to -2.9, with an average of -1.66 implying a decline of 13.29 percent (significant at the 5 percent level).

and transaction costs for other firms (e.g., Shapiro 2001, Lerner and Tirole 2004). Reduced competition among pool members that improve substitute technologies may, however, also discourage innovation.[37]

Empirically, variation in the number of pool patents (and in the number of pool members) across subclasses allows us to separate these effects. In subclasses with one single pool patent, the pool technology benefits from complementarities with other pool technologies, which may increase incentives to invent (e.g., Shapiro 2001, Lerner and Tirole 2004). In the current data set, 327 of 433 pool subclasses include only one pool patent. In subclasses with two or more patents, the pool technology benefits from complementarities with other pool technologies, but it also potentially affected by a decline in the intensity of competition, which, at low levels of competition, may discourage innovation. In the current data set, 106 subclasses include more than one pool patent; 38 of these subclasses include patents by more than one firm; 53 subclasses include more than two pool patents, 27 of these subclasses include patents by more than one firm.

Descriptive statistics indicate that pool subclasses with pool patents by more than one firm drive the observed decline in patenting. In subclasses with 1 or 2 pool patents invention rises slightly from 2.27 patents per year before the pool

[37] Specifically, patent pools that combine intellectual property rights by several firms may reduce competition at a low level of competition where increases in competition would increase incentives to invest in R&D to avoid neck-and-neck competition (Aghion, Howitt, Harris, and Vickers 2001). Empirically, Acs and Audretsch (1999) establish a negative correlation between concentration and innovation for 8,074 U.S. manufacturing innovations introduced in 1982 that were identified from engineering and trade generals, while Aghion, Bloom, Blundell, Griffith, and Howitt 2005 (2005) establish an inverted-U shape relationship in U.K. patents issued to 311 firms between 1973 and 1994.

forms to 2.29 afterwards and from 2.52 to 2.61, respectively. In subclasses with more than 2 pool patents, however, patenting declines from 4.23 to 2.84 patents (Table 2).

Summary statistics also indicate that the decline in patenting is strongest in subclasses where a pool combined patents for substitute technologies by competing firms. In subclasses with two or more firms, invention declines from an average of 4.43 per year in the ten years preceding the creation of a pool to 2.73 patents per year in the ten years after the creation of a pool (Figure 5). In comparison, subclasses in which only one pool member was an active inventor before the creation of the pool experience a much weaker decline, from 2.64 to 2.45.

Difference-in-differences regressions with interactions for variation in the number of pool patents estimate these differential decline in patenting for subclasses with pool patents by more than one firm:

$$(3)\ Patents_{ct} = \alpha + \beta_1\, pool_{ct} * 1\ pool\ patent_c + \beta_2\, pool_{ct} * 2\ pool\ patents_c + \beta_3\, pool_{ct} * more\ than\ 2\ pool\ patents_c + \beta_4\, t * pool\ subclass_c + \beta_5\, t^2 * pool\ subclass_c + f_c + \delta_t + \varepsilon_{ct}$$

where $1\ pool\ patent_c$ indicates subclasses with one pool, $2\ pool\ patents_c$ indicates subclasses with two pool patents, and $more\ than\ pool\ patents_c$ indicates subclasses with more than two pool patents.

OLS estimates confirm that the decline in patenting is significantly stronger in subclasses where a pool may combine patents by competing firms. Interactions for subclasses with more than 2 pool patents imply a decline of 1.60 patents per year after the creation of a pool (significant at 1 percent, Table 5, column 1), while interactions for subclasses with fewer than two pool patents are small and not statistically significant (with -0.10 and 0.02, respectively)

OLS estimates also indicate that each additional pool patent in subclasses with two or more pool members is associated with 0.44 fewer patents (significant at 1 percent, Table 5, column 3), implying a 13.02 percent decline relative to mean of 3.38 patents per year in pool subclasses with two or more pool members. By comparison, each pool patent in subclasses with only pool member is associated with 0.30 fewer patents (not statistically significant, Table 5, column 3).

Citations-weighted counts also confirm that the decline in patenting is strongest for subclasses where the pool combines patents by competing firms.[38] Subclasses, in which pool patents were owned by more than one member before the creation of the pool, produce 1.37 fewer citation-weighted patents after the creation of a pool (significant at 1 percent, Table 5, column 6), implying a decline of 9.15 percent relative to mean of 14.98 patents per year in pool subclasses with two or more pool members. By comparison, subclasses in which pool patents were owned by a single member before the creation of the pool, produce 0.49 fewer citation-weighted patents (not significant, Table 5, column 6).

