Do (Unregulated) Patent Pools Encourage Innovation? Evidence from U.S. Industries under the New Deal

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Patent pools, which allow competing firms to combine their patents as if they are a single firm, have become a prominent mechanism to address problems with the current patent system. Pools are expected to encourage innovation by limiting litigation risks for pool members and by lowering transaction costs and license fees for outside firms. But pools may also have important anti-competitive effects, as they encourage cooperation among competing firms. Today and nearly always since the Sherman Act in 1890, antitrust regulation is in place to prevent such anti-competitive effects, making it impossible to observe what would happen if pools were left free reign. New Deal policies in the 1930s, which aimed to encourage economic recovery, relaxed antitrust regulation and allowed anti-competitive pools to form. This paper examines the effects of such pools on innovation. Difference-in-difference estimates that compare changes in patent applications in pool technologies with a control group of related technologies in the same industry indicate a 16 percent decline in innovation after the formation of a pool. This decline is strongest for technologies that pool members competed to improve before the creation of a pool.

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Patent pools, which allow a group of firms to combine their patents as if they are a single firm, have become a prominent policy mechanism to resolve litigation and blocking patents when competing firms own overlapping patents for the same technology. For example, pools have been proposed as a means to prevent litigation over tablet computers, smart phones, and video compression technologies, and are expected to facilitate licensing and encourage scientific progress in molecular diagnostic testing for breast cancer and treatments for HIV, cholera, and malaria.[1]

Enthusiasm for pools is fueled by the expectation that pools encourage the adoption of new technologies and encourage investments in R&D. For example, pools that allow competing firms to combine complementary patents that block the production of new technologies are expected to reduce litigation risks and facilitate production (Shapiro 2001). "In a case involving blocking patents, such an arrangement is the only reasonable method for making the invention available to the public" (*International Mfg. Co. v. Landon*, 336 F.2d 723, 729 (9th Cir. 1964)). Pools of complementary patents are also expected to reduce license fees by preventing "royalty stacking," which occurs when multiple firms charge license fees for individual parts of the same product (Merges 1999; Shapiro 2001, p. 134).[2]

[1] In April 2010, for example, MPEG LA, which previously organized patent pools for video compression standards, announced the development of a patent pool for diagnostic genetic tests. UNITAID's Medicines Patent Pool aims to improve access to HIV treatments in developing countries. In August 2010 the Pool for Open Innovation against Neglected Tropical Diseases announced Medicines for Malaria Venture's contribution of patents for malaria treatments.

[2] Technologies that are covered by complementary patents can be used together to build a new product, while substitute patents cover competing technologies that replace each other in building a technology. While pools that combine complementary patents reduce license fees, theoretical

Patent pools may, however, also have anti-competitive effects as they encourage cooperation across competing firms. Specifically, pools may discourage innovation if they reduce the intensity of competition by allowing firms to pool patents for substitute technologies that could otherwise replace each other.[3] Since the Sherman Act of 1890, antitrust regulation has been in place to prevent anti-competitive practices, making it impossible to observe what would happen if pools were left free reign. A historical case study, for the first pool in U.S. history, which preceded regulation, indicates that pools may discourage innovation (Lampe and Moser 2010). In fact, the sewing machine pool appears to have diverted innovation away from pool technologies and towards technologically inferior substitutes that did not compete directly with the pool (Lampe and Moser 2011).[4]

This paper uses a unique window under the New Deal Program in the 1930s, when antitrust regulation was largely suspended to encourage economic recovery, to examine the effects of anti-competitive pools. New Deal policies, such as the National Industrial Recovery Act (NIRA, 1933-35), which exempted the large majority of U.S. industries from antitrust regulation to encourage higher

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models predict that pools that combine substitute patents may increase license fees (Lerner and Tirole 2004).

[3] Lerner and Tirole (2004) however, predict that the creation of a pool may discourage patenting and invention if they include grant back provisions that allow pool members to free-ride on the R&D efforts of other members. Aoki and Nagaoka (2004) predict that innovation may decline if firms with essential patents refuse to contribute their patents or leave the pool after a standard has been established; as firms maximize profits independently, the pool's profits decline and pool members' incentives to invest in R&D weaken.

[4] Qualitative evidence from the optical disk drive industry (Flamm 2012) confirms the historical evidence from the sewing machine industry, while evidence for CD suggests that the creation of a pool may have in fact encouraged innovation. Data on the entry of new firms with open source software indicates that patent classes in which IBM contributed patents to the Patent Commons Pool after 2005 experienced a small but statistically significant increase in firm entry (Ceccagnoli, Forman, and Wen 2012).

wages, created a favorable environment for pools and other types of cooperative agreements.[5]

> "Through patent pools, territorial restrictions, and agreements not to compete, by the early 1930s a high proportion of all major manufactures and basic industrial commodities had become subject to price-fixing or output-restraining agreements" (Haley 2001, p. 8).

In 1931, the U.S. Supreme Court upheld the Standard Oil pool for gasoline cracking even though it controlled 55 percent of output arguing that

> "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 (1931), 167-168).[6]

The regulatory climate, however, began to change in 1935, beginning with Congressional hearings to scrutinize patent pools from February 11 to March 7 of that year.[7] A few months later, on May 27, 1935, the U.S. Supreme Court ruled in *Schechter Poultry Corp. vs. United States* that price and wage-fixing in the

[5] 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). There is, however, an increasing amount of evidence that a broad range of industries experienced productivity increases along with higher wages in the 1930s. Field (2003) documents productivity increases in telephones, electric utilities, and railroads; Field (2011) reports productivity increases in communications (4.13 percent per year), public utilities (3.79), transportation (2.87), real estate (2.74), mining (2.39), trade (2.33), manufacturing (2.30), services (1.70), construction (0.91), finance/insurance (Table 4.2). Some of these advances may have been as a result of U.S. firms' ability to produce and improve foreign-owned inventions under the Trading-with-the-Enemy Act after World War I (Moser and Voena 2011).

[6] *Standard Oil vs. United States* 1931, p. 175-176.

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

poultry industry, which were sanctioned under the NIRA, violated the U.S. Constitution by imposing restrictions on intrastate commerce.[8] Although, the U.S. government continued to tolerate collusion and price fixing in many industries (Hawley 1966), patent pools became less frequent and became more likely to license their inventions (Lampe and Moser 2012).[9]

On March 11, 1938, President Roosevelt appointed Thurman Arnold to reorganize the Antitrust Division of the Department of Justice. The revamped agency began to enforce antitrust rules more aggressively: 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). From June 16, 1938 to April 3, 1941, Congressional hearings of the Temporary National Economic Committee investigated antitrust violations through cartels and pools.[10] In 1942, the U.S. Senate's "Bone Hearings" investigated patents and patent licensing, with a focus on agreements between U.S. and German (enemy) firms.[11]

For patent pools, the U.S. Supreme Court's 1942 decision to break up the *Hartford Empire* pool marked a definite turning point.[12] Hartford Empire had grown to include more than 600 patents, which covered machinery to produce 94

[8] *A.L.A. Schechter Poultry Corp. v. United States*, 295 U.S. 495 (1935).
[9] Only 5 of the 20 pools in our sample form after 1935; historical records include references to 3 additional pools between 1938 and the Hartford Empire decision in 1942: a pool for petroleum refining-alkylation formed in 1939, and a pool for dyestuffs formed in 1940 (Lerner, Strojwas, and Tirole 2007). Both pools were subject to Congressional hearings. A pool for television equipment formed in 1942, but was dissolved by a consent decree in 1949.
[10] The final report of the committee was released on March 31, 1941. See *Investigation of Concentration of Economic Power, Final Report and Recommendations of the Temporary National Economic Committee.* Washington, DC: U.S. G.P.O., 1941.
[11] *Patents, Hearings before Senate Committee on Patents on Senate Resolutions 2303 and 2491, Parts 1-9,* 77 Cong., 2 sess. (Bone).
[12] *Hartford-Empire Co. Et Al. v. United States*, 46 F. Supp. 541 (1942), *modified*, 323 U.S. 386 (1945).

percent of glass containers in the United States in 1938. The Court found that the pool discouraged invention and suppressed competition by imposing production quotas on its licensees and preventing licensees from adopting competing technologies. In 1945, 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 than that accomplished by these appellants."[13]

Few pools formed after *Hartford Empire* until the Department of Justice approved the MPEG and DVD standards pools in 1997 and 1999.

This paper takes advantages of the window of regulatory tolerance between 1930 and 1938 to explore the effects of patent pools across a broad range of 20 industries. These industries high-tension cables, railroad springs, textile machines, Phillips screws, lecithin, dry ice, variable condensers (used in radios), stamped metal wheels (used in the production of cars), wrinkle paint finishes, and fuse cutouts.

To examine the effects of patent pools on innovation, we compare changes in patent applications across related technologies that are differentially affected by the creation of a pool. 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).[14] The systematic classification of patented technologies, however,

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[13] Justice Hugo Black, *Harford Empire Co. v. U.S.* 323 U.S. 386, 400 (Jan., 1945).
[14] 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

offers important benefits for empirical analyses of changes in innovation across technologies and over time, as well as methods to address variation in the match between patents and innovations across technologies, over time, and across quality levels.

