DO PATENT POOLS ENCOURAGE INNOVATION? EVIDENCE FROM 20 INDUSTRIES IN THE 1930S

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Patent pools, which allow competing firms to combine their patents as if they are a single firm, have become one of the most prominent mechanisms to address problems with the current patent system. Regulators expect pools to encourage innovation by limiting litigation risks for pool members and by lowering transaction costs and license fees for outside firms. There is, however, no empirical evidence on the effects of contemporary pools on innovation because modern pools are too recent to observe their effects on innovation. This paper investigates patent pools in 20 industries that formed from 1930 to 1938, the last golden age of patent pools before the current period. Difference-in-difference estimates across industries indicate a substantial *decline* in patenting after the formation of a pool. An analysis at the level of individual technologies indicates that the decline is 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.

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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 that are inefficiently high (Merges 1999; Shapiro 2001, p. 134).[2]

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[1] For example, the Medicines Patent Pool, a pool developed by UNITAID to improve access to HIV treatments in developing countries, recently announced its first licensing agreement with a pharmaceutical company, Gilead Sciences. In April 2010 MPEG LA, which previously organized patent pools for video compression standards, announced the development of a patent pool for diagnostic genetic tests. Finally, 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

Patent pools may, however, also discourage innovation if they reduce the intensity of competition by allowing firms to pool patents for substitute technologies that could otherwise replace each other. Although these effects are difficult to examine with contemporary data, historical data indicate that a pool that formed in the 19th-century sewing machine discouraged 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).

This paper investigates evidence from an earlier "golden age" of patent pools in the 1930s, when regulators allowed pools to form as part of the New Deal program to end the Great Depression. 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 wages, created a favorable environment for pools and other types of cooperative agreements.[3]

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a technology. While pools that combine complementary patents reduce license fees, theoretical models predict that pools that combine substitute patents may increase license fees (Lerner and Tirole 2004).

[3] By 1934, NRA codes covered over 500 industries, which accounted for nearly 80 percent of private non-agricultural employment. Excluded sectors were steam railroads, nonprofit organizations, domestic services, and professional services (Cole and Ohanian 2004, p. 784). Even after the Supreme Court ruled in 1935 that the NIRA was unconstitutional, the U.S. government continued to tolerate collusion and price fixing in many industries (Hawley 1966). 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-

> "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).

Statements in the 1930s anticipate arguments for patent pools today. In 1931, for example, the U.S. Supreme Court upheld the Standard Oil pool for gasoline cracking even though it controlled 55 percent of output for cracked gasoline[4] because

> "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).

Regulators continued to tolerate pools until President Roosevelt appointed Thurman Arnold to reorganize the Antitrust Division of the Department of Justice in 1938. 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).

With respect to patent pools, the U.S. Supreme Court's 1942 decision to break up the *Hartford Empire* pool marked a definite turning point. Hartford Empire had grown to include more than 600 patents, which covered machinery to produce 94 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 (*Harford Empire Co. v. U.S.* 323 U.S. 386, 400

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owned inventions under the Trading-with-the-Enemy Act after World War I (Moser and Voena 2011).

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

(Jan., 1945)). Few pools formed after *Hartford Empire* until the Department of Justice approved the MPEG and DVD standards pools in 1997 and 1999.

This paper take 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. 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 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 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.

Pool patents are identified from primary documents at the National Archives in Chicago, Kansas City, New York City, and Riverside. Twenty patent pools that formed between 1930 and 1938 covered a total of 606 pool patents in 1,106 USPTO subclasses. Data on changes in patenting include application years and subclass information for 70,052 U.S. patents between 1921 and 1948 in 1,106 USPTO subclasses that include at least one pool patent or were identified by a patent examiner as a related technology. An additional search captures citations to these 70,052 patents by patents that were granted after 1921.

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.[5] To address this issue, we estimate

[5] 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

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.[6] In years 6 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 innovation. It takes advantage of the fact 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 structure of innovation 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

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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.

[6] 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).

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.[7]

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., Lerner and Tirole 2004) the 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.

Another set of tests address the issue that patent data may be an imperfect measure of changes in innovation across technologies and over time because the share of innovations that are patented varies across technologies and over time (Moser 2012). To address this, all regressions include subclass and year fixed effects as well as linear and quadratic time trends at the subclass level to control for variation in the mapping between patents and innovation over time.

In additional tests, citations-weighted patent counts control for the quality of patented inventions.[8] Controlling for citations by later patents also help to

[7] Previous analyses have used the existence of private or federal antitrust litigation as a way to distinguish pools of substitute patents (which are more likely to violate antitrust regulation) from pools of complementary patents (Lerner, Strojwas, and Tirole 2007). Litigation is, however, commonly triggered by price-fixing provisions or a pool's refusal to accept new members, which may affect pools of substitute as well as complementary patents (Lernger, Strojwas, and Tirole 2007, p. 619). Thirty-seven of 63 pools that formed between 1895 and 2001 were litigated.