[38] In absolute terms, citations-weighted patents increase for all types of subclasses, but substantially less for subclasses with more than 2 pool patents. In subclasses with 1 pool patent, citations-weighted patents increase from 9.12 per year before the creation of a pool to 14.91 afterwards; in subclasses with 2 pool patents, citations-weighted patents increase from 10.15 per year before to 15.78 afterwards (Table 2). In subclasses with more than 2 pool patents – which combine patents by competing firms in 51 percent of all cases - this increase is significantly smaller, with 14.40 per year before the creation of a pool to 15.75 afterwards.

D. Robustness checks

A series of robustness checks estimates the main specifications with alternative definitions of the control group, without pool patents, as Poisson regressions, excluding pools that formed after NIRA was ruled unconstitutional, and excluding individual pools.

The first robustness check further strengthens similarities between pool classes and the control by restricting the control to cross-reference subclasses in the same main class.[39] In this test, the control consists of 631 cross-reference classes in the same 108 main classes that also include one of 433 pool subclasses. Compared with cross-reference subclasses in the same main class, pool subclasses with an additional pool patent produce 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).

A second robustness check expands the control to include all 69,316 subclasses without pool patents in 108 main classes that include a pool patent and 61 additional main classes that examiners identified as cross-reference classes.[40] Compared with all subclasses without pool or cross-reference patents, pool subclasses produce 0.41 fewer patents for each additional pool patent per year after the creation of a pool, implying a decline of 16.60 percent, and 0.89 fewer

[39] For example, we restrict the control for subclass 411/403, which covers the Phillips screw, to subclass 411/919 in the same main class (411, "fasteners").
[40] 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 with pool patents and subclasses that are cited as a secondary (cross-reference) subclass for at least one pool patent are included in the sample.

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

A third robustness test excludes all 2,182 patents by pool members from the sample; this test checks whether the estimated decline may be driven by a decline in the need for strategic patenting by pool members. Excluding patents by pool members leaves our estimates substantially unchanged. Pool subclasses with an additional pool patent produced -0.36 fewer patents per year after the creation of a pool, implying a 15.45 percent decline, and 1.02 fewer citation-weighted patents, implying a 8.61 percent decline (significant at 1 percent, Table 6, columns 5 and 6).

We also repeat the main specifications as conditional fixed-effects Poisson regressions (to control for the count data characteristics of patents with standard errors that are robust to serial correlation across subclasses).[41] These estimates imply that subclasses with one additional pool patent produce 8.42 percent fewer raw patents and 7.22 percent fewer citation-weighted patents after the creation of a pool (significant at 1 percent, Table 7, columns 1 and 2).[42]

An additional robustness check excludes two subclasses with a large number of pool patents from the sample. With 12 pool patents by the French Société du Carbureteur Zenith, USPTO subclass 261/41.5 for gas and liquid contact aircraft instruments includes the largest number of pool patents. Before

[41] Robust standard errors are estimated using Tim Simcoe's STATA command *xtpqml,* which implements Woolridge's (1999, p. 83) estimate of the asymptotic variance for the fixed effects Poisson model; Wooldridge's estimator is robust to serial correlation across subclasses.
[42] Percentage changes are calculated from the coefficients as exp(-0.088)-1=-0.09 and exp(-0.075)-1=-0.07, respectively.

the pool formed, this subclass produced 21.7 patents per year, including patents by pool members and other firms. After the pool had formed, patenting declined to 8.4 patents per year. With 10 patents by the pool's three members, Kelsey-Hayes Wheel Company, The Budd Company, and Motor Wheel Corporation, USPTO subclass 301/35.59 for stamped metal wheels includes the second largest number of pool patents.[43] This subclass produced an average of 3.8 patents per year between 1927 and 1936, and no patents after the pool had formed in 1937.

Results are robust to dropping these subclasses from the sample. Estimates with the restricted sample imply 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 3 and 4).

Estimated effects are also robust to restricting the data set to pools that formed before the U.S. Supreme Court declared the NIRA to be unconstitutional on May 27, 1935. Pool subclasses with an additional pool patent produced 0.31 fewer patents per year after the creation of a pool, implying a 13.54 percent decline, and 0.92 fewer citation-weighted patents, implying a 8.18 percent decline (significant at 1 percent, Table 7, columns 5 and 6).[44]

A final robustness check estimates 20 separate regressions, excluding one of the 20 industries in each regression, to check whether the decline in patenting

[43] The full name for class 261/41.5 is Gas and liquid contact apparatus: fluid distribution: valved: multiple jet: progressive: bypass opening beyond throttle. The full name for class 301/35.59 is Land vehicles: wheels and axles: wheel: detachable wheel section: spoke formations bolted to hub.
[44] In alternative specifications that extend the main specification to include an interaction between *Pool*Pool Patents* and a dummy variable for pools forming after NIRA was ruled unconstitutional the estimate for the interaction is -0.15, with a standard error of 0.46. The estimate for the coefficient on *Pool*Pool Patents* remains (at -0.32, significant at 1 percent, not reported).