Specifically, baseline estimates compare changes in patent applications per year in USPTO subclasses that include pool patents with changes in patents per year in cross-reference subclasses that patent examiners identify as closely related technologies for pool patents. Using examiner-added cross-reference subclasses as a control group helps to address a common concern with difference-in-difference estimates, which is that observed "effects" may be a reflection of differential pre-trends. Specifically, pools may be more likely to form in technologies where patenting grows more rapidly, for example, as a result of a patent race (Shapiro 2001; Dequiedt and Versaevel 2007). Using examiner-added cross-reference subclasses mitigates this problem, by comparing changes in patenting in pool subclasses with cross-reference subclasses that exhibit similar pre-trends in patenting before the creation of a pool.

In addition, investigating 20 patent pools that were created in different years between 1930 and 1938 allows us to investigate changes in patenting relative to a pool-specific year of pool creation, rather than a calendar year, which could be biased as a result of an unobservable policy change, such as the variation

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).

in spending or work relief programs under the New Deal (e.g., Wright 1974) that may have triggered differential changes in patenting in pool technologies.

Technology (subclass) and year fixed effects, as well as linear and quadratic time trends at the level of individual technologies (subclasses) make it possible to control for variation in the correspondence between patent counts and innovations across technologies and over time. Citations to patents in our data by patents that were granted between 1921 and 2002 allow us to control for the quality of patented inventions.[15] Controlling for citations by later patents also help to address the issue that changes in raw patent counts may reflect changes in the need for strategic patenting, rather than a true changes in innovation. For our analysis, the most important issue is that the creation of a pool may reduce litigation risks, which in turn reduce the need for strategic patenting.

Pool patents are identified from primary documents at the National Archives in Chicago, Kansas City, New York City, and Riverside, CA. Twenty patent pools that formed between 1930 and 1938 covered a total of 376 "pool" subclasses (with at least one pool patent) and 730 cross-reference subclasses (without pool patents) that patent examiners identified as related technologies. These 1,106 subclasses produced a total of 70,052 patent applications between 1921 and 1948. A key word search for the patent numbers of these 70,052 patents in the full text of all U.S. patent grants captures citations in patent grants after 1921.

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

Difference-in-differences estimates imply that subclasses with an 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.[16] 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 for the pre-pool period are not statistically significant. Estimates increase after the creation of a pool and become consistently negative and statistically significant six years after the creation of a pool.[17] In years six and above, the average subclasses with an additional pool patent experiences a 17 percent decline in patent applications.

An additional test aims to shed light on the mechanisms by which the creation of a patent pool may discourage patenting. It takes advantage of the fact

[16] For example, Layne-Farrar and Lerner (2011) find that vertically integrated firms are more likely to join a patent pool, such that - if vertically integrated industries are more likely to experience a decline in patenting – the basic difference-in-differences estimator may overestimate the decline in patenting after the creation of the pool. We address this issue by estimating changes in patenting in pool technologies *before* the creation of a pool.

[17] Some portion of this delay may be due to a lag between research decisions and R&D. Empirical analyses indicate that this lag is less than one year. Sanders' (1962, p. 71) *Patent Use Survey* suggests that the average patent application occurred nine month after firms had incurred research expenses for related products. Sanders surveyed a random 2 percent sample of U.S. patents issued in 1938, 1948 and 1952; 600 of 1,220 patent owners responded to this survey. Hall, Griliches, and Hausman (1986) 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. Anecdotal evidence, however, suggests that patent applications can occur with substantially longer lags, if projects are ambitious relative to a firm's existing knowledge base. For example, the U.S. chemical firm Du Pont required several years to reverse-engineer German processes for producing synthetic indigo after it had gained access to German-owned U.S. patents (Haynes 1945, p.245; Moser and Voena 2012).

that the formation of a pool creates a differential impact on technologies, which are developed by a single firm and technologies which are developed by two or more firms. For technologies that are developed by a single firm before a pool forms, the formation of a pool should only affect invention through linkages with complementary technologies because it has no direct effect on the ownership of invention in that technology. For technologies that are improved by more than one pool member, the creation of a pool affects linkages with complementary technologies, but also affects the nature of competition by allowing competing firms to combine patents for competing substitute technologies. As a result, the pools effect on competition should be more pronounced for technologies – measured at the level of USPTO subclasses – for which the pool combines patents by competing firms.[18]

Regressions that separately estimate the effects of a pool on subclasses with one or more pool patents confirm that declines in patenting are most significant for pools that combined patents by competing firms. Consistent with theoretical arguments which suggest that pools that combine substitute patents may discourage innovation (e.g., Shapiro 2001, Lerner and Tirole 2004) the

[18] Pools of complementary patents are inherently difficult to separate from pools of substitute patents. 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), Lerner, Strojwas, and Tirole (2007) use litigation as an indicator for pools of substitute patents. Litigation may, however, be triggered by other behaviors of pools, such as price-fixing (Lerner, Strojwas, and Tirole 2007, p. 619). Data on pool patents and pooling agreement are also most easily available from court records. Lerner, Strorwas and Tirole find pooling agreements for 63 pools in a subset of 125 pools that formed between 1856 and 2001 at the National Archives and in Congressional Hearings. Thirty-seven of these pools were litigated.

decline in patenting is strongest for subclasses with more than 2 pool patents and for subclasses where a pool combined patents by 2 or more firms.

Regressions with citations-weighted patents indicate a slightly smaller increase in invention, suggesting that the creation of a pool may, in fact, reduce the need for strategic patenting. Subclasses with an additional pool patent produce eight percent fewer patents after the creation of a pool. Similar to regressions for raw patents, effects are strongest for later years (with a 12 percent decline in years six and above, and no significant effects until year five) and for subclasses with more than two pool patents (with a 30 percent decline).[19]

A series of robustness checks confirm the main results. Estimates are robust to varying the set of control subclasses, excluding patents assigned to pool members, and conditional fixed-effects Poisson regressions that control for the count data properties of patents. Estimates are also robust to restricting the sample to pools that formed before the NIRA became unconstitutional in 1935.

Regressions that drop individual pools from the sample indicate that observed effects are not driven by a single pool. Dropping aircraft instruments and variable condensers yields the largest decline in estimated effects, but estimates remain large and statistically significant. Without aircraft instruments the estimated decline is -0.34 (instead of -0.41) patents per subclass and year; without variable condensers it is -0.37 patents per subclass and year. Archival

[19] These results are consistent with related evidence from the 19th-century sewing machine industry, which suggest that the creation of a pool not only lowered patenting but also slowed improvements in the performance of sewing machines (Lampe and Moser 2010). In the sewing machine industry, the creation of a pool increased litigation risks for outside firms, even as it reduced such risks for pool members (Lampe and Moser 2010, 2012).

evidence for these two industries suggests two mechanisms by which pools may discourage innovations: by limiting competition among pool members and by increasing litigation risks for outside firms.

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 376 subclasses that included at least one pool patent with changes in patent applications per year in 730 cross-reference subclasses without pool patents that patent examiners identified as related technologies. These data cover a total of 70,052 patent applications between 1921 and 1948.

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 for 15 pools are listed in written complaints or consent decrees, which required the pools to license their patents to outside firms.[20] Patents for three pools are listed in written opinions, and patents for two pools are listed in the original license agreements.[21]

[20] A consent decree is granted by a court in place of a decision and based on an agreement already reached between the government and a defendant; it generally presents the minimum, which the Department of Justice is willing to accept in lieu of a court decision (Vaughan 1956, p. 47)

[21] In comparison with Lerner, Strojwas, and Tirole's (2007) sample of 31 pools between 1930-39, our sample includes 8 additional pools, and omits 12 pools that were the subject of Congressional

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).[22]

B. Patent Applications in Pool and Control Technologies

The main specifications compare changes in patent applications per year in 376 pool subclasses with changes in patent applications in a control group of 730 cross-reference subclasses. 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."[23]

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hearings but were not antitrust litigation and 1 pool for television/radio apparatus comprised exclusively of Australian firms. Our sample also excludes a short-lived pool for male hormones (1937-1941), a pool for railroad joint bars (1928-1944) because it formed before 1930, and a "pool" for grinding hobs (1931-1943) because it combined two patents owned by the same firm, the Barber-Colman Company. Barber-Colman Company illegally fixed prices on unpatented hobs produced by licensees of its patented machine and method for grinding (*Barber-Colman Co. v. National Tool Co.*, 136 F. 2d 339 (N.D. Ohio, 1943)). Our sample also omits one 1935 pool for acrylic acid and two 1938 pools for pour depressants and induction heat treatments, because we could not locate records on licensing agreements or patents for these pools.

[22] The average pool was active for 16 years. The average patent that was included in a pooling agreement was six months old counting from the day of the patent grant.

[23] There is almost no overlap in the technology areas that are covered by these pools. Only four subclasses are listed as pool subclasses (340/524 for water conditioning apparatuses, 62/056 for dry ice, 524/594 for wrinkle finishes, and 174/152R for fuel injection equipment) and also listed as cross-reference subclasses for another pool. An additional two subclasses are listed as cross-reference classes 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. The USPTO modifies its classification system over time to accommodate the development of new technologies; with each revision, older patents are retroactively assigned to newly created subclasses. We measure subclass information based on the USPTO's classification of technologies in 2010 (http://www.uspto.gov/patents/resources/classification/overview.pdf).