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* (Table 8, significant at 1 percent). Estimates also remain large and statistically significant when other pools are excluded from the sample. Excluding aircraft instruments has the largest effect on the size of the estimates, but it leaves estimated effects at -0.31, implying a 13.84 percent decline in that sample (compared with an average of 2.24 patents per year across all pool subclasses in this sample, significant at 1 percent, Table 8). Excluding variable condensers has the second largest effect; it reduces the size of the estimated decline to -0.34, implying a 13.71 percent decline in invention, compared with an average of 2.48 patents per year across all pool subclasses in this sample (significant at 5 percent, Table 8).

Archival records indicate that the aircraft instruments pool (1935-1940) may have weakened incentives to innovate by weakening competition between the American pool member, Bendix Aviation and foreign producers. For example, a January 31, 1935 pooling agreement between Bendix and four firms from Switzerland, the United Kingdom, France and Italy stipulated that Bendix would not sell carburetors in Europe, and that, in return, the European firms and their associates would not sell carburetors in the United States and Canada.[45] By 1940, the pool had expanded these agreements to include 17 foreign producers.

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[45] *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).

For variable condensers, historical records suggest that the pool (1934-1953) discouraged innovation by intensifying concentration and litigation risks for outside firms. When it formed, the pool combined three firms that jointly produced more than 75 percent of all variable condensers in the United States. Their agreement included a joint defense provision, which allowed members to use any pool patent to defend themselves from litigation, and a litigation fund of $9,000, roughly $150,000 dollars in 2011.[46]

E. Grant-back rules, licensing, and litigation

Existing literature on patent pools has focused on the determinants of pool characteristics (e.g. Lerner, Strojwas, and Tirole 2007; Lerner and Layne-Farrar 2011). Of these characteristics, the presence of grant-back rules – which require pool members to offer any new patents to the pool – is most closely related to predictions about the effects of patent pools on innovation. Ex ante, the predicted effects of grant-back rules on innovation are ambiguous. Grant-back rules may encourage innovation by preventing opportunistic pool members from withholding relevant patents. But by requiring pool members to offer future patents to the pool, grant-back rules also reduce individual firms' payoffs from R&D and may encourages members to free-ride on the investments of others (Aoki and Nagaoka 2004; Lerner, Tirole, and Strojwas 2007, p. 613). For

[46] 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).

example, the Department of Justice and Federal Trade Commission (1995, §5.6) cautioned that

> "Grantbacks may adversely affect competition, however, if they substantially reduce the licensee's incentives to engage in research and development and thereby limit rivalry in innovation markets."

Sixteen of 20 pools in our sample included grant-back rules. In regressions that include an interaction term between *pool*pool patents* and an indicator variable for the four pools without grant back rules, the coefficients for *pool*pool patent* and *pool*pool patents* no grant-backs* are -0.42 and 0.42 (Table 9, column 1, significant at 1 percent). Although there is not enough variation in our sample to provide the definite test, these results suggest that grant-back provisions may discourage innovation.

Openness to licensing is another important characteristic. Theoretical models predict that pools, which improve overall welfare, are more likely to allow members to license their patents independently of each other (Lerner and Tirole 2004),[47] and regulators are more likely to allow pools that license their technologies to outside firms.[48] Nine of 20 pools in our sample licensed their technologies to outside firms. The coefficient on *pool * pool patents * licensees*

[47] Pools that reduce welfare may be less likely to allow independent licensing, because independent licensing may constrain prices only for pools that reduce welfare (but not pools that increase welfare, Lerner and Tirole 2004). Consistent with this idea, 28 pools that allowed independent licensing, were on average less likely to be litigated compared with 35 other pools that formed between 1895 and 2001 (Lerner, Strojwas, and Tirole 2007). Brenner's (2009) model implies that the predictions of Lerner and Tirole (2004) only hold if incumbent pool members are allowed to prevent rivals from entering the pool as new members.

[48] For example, the Department of Justice and Federal Trade Commission argued in 2007 that pools create barriers to entry by making it harder for "new firms to come in and overcome the patent thicket."

is negative at -0.18, but not statistically significant (Table 9, column 2), possibly because some pools used licensing as a mechanism to soften competition.[49]

Finally, a key argument for pools is that they help firms to resolve litigation over overlapping patents and encourage the production of new technologies (e.g., Shapiro 2001). Six of 20 pools formed to resolve litigation. Estimates for *pool*pool patents*prior litigation* are negative, at -0.19, but not statistically significant (Table 9, column 3), possibly because pools that resolved litigation were more likely to combine patents for substitute technologies.

III. CONCLUSIONS

Patent pools have emerged as a prominent policy tool to mitigate litigation risks due to mutually infringing (blocking) patents and encourage the adoption of new technologies. Pools, which allow competing firms to combine their patents, are expected to facilitate the production of new technologies and increase the expected returns from R&D by resolving blocking patents (Bittlingmayer 1988; Lerner and Tirole, 2004; Shapiro, 2001).

Pools may, however, also discourage innovation if they weaken competition among pool members to improve a new technology or if they discourage innovation by outside firms. Data for the 19th-century sewing machine industry suggest that – in the absence of effective regulation – pools may discourage innovation (Lampe and Moser 2010) and divert patenting and entry towards technologically inferior substitutes for pool technologies (Lampe and

[49] See Lampe and Moser (2012) for a qualitative analysis of the licensing strategies of the 20 pools in this sample.

Moser 2011). Pools that would form in the absence of effective regulation are, however, difficult to observe after the Sherman Act of 1890.

This paper has taken advantage of a unique window or regulatory tolerance under the New Deal, which suspended antitrust regulation in the majority of U.S. industries. Difference-in-differences regressions for 20 U.S. industries compare changes in patenting across technologies that were differentially affected by the creation of a pool. This analysis yields robust evidence for a large decline in patenting after the creation of a pool. USPTO subclasses with one additional pool patent experienced a 16 percent decline in patenting after the creation of a pool, compared with cross-reference subclasses that patent examiners identify as closely related technologies. Results are robust to the inclusion of subclass and year fixed effects, subclass-specific trends to control for variation in the use of patents, as well as interactions between year and industry fixed effects to control for differential time trends in patenting across the technology life cycle.

Analysis of citations-weighted data yield slightly smaller estimates, suggesting that patent pools may, in fact, reduce the need for firms to protect their inventions through thickets of "strategic" patents (e.g., Merges 1999; Shapiro 2001) but even the citations-weighted data indicate a decline in patenting of eight percent.

How may the creation of a patent pool discourage innovation? Regulators are most concerned about pools that combine patents for substitute technologies, but have found it difficult to recognize substitutes in patent pools (e.g., Department of Justice and Federal Trade Commission 2007; Lerner, Strojwas, and Tirole 2007). Results of this paper suggest that it may be possible to take advantage of a well known characteristic of the USPTO's classification system: All patented inventions are assigned to subclasses based on the function that they perform, so that, by definition, pool patents in the same USPTO subclass may be more likely to act as substitutes.

Difference-in-differences comparisons indicate that declines in patenting after the creation of a pool were driven almost exclusively by USPTO subclasses in which the creation of a pool combined patents by two or more pool members. This result confirms theoretical predictions that pools which combine substitutes are likely to discourage innovation and reduce welfare (e.g., Lerner and Tirole 2004) and indicate a simple way to identify situations when the creation of a patent pool may discourage innovation.

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TABLE 1 - 20 PATENT POOLS FORMED BETWEEN 1930 AND 1938

Industry	Year Formed-Dissolved	Member Firms at Formation	Pool Patents	Grant-back Rules	Licensees	Prior Litigation
High Tension Cables	1930-48	2	73	Yes	0	-
Water Conditioning	1930-51	3	4	Yes	0	-
Fuel Injection	1931-42	4	22	Yes	0	Yes
Pharmaceuticals	1932-45	2	5	Yes	0	-
Railroad Springs	1932-47	2	8	Yes	9	-
Textile Machines	1932-50	2	40	-	0	-
Hydraulic Oil Pumps	1933-52	2	3	Yes	0	-
Machine Tools	1933-55	5	3	Yes	0	-
Phillips Screws	1933-49	2	2	Yes	28	-
Color Cinematography	1934-50	2	143	Yes	0	-
Dry Ice	1934-52	4	37	Yes	0	-
Electric Generators	1934-53	2	30	Yes	0	-
Lecithin	1934-47	4	36	Yes	1	-
Variable Condensers	1934-53	3	60	Yes	3	Yes
Aircraft Instruments	1935-46	2	94	Yes	0	-
Stamped Metal Wheels	1937-55	3	90	Yes	12	Yes
Wrinkle Paint Finishes	1937-55	2	20	Yes	185	Yes
Fuse Cutouts	1938-48	2	3	-	10	-
Ophthalmic Frames	1938-48	4	23	-	13	Yes
Furniture Slip Covers	1938-49	2	2	-	2	Yes

Notes: *Grant-back rules* require member firms to offer all new patents for licensing to the pool. C=Canada; D = Denmark; F = France; G = Germany; I = Italy; J = Japan; S = Switzerland; UK = United Kingdom. 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).