Variation in the number of pool patents across subclasses allows us to investigate effects of pool patents that fulfill the same USPTO function (substitutes) and pool patents that are complementary with other pool technologies. 287 pool subclasses include only 1 pool patent (76 percent, Figure 1); 43 pool subclasses (11 percent) include 2, and 46 pool subclasses (12 percent), include more than 2 pool patents; one subclass includes 12 pool patents.

License agreements, written complaints, and final judgments typically list the owners of pool patents;[24] this data allows us to identify pool subclasses with patents from multiple firms. 23 percent of subclasses with 2 pool patents combine pool patents by more than 1 firm; 57 percent of subclasses with 3 or more pool patents combine pool patents by more than one firm.

The control for pool patents consists of cross-reference subclasses, which patent examiners identify as related technologies. Each pool patent is assigned to one primary (pool) subclass, which covers the key technology areas of each pool patent.[25] 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

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[24] 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).

[25] 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).

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, the first three cross-reference subclasses form the control for the pool subclass 411/403.[26] The average pool patent is assigned to 2.1 cross-reference subclasses in addition to its primary class.[27] 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."

These data extend existing data sets in two 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 primary subclasses.[28]

Second, our data include application years in addition to grant years to more accurately measure the timing of invention. The distinction between application

[26] Patents that cannot be assigned to a unique subclass are assigned to digest subclass in the main class that covers all of the functions that the invention can perform. 15 digest subclasses are excluded from the data.
[27] The average patent pool covers 18.8 primary subclasses and 36.5 cross-reference subclasses.
[28] Brenner 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.

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.[29] This search yields application years for 97.7 percent of 1,069,414 patents issued between 1921 and 1948.[30] With a mean lag between application and grant of 2.7 years and a standard deviation of 1.9 years (Figure 2).[31]

E. Citations by later patents, 1921-2002

Another potential issue with using patent counts to measure innovation is that there is a large amount of variation in the quality of patents (e.g., Griliches 1990, p. 1669). 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.[32]

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[29] 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.

[30] In a random sample of 300 patents, application years were correctly recorded for 296 patents.

[31] 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).

[32] 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

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 on U.S. patents are checked by patent examiners who strike out erroneous citations and add relevant citations that inventors may withhold to overstate the size of their inventions.[33]

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 70,052 patent numbers in our data. Until February 4, 1947, USPTO patent grants recorded citations anywhere in the text of the patent document; we 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, and we extract citations directly from these sections.[34]

This data collection yields a total of 220,583 citations from patents between January 4, 1921 and December 31, 1974 to 70,052 unique patents in our data, including 14,391 citations before 1947 and 206,192 citations after 1947. We augment these data with citations between January 7, 1975 and December 31,

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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.

[33] For example, for U.S. patent grants between January 2001 and December 2002, patent examiners added between 21 and 32 percent of relevant citations to prior art (Lampe 2011).

[34] To check the data, we examine the page scans of 150 randomly chosen patents between 1947 and 1974 on Google Patents (www.google.com/patents), to check for citations. Our algorithm correctly identifies 636 of 741 (85.58 percent) 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.

2002 from the NBER patent citations data set (Hall, Jaffe, and Trajtenberg 2001); this adds 77,120 citations after 1974. In total, 57,213 patents, 82 percent of the data, are cited at least once; conditional on being cited once, the average patent was cited 5.20 times.[35] In comparison, 2,034,394 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.

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 2.64 patents per year before a pool formed and 2.51 patents per year afterwards (Table 2). In comparison, cross-reference subclasses produce 2.85 patents per year before a pool formed and 3.10 afterwards. Restricting the sample to patent applications within 10 years of the creation of a pool strengthens this difference. Within a 20-year window, the average pool subclass produces 2.93 patents per year before a pool formed and 2.60 afterwards; in comparison, cross-reference subclasses produce 3.12 patents per year before a pool formed and 3.20 afterwards (Figure 3).

A. Baseline estimates

[35] Citations data in Nicholas (2010, p. 63) indicate that 68.2 percent of 4,524 randomly chosen patents issued in 1930 are cited by patents issued between 1947 and 2008; conditional on being cited, the average patent in Nicholas' data was cited 3.54 times. Nicholas (2010) uses these data to document that independent inventors contributed a large number of highly-cited inventions in the 1930s, which is consistent with the large share of non-member patents in our data.

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.[36] 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 screw pool subclass 411/403; cross-reference subclasses 411/919, 470/60, and 470/9 form the control.[37]

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

[36] Six 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.

[37] 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).

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 0.41 fewer patents per year after the creation of a pool (significant at 1 percent, Table 3, column 2). Compared with a mean of 2.58 patents per year in pool subclasses, this implies a 15.95 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 -0.38, which implies a 14.69 percent decline in patents per year (significant at 1 percent, Table 3, column 3).

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 would 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 10.29 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.[38] Below, we will be able to 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 -0.32 with an average -0.24, implying a decline of 9.32 percent for the first five years, and from -0.34 to -0.68 with an average of -

[38] With respect to competing inventors in a patent race, 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. With respect to strategic patenting, Hall and Ziedonis (2001) document that firms in the semiconductor industry use patents strategically to protect themselves from litigation.

0.44 implying a decline of 17.08 percent for years six and above (significant at the 5 percent level in years one, three, four and all years above six, Figure 5).

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 -0.33 at the 5 percent level in year 3 (Figure 6). Estimates remain significant through the end of the sample, with an estimate of -0.42 in year 10.

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.[39] 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.[40]

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[39] 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).

[40] In semiconductors, firms with large capital investments use patents strategically to discourage litigation (Hall and Ziedonis 2001). In the biotech sector, start-ups with less paid-in capital are

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 10.25 citations-weighted patents per year before a pool has formed and 15.61 citations-weighted patents per year afterwards. In comparison, cross-reference subclasses produce 12.29 patents per year before a pool has formed and 20.33 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 1.00 fewer citations-weighted patents after a pool has formed (significant at 1 percent, Table 4, column 2), implying a 7.71 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,

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less likely to patent in subclasses that already include a competitor's patent, where the risk of litigation might be high (Lerner 1995).

subclasses with an additional pool patent produce 0.80 fewer patents per year after the creation of a pool, implying a 6.20 percent decline in citations-weighted patents (significant at 5 percent, Table 4, column 3).[41]

C. Subclasses where 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 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.[42]

Empirically, variation in the number of pool patents (and in the number of pool members) across subclasses allow 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, 287 of 376 pool

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[41] 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 0.43 to -0.64 with an average of -0.26, implying a decline of 2.01 (not statistically significant). In years six and above, annual coefficients range from -1.00 to -1.62, with an average of -1.46 implying a decline of 11.31 percent (significant at the 5 percent level).

[42] 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.

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, 89 subclasses include more than one pool patent; 36 of these subclasses include patents by more than one firm; 46 subclasses include more than two pool patents, 26 of these subclasses include patents by more than one firm.

Descriptive statistics indicate that pool subclasses with more than 2 pool patents drive the observed decline in patenting. In subclasses with 1 and 2 pool patents invention rises slightly from 2.32 patents per year before the pool forms to 2.35 afterwards and from 2.82 to 2.94, respectively. In subclasses with more than 2 pool patents, however, patenting declines from 4.53 to 3.05 patents (Table 2). Restricting the sample to patents applications ten years before and after the creation of a pool increases the relative decline. Pool subclasses with more than two pool patents produce 5.06 patents before a pool and 3.27 patents afterwards (Figure 4). Difference-in-differences regressions with interactions for variation in the number of pool patents estimate these effects:

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

where *1 pool patent*$_c$ indicates subclasses with 1 pool, *2 pool patents*$_c$ indicates subclasses with 2 pool patents, and *more than pool patents*$_c$ indicates subclasses with more than 2 pool patents. The large majority of pool subclasses (287 out of 376) include only 1 pool patent; 43 pool subclasses (11 percent) include 2, and 46 subclasses (12 percent) include more than 2 (Figure 1).

OLS estimates confirm that the decline in patenting is significantly stronger in subclasses where a pool may combine patents by competing firms. Interactions between pool variables are not statistically significant for subclasses with 1 or 2 pool patents (with coefficient estimates of -0.09 and 0.05, respectively). Interactions for subclasses with more than 2 pool patents, however, imply a decline of 1.71 patents per year after the creation of a pool (significant at 1 percent, Table 5, column 1).

Citations-weighted counts also confirm that the decline in patenting is strongest for subclasses where the pool combines patents by competing firms.[43] Estimates indicate no significant change in quality-adjusted patents for subclasses with 1 or 2 pool patents (with estimates of -0.20 and 1.05, respectively, Table 5, column 5). Subclasses with more than 2 pool patents, however, produce 4.77 fewer citations-weighted patents after the creation of a pool (significant at 1 percent, Table 5, column 5).

[43] 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 9.25 per year before the creation of a pool to 15.02 afterwards; in subclasses with 2 pool patents, citations-weighted patents increase from 11.78 per year before to 18.12 afterwards (Table 2). In subclasses with more than 2 pool patents – which combine patents by competing firms in 56 percent of all cases - this increase is significantly smaller, with 15.14 per year before the creation of a pool to 16.92 afterwards.

To further explore these effects we incorporate firm-level data on the identity of pool members. These data allow us to compare changes in patenting for subclasses where pool patents were owned by a single firm with subclasses where pool patents were owned by two or more competing firms. The likelihood of separate ownership is largest for subclasses with more than 3 pool patents; 10 of 43 subclasses with 2 pool patents combine patents by more 1 firms; 26 of 46 subclasses with more than 2 pool patents combine patents by more than 1 firm (Figure 1).

Comparisons of summary statistics indicate that the decline in patenting is strongest in subclasses where a pool combined patents by competing firms. In subclasses with 2 or more firms, invention declines from an average of 4.58 across ten years before the creation of a pool to 2.80 patents per year across ten years afterwards (Figure 7). In comparison, subclasses with only one firm experience a much weaker decline, from 2.76 patents per year before the creation of a pool to 2.58 afterwards.

OLS estimates indicate that each additional pool patent in subclasses with two or more pool members is associated with 0.46 fewer patents (significant at 1 percent, Table 5, column 3), implying a 17.83 percent decline relative to mean of 2.58 patents per year in pool subclasses. By comparison, each pool patent in subclasses with only pool member is associated with 0.32 fewer patents (not statistically significant, Table 5, column 3).

Estimates for citations-weighted patents also confirm that the decline in patenting is strongest for subclasses where the pool combined patents by two or more member firms. Subclasses, in which pool patents were owned by more than one member before the creation of the pool, produce 1.39 fewer citation-weighted patents after the creation of a pool (significant at 1 percent, Table 5, column 6), implying a decline of 10.77 percent. By comparison, subclasses in which pool patents were owned by a single member before the creation of the pool, produce 0.23 fewer citation-weighted patents (significant at 1 percent, Table 5, column 6)

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.[44] In this test, the control consists of 549 cross-reference classes in the same 103 main classes that also include one of 376 pool subclasses. Compared with cross-reference subclasses in the same main class, pool subclasses with an additional pool patent produce 0.41 fewer patents per year after the creation of a pool, implying a 15.92 percent decline, and 1.04 fewer citation-weighted patents, implying a 8.06 percent decline (significant at 1 percent, Table 6, columns 1 and 2).

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[44] 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”).

A second robustness check expands the control to include all 65,801 subclasses without pool patents in 103 main classes that include a pool patent and 58 additional main classes that examiners identified as cross-reference classes.[45] Compared with all subclasses without pool or cross-reference patents, pool subclasses produce 0.44 fewer patents for each additional pool patent per year after the creation of a pool, implying a decline of 16.96 percent, and 0.87 fewer citation-weighed patents per year, implying a decline of 6.77 percent (significant at 1 percent, Table 6, columns 3 and 4).

A third robustness test excludes all 2,160 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 -0.39 fewer patents per year after the creation of a pool, implying a 16.03 percent decline, and 1.00 fewer citation-weighted patents, implying a 8.22 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).[46] These estimates imply that subclasses with one additional pool patent produce 8.42 percent fewer

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[45] In this test, 281 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.

[46] 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.

raw patents and 7.13 percent fewer citation-weighted patents after the creation of a pool (significant at 1 percent, Table 7, columns 1 and 2).[47]

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 -0.35 fewer patents per year after the creation of a pool, implying a 14.58 percent decline, and 0.89 fewer citation-weighted patents, implying a 7.71 percent decline (significant at 1 percent, Table 7, columns 3 and 4).[48]

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. In these regressions, estimates remain large and statistically significant. Excluding aircraft instruments has the largest effect on the size of the estimates, but it leaves estimated effects at -0.34, implying a 14.66 percent decline in that sample (compared with an average of 2.32 patents per year across all pool subclasses in this sample, significant at 1 percent, Table 8).[49] Excluding variable condensers has the second largest effect; it reduces the size of the estimated decline to -0.37, implying a 14.23 percent decline in invention, compared with an average of 2.60 patents per year across all pool subclasses in this sample (significant at 5 percent, Table 8).

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[47] Percentage changes are calculated from the coefficients as exp(-0.088)-1=-0.08 and exp(-0.074)-1=-0.07, respectively.

[48] 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 -0.13, with a standard error of 0.21. The estimate for the coefficient on *Pool*Pool Patents* remains (at -0.35, significant at 1 percent, not reported).

[49] Excluding aircraft instruments, the average number of patents in pool subclasses is 2.32 per year, excluding variable condensers, the average number is 2.60.

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.[50] By 1940, the pool had expanded these agreements to include 17 foreign producers.

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.[51] As a result, outside firms whose inventions competed directly with any of the members faced a formidable opponent in production and potentially in court. Data on changes in patents and alternative measures of innovation for the 19th-century sewing machine pool suggest that such changes discourage innovation in pool technologies and divert the R&D efforts of outside firms (Lampe and Moser 2010, 2011).

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[50] *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).

[51] 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).

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. Grant back rules may encourage innovation by preventing hold-up by opportunistic pool members or discourage innovation by allowing member firms to free ride on the innovations of other members (Department of Justice and Federal Trade Commission 1995, Lerner, Strojwas, and Tirole 2007). Sixteen of 20 pools in our sample included grant-back rules; a coefficient of -0.46 for the interaction between *pool*pool patents* and *grant-backs* implies that an additional pool patent produced 0.46 fewer patents per year after the creation of a pool with grant-backs (significant at 1 percent, Table 9, column 1).

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),[52] and regulators are more likely to allow pools that license their

[52] 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..

technologies to outside firms.[53] Nine of 20 pools in our sample licensed their technologies to outside firms. The coefficient on *pool * pool patents * licensees* is negative at -0.13, but not statistically significant (Table 9, column 2), possibly because some pools used licensing as a mechanism to soften competition.[54]

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 -0.18, but not statistically significant (Table 8, 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 address the shortcomings of the current patent system. Pools, which allow competing firms to combine their patents, are expected to encourage innovation and the adoption of new technologies by resolving blocking patents and by reducing litigation risks as a result of overlapping patents (Bittlingmayer 1988; Lerner and Tirole, 2004, Shapiro, 2001). Data for the 19th-century sewing machine industry suggest that pools may discourage innovation (Lampe and Moser 2010, 2011), but there is no systematic empirical evidence across industries.

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[53] For example, the Department of Justice and Federal Trade Commission argued in 2007 that pools may pose a barrier to entry if existing relationships make it harder for "new firms to come in and overcome the patent thicket."

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

This paper has investigated effects on innovation for patent pools in 20 industries in the 1930s, the last golden age of pool creation before the current period. In the immediate aftermath of the Great Depression, regulators hoping to encourage economic recovery were relatively tolerant towards pools and other types of cooperation (e.g., Hawley 1966, Posner 1970, Haley 2001, Cole and Ohanian 2004), allowing for the creation of pools across a broad range of industries, similar to today.

Difference-in-differences analyses that compare changes in patenting across technologies that were differentially affected by the creation of a pool yield robust evidence that pools discouraged innovation. 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. These results are robust to the inclusion of subclass and year fixed effects, and subclass-specific trends to control for variation in the use of patents to protect intellectual property across technologies and over time, which could otherwise compromise the usefulness of patents as a measure of innovation (e.g., Moser 2012). Results are also robust to controls for the quality of patented inventions through historical citations, which we construct by searching U.S. patent documents between 1921 and 1975 for citations to the patents in our sample. Estimates are also robust to alternative definitions of the control group and conditional fixed effects Poisson regressions to control for the count data nature of patents.

Interestingly, anecdotal evidence suggests that patent pools may discourage innovation even as they enable the production of new technologies. 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" (Vaughan 1956, p. 67).[55]

What are the mechanisms by which patent pools discourage innovation? Difference-in-differences comparisons at the level of individual technologies indicate that the decline in patenting was strongest for technologies where more than one pool member was an active inventor before the creation of a pool, suggesting that pools may discourage innovation in pool technologies by weakening competition. This analysis exploits the fact that the creation of a pool limits the intensity of competition only in technology fields in which more than one pool member innovates, to investigate whether changes in the intensity of competition may drive the observed effects. For USPTO subclasses in which competing firms were active inventors before the creation of the pool, the creation of a pool weakens the intensity of competition. For USPTO subclasses in which all pool patents are owned by a single firm before the creation of a pool, the pool

[55] The Department of Justice finally dissolved the aircraft pool with a consent decree in 1975 because the "patent cross-license agreement amongst [the pool] and its 20 stockholder members lessened competition in research and development on, and acquisition of airplane patents" (Federal Register 40(142), July 23, 1975, p. 30848.) Bittlingmayer (1988, p. 240) cautions that even "if the agreement succeeded in curtailing research and development expenditures, it did so in a limited area of technology" because certain technology fields such as sound suppressors and fuel cells were excluded from the agreement," and consistent with the findings of this paper, pool members accounted for less than a quarter of all aerospace patents between 1968 and 1972.

has no direct effect on competition, even though complementarities with other pool technologies may increase the value of the pool technology in that subclass.