TABLE 2: 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
2 pool patents (n=53)	2.52	2.61	2.57
More than 2 pool patents (n=53)	4.23	2.84	3.53
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
Citations-weighted patents			
Pool subclasses (n=433)	9.89	15.12	12.49
1 pool patent (n=327)	9.12	14.91	12.00
2 pool patents (n=53)	10.15	15.78	12.90
More than 2 pool patents (n=53)	14.40	15.75	15.08
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. *Citations-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

	(1)	(2)	(3)
Pool * pool patents	-0.355**	-0.385**	-0.358**
	(0.096)	(0.117)	(0.132)
Constant	1.975**	1.975**	2.530**
	(0.073)	(0.072)	(0.086)
Subclass fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	-
Linear and quadratic trends	-	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
R-squared	0.554	0.554	0.581

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 for all years after a pool forms. The variable *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. The control group consists of patent counts in 828 cross-reference subclasses that patent examiners have identified as related technologies.

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

	(1)	(2)	(3)
Pool * pool patents	-1.415**	-1.030**	-0.867**
	(0.289)	(0.280)	(0.312)
Constant	6.608**	6.608**	14.301**
	(0.397)	(0.397)	(0.595)
Subclass fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	-
Linear and quadratic trends	-	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
R-squared	0.474	0.474	0.496

Notes: Citations-weighted patents are constructed as 1+ # of citations by later patents (following Trajtenberg 1990). We constructed citations data by searching the full text of patent grants 1921-1974 for citations to all patents in our data set, and complemented these data with citations after 1975 from (Jaffe, Hall, and Trajtenberg 2001). The timing of invention is measured by the application year for granted patents. The variable *pool* equals 1 for years after the pool forms. *Pool patents* counts patents that were included in the initial pooling agreement and list one of 432 subclasses as their primary subclass. There are 433 (pool) subclasses with one or more pool patents. The control group consists of patent counts in 828 cross-reference subclasses that patent examiners have identified as related technologies.

TABLE 5: OLS – VARIATION IN THE NUMBER OF POOL PATENTS AND POOL MEMBERS ACROSS SUBCLASSES; DEPENDENT VARIABLE IS PATENTS PER SUBCLASS AND YEAR

	Raw patents (1-4)				Citations-weighted patents (5-6)	
	(1)	(2)	(3)	(4)	(5)	(6)
Pool * 1 pool patent	-0.100	-0.239			0.003	
	(0.148)	(0.156)			(0.926)	
Pool * 2 pool patents	0.019	-0.040			0.435	
	(0.388)	(0.387)			(2.446)	
Pool * more than 2 pool patents	-1.599**	-1.436**			-4.922**	
	(0.505)	(0.515)			(1.902)	
Pool * pool patents * pool patents owned by 1 firm			-0.296	-0.306		-0.485
			(0.219)	(0.246)		(0.496)
Pool * pool patents * pool patents owned by > 1 firm			-0.440**	-0.390**		-1.365**
			(0.115)	(0.117)		(0.328)
Constant	1.975**	2.835**	1.975**	2.573**	6.608**	6.608**
	(0.073)	(0.089)	(0.073)	(0.085)	(0.397)	(0.397)
Subclass fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	-	Yes	-	Yes	Yes
Linear and quadratic trends	Yes	Yes	Yes	Yes	Yes	Yes
Industry - year fixed 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	35,308	35,308
R-squared	0.553	0.580	0.554	0.581	0.474	0.475

Notes: The dependent variable counts patents per subclass and year. *Citations-weighted patents* are constructed as 1+ # of citations by later patents (following Trajtenberg 1990). The variable *pool patents owned by more than 1 firm* equals 1 if pool patents in subclass *c* are owned by more than 1 firm. The timing of invention is measured by the application year for granted patents. The variable *pool* equals 1 for years after the 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. The control group consists of patent counts in 828 cross-reference subclasses that patent examiners have identified as related technologies.

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

	Control is cross-reference subclasses in same main class as pool subclasses		Control is all cross-reference and other subclasses in same main class as pool subclasses		Excluding all pool-owned patents; 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**	-0.361**	-1.018**
	(0.117)	(0.281)	(0.112)	(0.280)	(0.115)	(0.272)
Constant	1.945**	6.516**	0.954**	3.110**	1.925**	6.437**
	(0.079)	(0.432)	(0.006)	(0.031)	(0.071)	(0.390)
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	0.557	0.475

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. *Citations-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 for years after the 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.

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

	Conditional fixed-effects Poisson; control is all cross-reference subclasses		Excluding subclasses with 10 and 12 pool patents from the sample		Excluding pools that formed after NIRA found unconstitutional in 1935	
	Raw patents (1)	Citation-weighted (2)	Raw patents (3)	Citation-weighted (4)	Raw patents (5)	Citation-weighted (6)
Pool*pool patents	-0.088**	-0.075**	-0.295**	-0.987**	-0.307**	-0.923**
	(0.017)	(0.017)	(0.095)	(0.336)	(0.092)	(0.252)
Constant			1.964**	6.587**	1.793**	6.375**
			(0.072)	(0.397)	(0.083)	(0.475)
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)	35,308	35,308	35,252	35,252	23,576	23,576
R-squared / Log-likelihood	-62693	-246547	0.551	0.473	0.556	0.460

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. *Citations-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 for years after the 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 (5) and (6) exclude six pools for aircraft instruments, 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 Machines	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,
as well as linear and quadratic time trends at the subclass level.
Standard errors clustered at the level of subclasses in parentheses.
** significant at 1 percent, * significant at 5 percent.