Difference-in-differences analyses suggest that patent pools may, in fact, discourage innovation if, and only if, they limit competition. Specifically, USPTO subclasses with more than 2 pool patents experience the strongest decline in innovation, and analyses at the firm level show the strongest decline in patenting in subclasses where a pool combined patents by 2 or more firms.

Historical court documents confirm these empirical results. Thus, the U.S. Supreme Court observed in 1948 that

> "Where two or more patentees with competitive non-infringing patents combine them and fix prices on all devices produced under any of the patents, competition is impeded to a greater degree than were a single patentee fixes prices for his licensees. The struggle for profit is less acute." (*United States v. Line Material Co.* (1948), p. 311).

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.

REFERENCES

Acs, Zoltan, and David Audretsch. "Innovation in Large and Small Firms – an Empirical Analysis." *American Economic Review*, 1988, 78(4), pp. 678-690.

Aghion, Philippe, Christopher Harris, Peter Howitt and John Vickers. "Competition, Imitation and Growth with Step-by-step Innovation." *Review of Economic Studies,* 2001, 68, pp. 467-92.

Aghion, Philippe, Nick Bloom, Richard Blundell, Rachel Griffith, and Peter Howitt. "Competition and innovation: an inverted-U Relationship." *Quarterly Journal of Economics,* 2005, 120(2), pp. 701-728.

Alchian, Armen. "Information Costs, Pricing, and Resource Unemployment." In *Microeconomic Foundation of Employment and Inflation Theory,* edited by Edmund S. Phelps et al. New York: Norton, 1970.

Aoki, Reiko, and Sadao Nagaoka. "The Consortium Standard and Patent Pools." *Hi-Stat Discussion Paper 32*, 2004.

Benner, Mary, and Joel Waldfogel. "Close to you? Bias and precision in patent-based measures of technological proximity." *Research Policy*, 2008, 37(9), pp. 1556-1567.

Bittlingmayer, George. "Property Rights, Progress, and the Aircraft Patent Agreement." *Journal of Law and Economics,* 1998, 31(1), pp. 227-248.

Ceccagnoli, Marco, Christopher Forman, and Wen Wen. "Patent Pools, Thickets, and the Open Source Software Entry by Start-up Firms." Georgia Institute of Technology working paper, January 2012.

Cohen, Wesley, Richard Nelson, and John Walsh. "Protecting Their Intellectual Assets: Appropriability Conditions and Why U.S. Manufacturing Firms Patent (or Not)." NBER Working Paper 7552, 2000.

Cole, Harold, and Lee Ohanian. "New Deal Policies and the Persistence of the Great Depression: A General Equilibrium Analysis." *Journal of Political Economy,* 2004, 112(4), pp. 779-816.

Department of Justice and Federal Trade Commission. "Antitrust Guidelines for the Licensing of Intellectual Property." DOJ and FTC: 1995.

Department of Justice and Federal Trade Commission. "Antitrust Enforcement and Intellectual Property Rights: Promoting Innovation and Competition," Washington, DC: GPO, 2007.

Dequiedt, Vianney, and Bruno Versaevel. "Patent Pools and the Dynamic Incentives to R&D." Working Paper No. 703, Groupe d'Analyse et de Théorie Économique, Université de Lyon, 2007.

Field, Alexander. "The Most Technologically Progressive Decade of the Century." *American Economic Review*, 2003, 93(4), pp. 1399-1414.

Field, Alexander. *A Great Leap Forward: 1930s Depression and U.S. Economic Growth.* New Haven, CT: Yale University Press, 2011.

Fisk, Catherine. "Removing the 'Fuel of Interest' from the 'Fire of Genius': Law and the Employee-Inventor, 1830-1930." *The University of Chicago Law Review*, 1998, 65(4), pp. 1127-1198.

Flamm, Kenneth. "A Tale of Two Standards: Patent Pools and Innovation in the Optical Disk Drive Industry." University of Texas at Austin working paper, January 2012.

Gans, Joshua, Scott Stern, and David Hsu. "The Impact of Uncertain Intellectual Property Rights on the Market for Ideas: Evidence for Patent Grant Delays." *Management Science*, 2008, 54(5), pp. 982-997.

Gilbert, Richard. "Antitrust for Patent Pools: A Century of Policy Evaluation." *Stanford Technology Law Journal*, 2004, no. 3 (April 2004): http://stlr.stanford.edu/STLR/Articles/04_STLR_3

Griliches, Zvi. "Patent Statistics as Economic Indicators: A Survey." *Journal of Economic Literature*, 1990, 28, pp. 1661-1707.

Haley, John. *Antitrust in Germany and Japan: The First Fifty Years, 1947-1998.* Seattle, WA: University of Washington Press, 2001.

Hall, Bronwyn, Zvi Griliches, and Jerry Hausman. "Patents and R&D: Is There a Lag?" *International Economic Review*, 1986, 27(2), pp. 265-283.

Hall, Bronwyn. Adam B. Jaffe, and Manuel Trajtenberg. "The NBER Patent Citation Data File: Lessons, Insights and Methodological Tools." NBER Working Paper 8498, 2001.

Hall, Bronwyn, and Rosemarie Ziedonis. "The Patent Paradox Revisited: An Empirical Study of Patenting in the U.S. Semiconductor Industry, 1979-1995." *The RAND Journal of Economics*, 2001, 32(1),pp. 101-128.

Hall, Bronwyn, Adam Jaffe, and Manuel Trajtenberg. "Market Value and Patent Citations." *The RAND Journal of Economics,* 2005, 36(1), pp. 16-38.

Hawley, Ellis. *The New Deal and the Problem of Monopoly: A Study in Economic Ambivalence.* Princeton, NJ: Princeton University Press, 1966.

Lampe, Ryan. "Strategic Citation." *The Review of Economics and Statistics,* 2012, v. 94(1), pp. 320-333.

Lampe, Ryan and Petra Moser. "Do Patent Pools Encourage Innovation? Evidence from the 19th-Century Sewing Machine Industry" *The Journal of Economic History*, 2010, 70(4), pp. 871-897.

Lampe, Ryan and Petra Moser. "Patent Pools and the Direction of R&D" (October 30, 2011). http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1468062.

Lampe, Ryan and Petra Moser. "Patent Pools and Licensing Strategies: Evidence from U.S. Industries Under the New Deal."

Layne-Farrar, Anne and Josh Lerner. "To Join or Not to Join: Examining Patent Pool Participation and Rent Sharing Rules" (January 7, 2008). Available at SSRN: http://ssrn.com/abstract=945189

Lee, Tom, and Louis Wilde. "Market Structure and Innovation: A Reformulation." *The Quarterly Journal of Economics*, 1980, 94(2), pp. 429-436.

Lerner, Josh, Marcin Strojwas, and Jean Tirole. "The Design of Patent Pools: The Determinants of Licensing Rules." *RAND Journal of Economics*, 2007, 38(3), pp. 610-625.

Lerner, Josh. "Patenting in the Shadow of Competitors." *Journal of Law & Economics*, 1995, 38(2), pp. 463-95.

Lerner, Josh, and Jean Tirole. "Efficient Patent Pools." *American Economic Review*, 2004, 94(3), 691-711.

Levin, Richard, Alvin Klevorick, Richard Nelson, and Sidney Winter. "Appropriating the Returns from Industrial Research and Development.'' Brookings Papers on Economic Activity, 1987, 3, pp. 783–820.

Loury, Glenn. "Market Structure and Innovation." *The Quarterly Journal of Economics*, 1979, 93(3), pp. 395-41.

Lucas, Robert E., Jr., and Leonard Rapping. "Unemployment in the Great Depression: Is There a Full Explanation?" *Journal of Political Economy*, 1972, 80(1), pp. 186-191.

Merges, Robert. "Institutions for Intellectual Property Transactions: The Case of Patent Pools." University of California at Berkeley, Working Paper, 1999.

Moser, Petra. "Innovation without Patents – Evidence from World's Fairs." *Journal of Law & Economics,* 2012, 55.

Moser, Petra, and Alessandra Voena. “Compulsory Licensing: Evidence from the Trading-with-the-Enemy Act.” *American Economic Review*, 2012, 102 (1), pp. 396-427.

Moser, Petra, Ohmstedt, Joerg and Rhode, Paul. “Patents, Citations, and Inventive Output - Evidence from Hybrid Corn” (July 24, 2011). Available at SSRN: http://ssrn.com/abstract=1888191

Nicholas, Tom. “The Role of Independent Invention in U.S. Technological Development, 1880-1930.” *Journal of Economic History*, 2010, 70(1), pp. 57-82.

Popp, David, Ted Juhl and Daniel Johnson. “Time in Purgatory: Examining the Grant Lag for U.S. Patent Applications." *Topics in Economic Analysis & Policy*, 2004, 4(1), Article 29.

Posner, Richard. “A Statistical Study of Antitrust Enforcement.” *Journal of Law and Economics*, 1970, 13(2), pp. 365-419.

Sanders, Barkev, “Some Difficulties in Measuring Inventive Activity.” In Richard Nelson (Ed.), *The Rate and Direction of Inventive Activity*, Princeton, NJ: Princeton University Press, 1962.

Shapiro, Carl. “Navigating the Patent Thicket: Cross Licenses, Patent Pools, and Standard Setting.” In Jaffe, Adam, Lerner, Josh, & Stern, Scott (Eds.), *Innovation Policy and the Economy*, Cambridge, MA: MIT Press, 2001.

Stubbs, Kevin. *Race to the Front: The Material Foundation of Coalition Strategy in the Great War.* Westport, CT: Greenwood Publishing Group, 2002.

Trajtenberg, Manuel, “A Penny for Your Quotes: Patent Citations and the Value of Innovations.” *RAND Journal of Economics*, 1990, 21(1), pp. 172-187,

United States Patent Office. *The Classification of Patents*. Washington, DC: GPO, 1915.

Vaughan, Floyd. *The United States patent system: legal and economic conflicts in American patent history*. Norman, OK: University of Oklahoma Press, 1956.

Williamson, Samuel. “Seven Ways to Compute the Relative Value of a U.S. Dollar Amount, 1774 to present.” MeasuringWorth, 2011.

Wooldridge, J.M. “Distribution-free estimation of some nonlinear panel data models.” *Journal of Econometrics*, 1999, 90(1), pp. 77-97.

Wright, Gavin. “The Political Economy of New Deal Spending: An Econometric

Analysis." *The Review of Economics and Statistics*, 1974, 56(1), pp. 30-38.

TABLE 1 - 20 PATENT POOLS FORMED BETWEEN 1930 AND 1938

Industry	Year Formed-Dissolved	Member Firms at Formation	Member Firms at Dissolution	Patents at Formation	Patents at Dissolution	Grant-back Rules	Licensees	Foreign Countries	Prior Litigation
High Tension Cables	1930-48	2	5	73	294	Yes	0	I, S	-
Water Conditioning	1930-51	3	4	4	130	Yes	0	UK, F, G	-
Fuel Injection	1931-42	4	4	22	171	Yes	0	G, UK, F	Yes
Pharmaceuticals	1932-45	2	2	5	110	Yes	0	G	-
Railroad Springs	1932-47	2	3	6	13	Yes	9	-	-
Textile Machines	1932-50	2	2	39	218	-	0	-	-
Hydraulic Oil Pumps	1933-52	2	2	3	44	Yes	0	-	-
Machine Tools	1933-55	5	5	3	9	Yes	0	-	-
Phillips Screws	1933-49	2	2	2	26	Yes	28	-	-
Color Cinematography	1934-50	2	2	59	162	Yes	0	-	-
Dry Ice	1934-52	4	4	36	58	Yes	0	-	-
Electric Generators	1934-53	2	2	30	222	Yes	0	G	-
Lecithin	1934-47	4	4	36	63	Yes	1	G, D	-
Variable Condensers	1934-53	3	3	60	74	Yes	3	-	Yes
Aircraft Instruments	1935-46	2	18	92	272	Yes	0	C, G, UK, I, F, S, J	-
Stamped Metal Wheels	1937-55	3	3	90	189	Yes	12	-	Yes
Wrinkle Paint Finishes	1937-55	2	2	20	77	Yes	185	-	Yes
Fuse Cutouts	1938-48	2	2	2	2	-	10	-	-
Ophthalmic Frames	1938-48	4	4	21	22	-	13	-	Yes
Furniture Slip Covers	1938-49	2	2	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=376)	2.64	2.51	2.58
1 pool patent (n=287)	2.32	2.35	2.34
2 pool patents (n=43)	2.82	2.94	2.88
More than 2 pool patents (n=46)	4.53	3.05	3.78
Control			
Cross-reference subclasses (n=730)	2.85	3.10	2.98
In the same main class (n=549)	2.89	3.16	3.02
All other subclasses in the same class (n=65,071)	0.99	1.11	1.06
Citations-weighted patents			
Pool subclasses (n=376)	10.25	15.61	12.91
1 pool patent (n=287)	9.24	15.02	12.11
2 pool patents (n=43)	11.78	18.12	14.88
More than 2 pool patents (n=46)	15.14	16.92	16.04
Control			
Cross-reference subclasses (n=730)	12.29	20.32	16.30
In the same main class (n=549)	12.22	20.76	16.46
All other subclasses in same class (n=65,071)	4.08	7.56	5.96

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	-0.376**	-0.411**	-0.379**
	(0.105)	(0.127)	(0.144)
Constant	2.015**	2.015**	2.493**
	(0.080)	(0.080)	(0.081)
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)	30,968	30,968	30,968
R-squared	0.550	0.550	0.578

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 376 (pool) subclasses with one or more pool patents. The control group consists of patent counts in 730 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	-1.419**	-0.995**	-0.804*
	(0.317)	(0.305)	(0.345)
Constant	6.576**	6.576**	12.251**
	(0.432)	(0.432)	(0.499)
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)	30,968	30,968	30,968
R-squared	0.474	0.474	0.497

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 376 subclasses as their primary subclass. There are 376 (pool) subclasses with one or more pool patents. The control group consists of patent counts in 730 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				Citations-weighted patents	
	(1)	(2)	(3)	(4)	(5)	(6)
Pool * 1 pool patent	-0.094	-0.286			-0.198	
	(0.156)	(0.172)			(0.999)	
Pool * 2 pool patents	0.045	-0.017			1.047	
	(0.471)	(0.471)			(2.975)	
Pool * more than 2 pool patents	-1.713**	-1.517**			-4.768*	
	(0.580)	(0.599)			(2.145)	
Pool * pool patents * pool patents owned by 1 firm			-0.308	-0.317		-0.228**
			(0.261)	(0.295)		(0.607)
Pool * pool patents * pool patents owned by > 1 firm			-0.463**	-0.410**		-1.390**
			(0.120)	(0.123)		(0.340)
Constant	2.015**	2.469**	2.015**	2.491**	6.576**	6.576**
	(0.080)	(0.087)	(0.080)	(0.086)	(0.432)	(0.432)
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)	30,968	30,968	30,968	30,968	30,968	30,968
R-squared	0.549	0.578	0.550	0.579	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 376 (pool) subclasses with one or more pool patents. The control group consists of patent counts in 730 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	Citation-weighted	Raw patents	Citation-weighted	Raw patents	Citation-weighted
	(1)	(2)	(3)	(4)	(5)	(6)
Pool*pool patents	-0.413**	-1.042**	-0.437**	-0.874**	-0.389**	-1.004**
	(0.127)	(0.305)	(0.122)	(0.307)	(0.125)	(0.296)
Constant	1.982**	6.424**	0.951**	3.072**	2.010**	6.571**
	(0.088)	(0.471)	(0.006)	(0.032)	(0.079)	(0.427)
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)	25,900	25,900	1,852,956	1,852,956	30,968	30,968
R-squared / Log-likelihood	0.526	0.454	0.516	0.393	0.553	0.474

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 376 (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 pools that formed after NIRA found unconstitutional in 1935	
	Raw patents (1)	Citation-weighted (2)	Raw patents (3)	Citation-weighted (4)
Pool*pool patents	-0.088**	-0.074**	-0.346**	-0.890**
	(0.017)	(0.017)	(0.104)	(0.276)
Constant			1.806**	6.237**
			(0.094)	(0.535)
Subclass fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Linear and quadratic trends	Yes	Yes	Yes	Yes
Standard errors clustered at the subclass level; ** significant at 1 percent, * significant at 5 percent.				
N (# subclasses * 28 years)	30,968	30,968	19,460	19,460
R-squared / Log-likelihood	-56631	-220419	0.552	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 376 (pool) subclasses with one or more pool patents. Columns (9) and (10) 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	-0.460**	-0.410**	-0.420**	-0.408**	-0.406**	-0.447**	-0.411**
	(0.144)	(0.127)	(0.133)	(0.127)	(0.128)	(0.128)	(0.127)
Constant	2.035**	2.024**	1.962**	2.031**	2.009**	2.026**	2.015**
	(0.085)	(0.080)	(0.079)	(0.080)	(0.080)	(0.081)	(0.080)
Subclasses*years	28,140	30,576	29,484	30,604	30,716	29,652	30,772
R-squared	0.55	0.55	0.55	0.55	0.56	0.55	0.55

	Machine Tools	Phillips Screws	Color Cinema.	Dry Ice	Electric Gen.	Lecithin	Variable Cond.
Pool*pool patents	-0.410**	-0.409**	-0.428**	-0.403**	-0.403**	-0.414**	-0.366*
	(0.127)	(0.127)	(0.130)	(0.132)	(0.128)	(0.128)	(0.151)
Constant	2.018**	2.018**	2.105**	2.011**	2.020**	2.107**	1.981**
	(0.080)	(0.080)	(0.088)	(0.082)	(0.080)	(0.085)	(0.082)
Subclasses*years	30,744	30,828	27,664	28,672	28,224	28,504	29,512
R-squared	0.55	0.55	0.55	0.55	0.55	0.55	0.55

	Aircraft Instr.	Metal Wheels	Wrinkle Finishes	Fuse Cutouts	Ophth. Frames	Slip Covers
Pool*pool patents	-0.337**	-0.412**	-0.418**	-0.412**	-0.420**	-0.411**
	(0.097)	(0.147)	(0.130)	(0.127)	(0.129)	(0.127)
Constant	1.865**	1.982**	2.020**	2.021**	2.021**	2.019**
	(0.086)	(0.081)	(0.082)	(0.080)	(0.081)	(0.080)
Subclasses*years	24,808	27,972	29,652	30,828	30,128	30,912
R-squared	0.54	0.56	0.55	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.