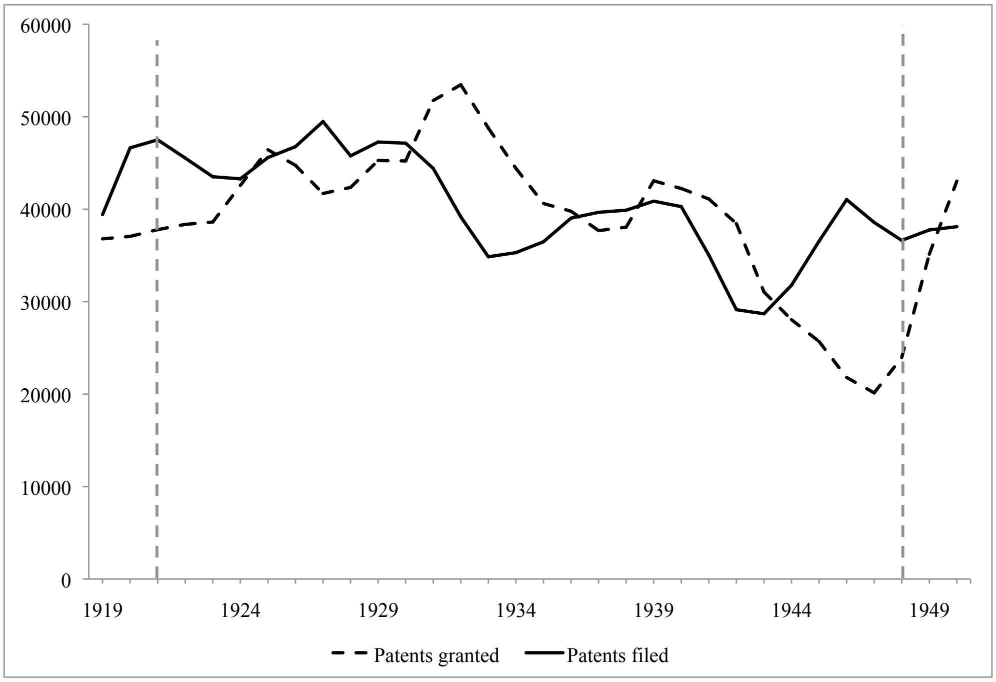
Notes: The dependent variable counts patents per subclass and year. The timing of invention is measured by the application year for granted patents. The variable *pool* equals 1 for years after the pool forms. *Pool patents* counts patents that were included in the initial pooling agreement and list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

TABLE 9: POOL CHARACTERISTICS
OLS – DEPENDENT VARIABLE IS PATENTS PER SUBCLASS AND YEAR

	(1)	(2)	(3)
Pool * pool patents	-0.415**	-0.300	-0.287
	(0.119)	(0.168)	(0.180)
Pool * pool patents * no grant-backs	0.423**		
	(0.145)		
Pool * pool patents * licensees		-0.177	
		(0.185)	
Pool * pool patents * prior litigation			-0.191
			(0.194)
Constant	1.975**	1.975**	1.975**
	(0.072)	(0.072)	(0.072)
Subclass fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Linear and quadratic trends	Yes	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
R-squared	0.554	0.554	0.554