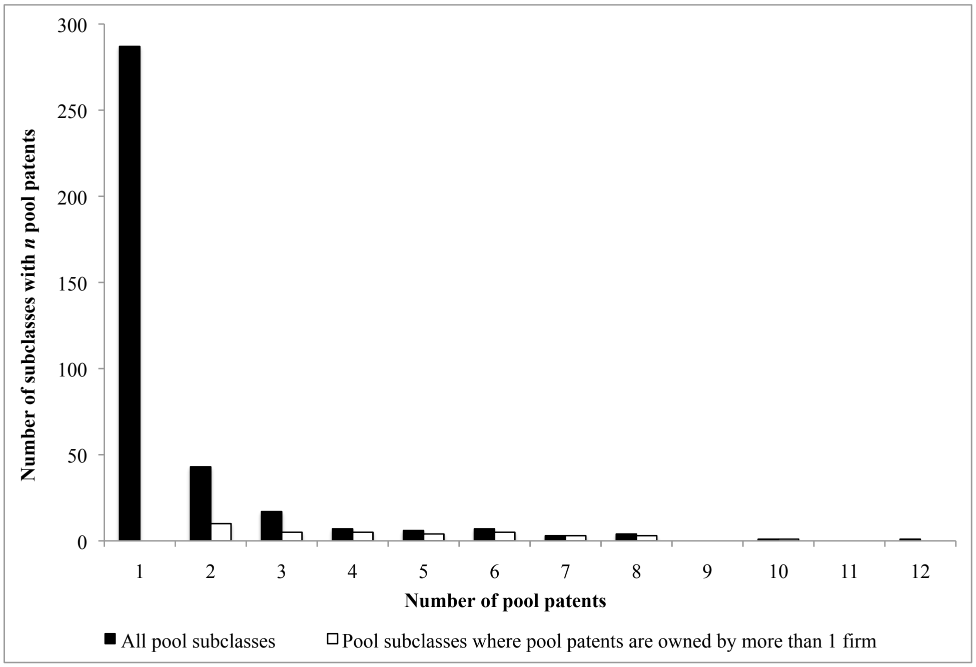
Notes: The dependent variable counts patents per subclass and year. The timing of invention is measured by the application year for granted patents. The variable *pool* equals 1 for years after the pool forms. *Pool patents* counts patents that were included in the initial pooling agreement and list subclass *c* as their primary subclass. There are 376 (pool) subclasses with one or more pool patents. The control group consists of patent counts in 730 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	0.016	-0.343	-0.312
	(0.136)	(0.190)	(0.210)
Pool * pool patents * grant-backs	-0.458**		
	(0.155)		
Pool * pool patents * licensees		-0.128	
		(0.203)	
Pool * pool patents * prior litigation			-0.175
			(0.216)
Constant	2.015**	2.015**	2.015**
	(0.079)	(0.080)	(0.079)
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)	30,968	30,968	30,968
R-squared	0.550	0.550	0.550

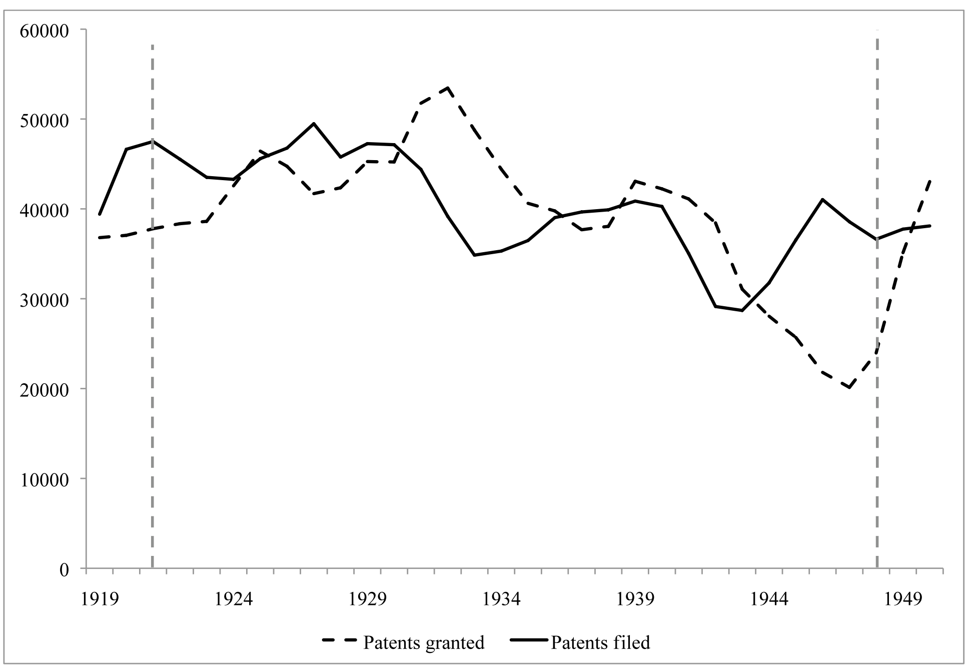
Notes: The timing of invention is measured by the application year for granted patents. The variable *pool* equals 1 for years after the pool forms. *Pool patents* counts patents that were included in the initial pooling agreement and list one of 376 subclasses as their primary subclass. There are 376 (pool) subclasses with one or more pool patents. The control group consists of patent counts in 730 cross-reference subclasses that patent examiners have identified as related technologies. The dummy variable *grant-backs* equals 1 for 16 pools that included 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 – VARIATION IN THE NUMBER OF POOL PATENTS



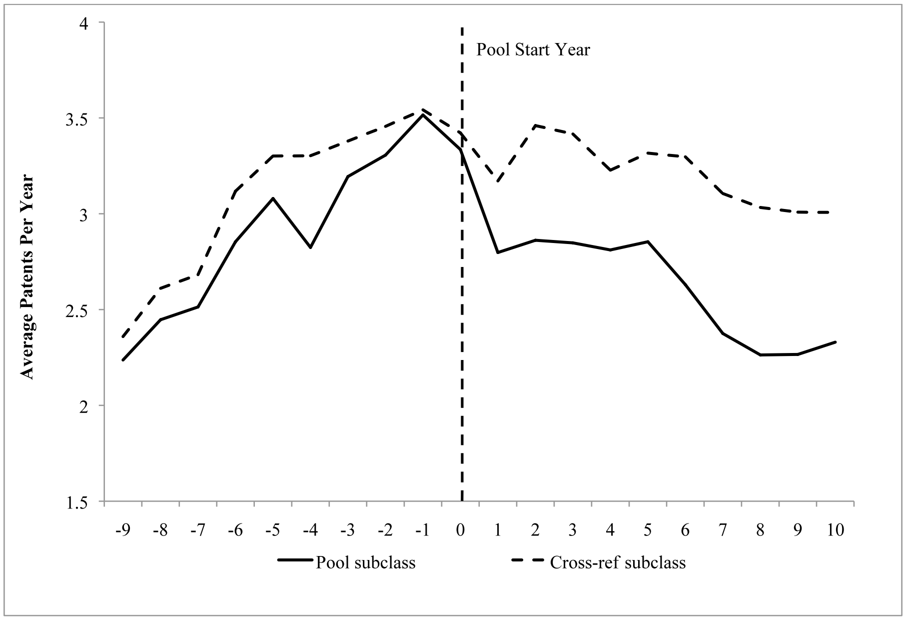
Notes: Data include 376 pool subclasses that include at least one pool patent. 43 pool subclasses include 2 pool patents, 10 of these subclasses include pool patents by more than firm; 46 pool subclasses include more than 2 pool patents; 26 of these subclasses include pool patents by more than one firm.