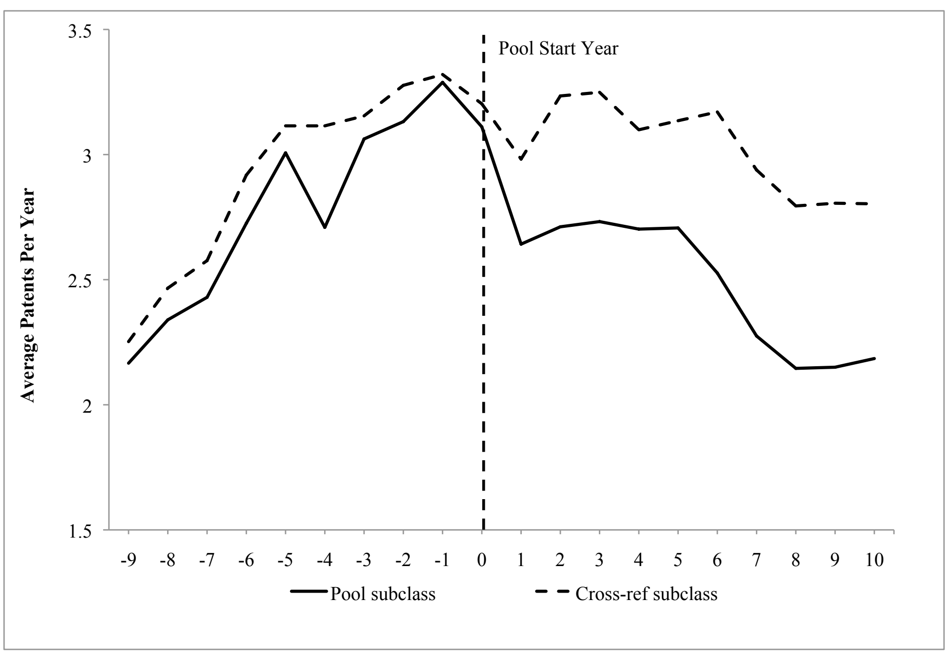
Notes: The timing of invention is measured by the application year for granted patents. The variable *pool* equals 1 for years after the pool forms. *Pool patents* counts patents that were included in the initial pooling agreement and list one of 376 subclasses as their primary subclass. There are 433 (pool) subclasses with one or more pool patents. The control group consists of patent counts in 828 cross-reference subclasses that patent examiners have identified as related technologies. The dummy variable *no grant-backs* equals 1 for 4 pools that did not include grant-back provisions. The dummy variable *licensees* equals 1 for 9 pools that licensed to outside firms. The dummy variable *prior litigation* equals 1 for 6 pools in which court records indicate that members were engaged in patent litigation prior to the formation of a pool.

FIGURE 1 – PATENT COUNTS PER YEAR OF APPLICATION AND GRANT



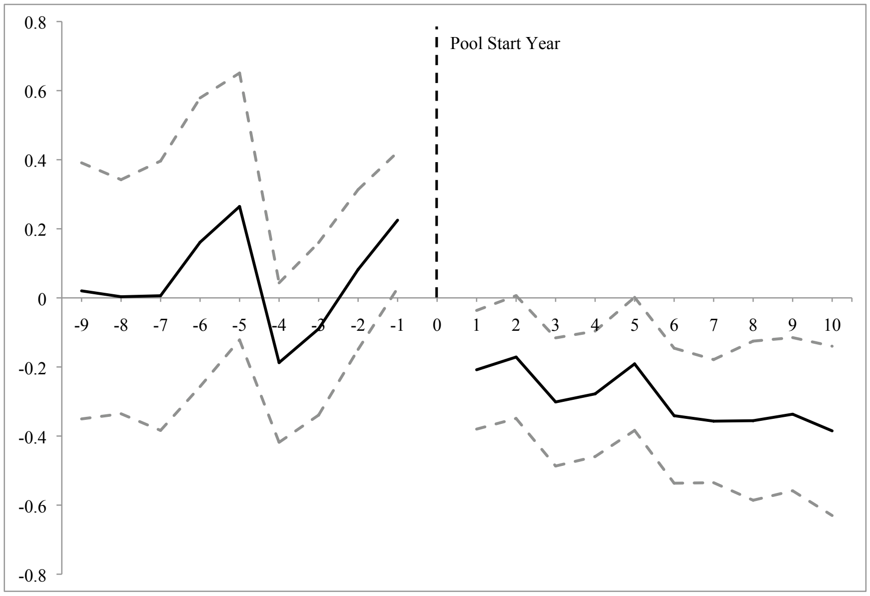
Notes: Patents per year of application and grant for granted U.S. patents. We collected data on filing years through a key word search of the full text of patent grants between 1920 and 1975, available at www.google.com/patents. This graph reveals truncation bias for patent applications before 1921; to avoid truncation bias, the empirical tests use data on applications between 1921 and 1948. The average lag between applications and grants is 2.7 years with a standard deviation of 1.9.