FIGURE 2 – PATENT COUNTS PER YEAR OF APPLICATION AND GRANT



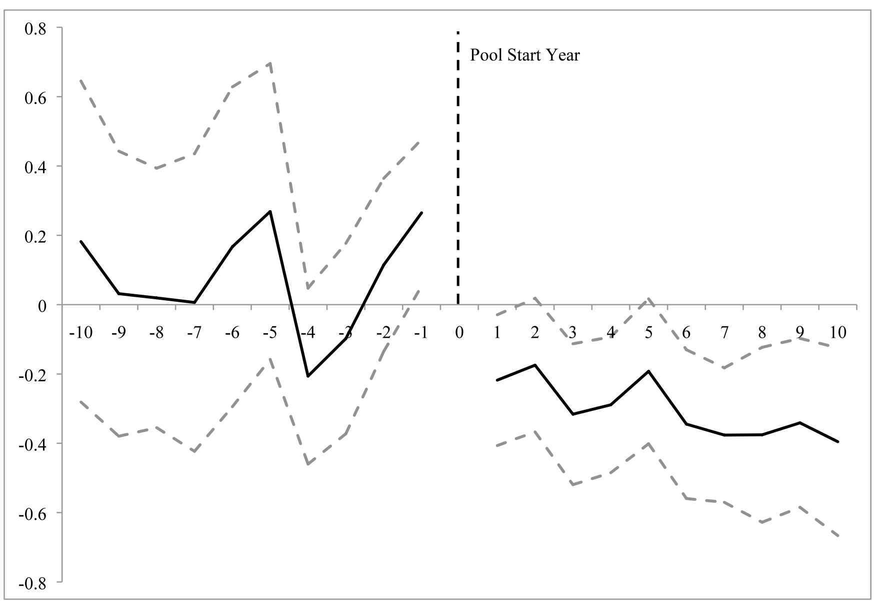
Notes: Patents per year of application and grant for granted U.S. patents. We collected data on filing years through an key word search of the full text of patent grants between 1920 and 1975, available at www.google.com/patents. This graph reveals truncation bias for patent applications before 1921; 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 3 – PATENTS PER SUBCLASS AND YEAR: POOL VERSUS CROSS-REFERENCE SUBCLASSES



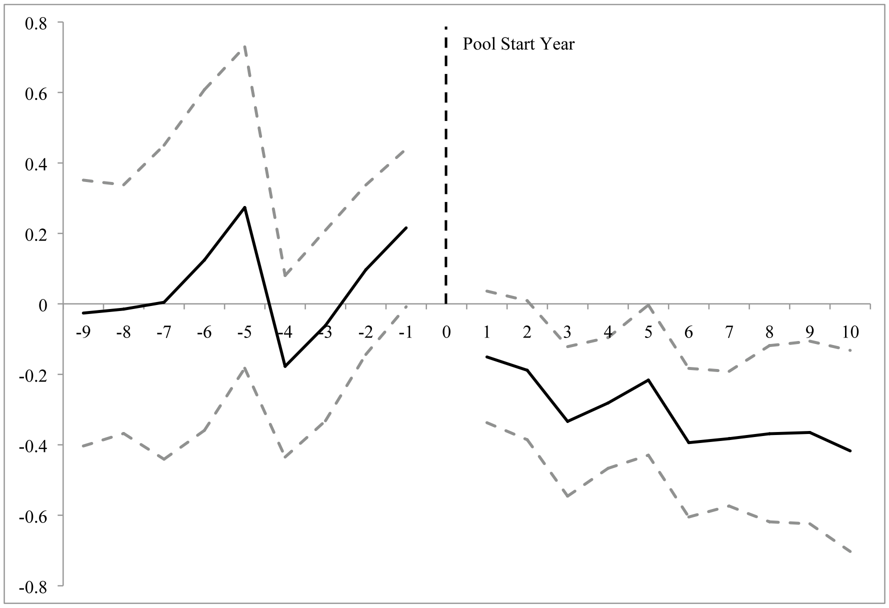
Notes: Data include 376 *pool subclasses* that include at least one pool patent and 730 *cross-reference subclasses* are subclasses that patent examiners identified as related technologies for pool patents. The timing of invention is measured by the year of the patent application; t=0 denotes the year when the pool formed.

FIGURE 4 – ANNUAL COEFFICIENTS, OLS,
DEPENDENT VARIABLE IS PATENTS PER SUBCLASS AND YEAR



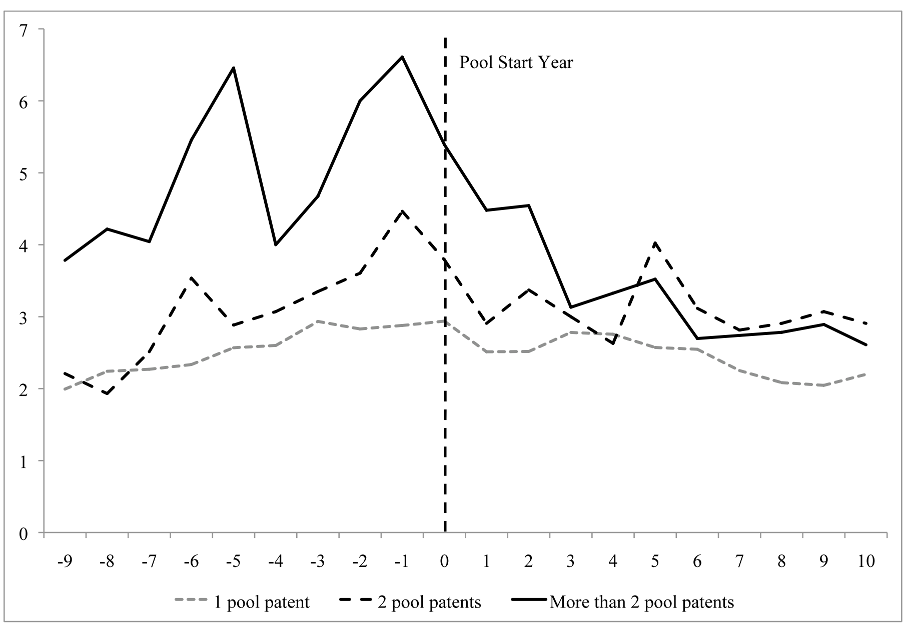
Notes: Coefficient estimates for β_k in the regression $Patents_{ct} = \alpha + \beta_k * Pool\ Patents_c + f_c + \delta_t + \varepsilon_{ct}$ where k =-17, ….17, 18, counts years before and after a pool forms. The timing of invention is measured at the year of the patent application; t=0 denotes the 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 376 (pool) subclasses with one or more pool patents. The control group consists of patent counts in 730 cross-reference subclasses that patent examiners have identified as related technologies.

FIGURE 5 – ANNUAL COEFFICIENTS, OLS WITH INDUSTRY-YEAR INTERACTIONS
DEPENDENT VARIABLE IS PATENTS PER SUBCLASS AND YEAR



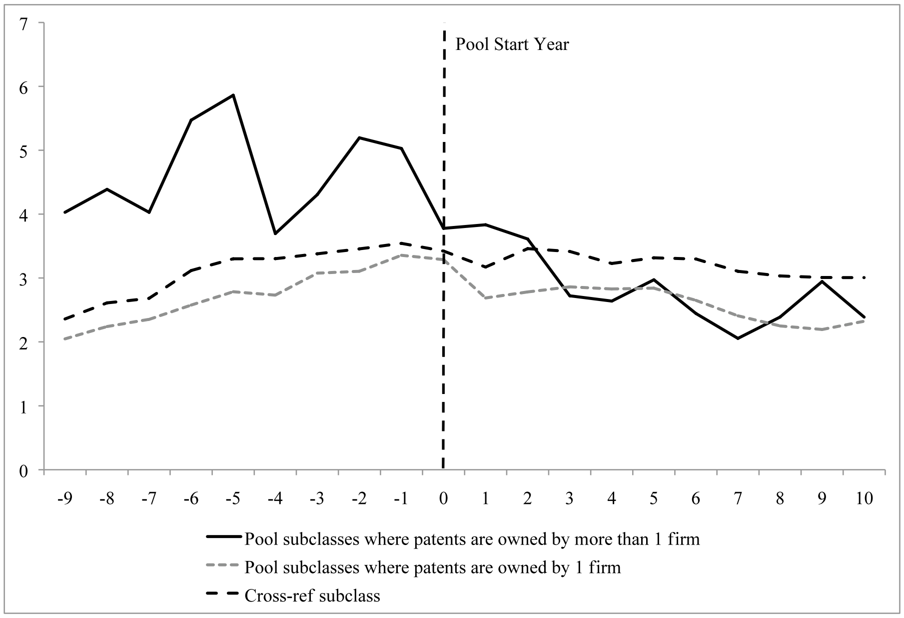
Notes: Coefficient estimates for β_k in the regression $Patents_{cit} = \alpha + \beta_k * Pool\ Patents_c + f_c + i_c*\delta_t$ where k =-17, ….17, 18, counts years before and after a pool forms, and $i_c*\delta_t$ represents interactions between industry and year fixed effects. The timing of invention is measured by the year of the patent application; t=0 denotes the year when the pool formed.

FIGURE 6 – PATENTS PER SUBCLASS AND YEAR:
VARIATION IN THE NUMBER OF POOL PATENTS ACROSS POOL SUBCLASSES



Notes: Data include 287 pool subclasses with *1 pool patent,* 43 pool subclasses with *2 pool patents*, and 46 pool subclasses with *more than 2 pool patents* include 3 or more pool patents. 10 subclasses with 2 pool patents include pool patents by more than 1 firm; 26 subclasses with more than 2 pool patents include pool patents by more than 1 firm.

FIGURE 7 – PATENTS PER SUBCLASS AND YEAR:
VARIATION IN THE NUMBER OF FIRMS THAT OWN POOL PATENTS IN A POOL SUBCLASS



Notes: Data include 376 subclasses in 103 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.