FIGURE 2 – PATENTS PER SUBCLASS AND YEAR: POOL VERSUS CROSS-REFERENCE SUBCLASSES



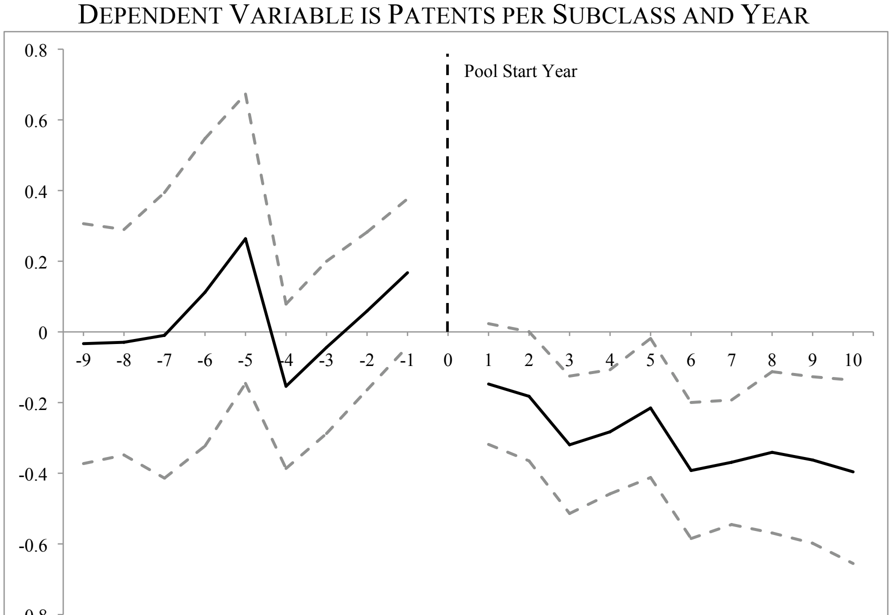
Notes: Data include 433 *pool subclasses* that include at least one pool patent and 828 *cross-reference subclasses* are subclasses that patent examiners identified as related technologies for pool patents. The timing of invention is measured by the year of the patent application; t=0 denotes the year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

FIGURE 3 – ANNUAL COEFFICIENTS, OLS,
DEPENDENT VARIABLE IS PATENTS PER SUBCLASS AND YEAR



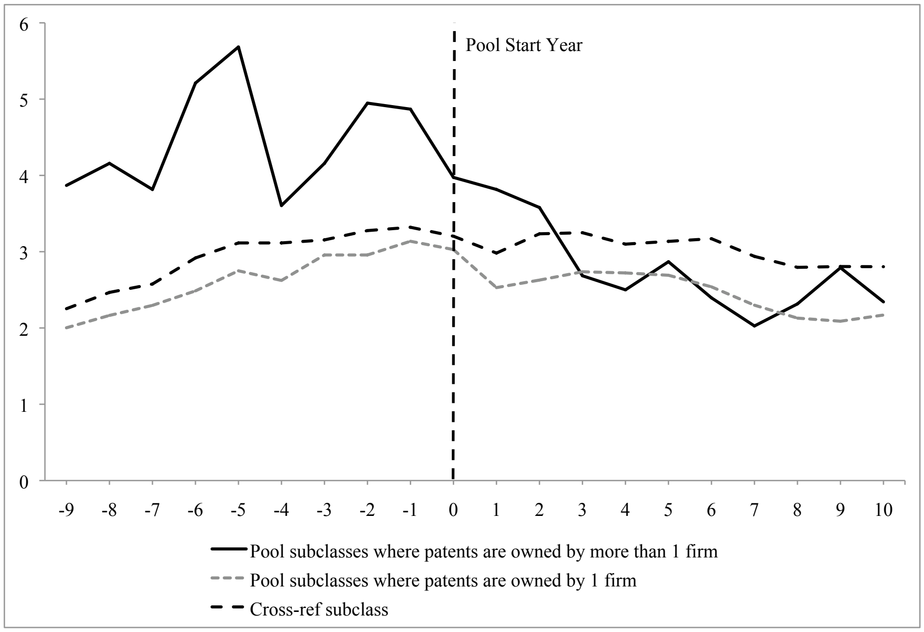
Notes: Coefficient estimates for β_k in the regression $Patents_{ct} = \alpha + \beta_k * Pool\ Patents_c + f_c + \delta_t + \varepsilon_{ct}$ where k =-17, ….17, 18, counts years before and after a pool forms. The timing of invention is measured at the year of the patent application; t=0 denotes the year when the pool formed. The variable *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. The control group consists of patent counts in 828 cross-reference subclasses that patent examiners have identified as related technologies.

FIGURE 4 – ANNUAL COEFFICIENTS, OLS WITH INDUSTRY-YEAR INTERACTIONS
DEPENDENT VARIABLE IS PATENTS PER SUBCLASS AND YEAR



Notes: Coefficient 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 timing of invention is measured by the year of the patent application; t=0 denotes the year when the pool formed.

FIGURE 5 – PATENTS PER SUBCLASS AND YEAR:
VARIATION IN THE NUMBER OF FIRMS THAT OWN POOL PATENTS IN A POOL SUBCLASS



Notes: Data include 433 subclasses in 108 main classes that include at least pool patent. The timing of invention is measured by the year of the patent application; t=0 denotes the year when the pool formed. *Pool subclasses* are listed as the primary subclass by at least one pool patent; pool patents are patents that were included in the initial pool agreement. *Cross-reference subclasses* are listed as the secondary, cross-reference subclass for at least one pool patent and not listed as a primary subclass.