[8] Using hedonic estimates of social value, Trajtenberg (1990) finds that patents for socially valuable improvements in CAT scanners were more heavily cited by later patents. Citations are also positively correlated with the size of patented inventions in hybrid corn, where the size of inventions is measured by improvements in yields and other characteristics of hybrid corn (Moser, Ohmstedt, and Rhode 2011).

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. To address this, we examine changes in citations-weighted patenting. These data indicate that subclasses with an additional pool patent produce 8 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 5) and for subclasses with more than two pool patents (with a 30 percent decline).[9]

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.

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 evidence for these two industries suggests two mechanisms by which pools may

[9] 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).

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.[10] Patents for three pools are listed in written opinions, and patents for two pools are listed in the original license agreements.[11]

[10] 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)
[11] In comparison with Vaughan (1956), our data omit a relatively short-lived pool for parking meters (1937-46). In comparison with Lerner, Strojwas, and Tirole's (2007) sample of 28 pools between 1930 and 39, our sample includes 8 additional pools, and currently omits 12 pools that were the subject of Congressional hearings but were not subject to antitrust litigation and therefore not available at the National Archives that we have visited so far. Our sample also excludes the 1937 male hormones pool because it lasted for fewer than 10 years, and the 1931 pool for grinding

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).[12]

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.

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;[13] 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

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hobs because it combined two patents by the same firm (the Barber-Colman Company); we also excluded two pools that formed in 1938 (for pour depressants and induction heat treatments), because we could not find a list of patents for these pools. For long-lived pools, the data may miss patents that were included early in the pool, but had expired by the time the pool was litigated.

[12] 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.

[13] In the language of the Patent Office, owners who are not the original inventors are referred to 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).

one primary (pool) subclass, which covers the key technology areas of each pool patent.[14] For example, U.S. patent 1,908,080 for the (Phillips) "screw" falls into primary subclass 403 ("externally threaded fastener element") within the main class 411 ("expanded…locked-threaded fastener"). In addition to the primary subclass, the patent examiner may also assign a patent to one or more secondary, cross-reference subclasses. For example, U.S. patent 1,908,080 for the Phillips screw is assigned to cross-reference subclasses 411/919 ("screw having driving contact"), 470/60 ("apparatus for making externally threaded fastener"), 470/9 ("threaded, headed fastener, or washer making: process-screw"), and 16/DIG.39 ("miscellaneous hardware-adjustment means"). The average pool patent is assigned to 2.1 cross-reference subclasses in addition to its primary class.[15]

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.[16]

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

[14] In the language of the Patent Office, these technology areas are "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).

[15] The average patent pool covers 18.8 primary subclasses and 36.5 cross-reference subclasses.

[16] 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.[17] This search yields application years for 97.7 percent of 1,069,414 patents issued between 1921 and 1948,[18] With an mean lag between application and grant of 2.7 years and a standard deviation of 1.9 years (Figure 2).[19]

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.[20]

[17] For example, we search the full text of patent grants for the words "iling" (for "Filing") and "Ser." (for "Serial Number") to recover the year associated with this block of text.
[18] In a random sample of 300 patents, application years were correctly recorded for 296 patents.
[19] In comparison, Popp, Juhl, and Johnson (2004) find that the average U.S. patent between 1976 and 1996 was granted 28 months after the application (with a standard deviation of 20 months).
[20] 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. Unlike citations in scholarly journals, 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 own innovations. 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).

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 the 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.[21]

These data collection yield a total of 220,583 citations from patents between January 4, 1921 and December 31, 1974 to 70,052 unique patents in our

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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.

[21] 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.

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, 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.[22] 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).

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[22] Citations data in Nicholas (2010, p. 63) indicates 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 the current data set.

A. Baseline estimates

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

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

where *pool patents*$_c$ counts the number of pool patents that list subclass *c* as their primary subclass, and *pool*$_{ct}$ equals 1 for subclasses with pool patents for all years after the creation of a pool.[23] 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.[24]

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

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[23] 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.

[24] 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).

for the difference-in-differences estimator $pool_{ct}$ * $pool\ patents_c$ measures the causal effect of a pool. Year fixed effects δ_t and subclass-fixed effects f_c, as well as separate linear and quadratic trends t * $pool\ subclass_c$ and t^2 * $pool\ subclass_c$ control for changes in patents per year across pool and cross-reference subclasses that are independent of the creation of a pool.

OLS estimates indicate that subclasses with one additional pool patent produce 0.41 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.

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, indicating that pools are more likely to form after an increase in patenting.[25]

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 -0.44 implying a decline of 17.08 percent for years six and above (significant at the 5 percent level in years 1, 3, 4 and all years above 6, Figure 5).

B. Subclasses where pools combine patents by competing firms

How may patent pools discourage innovation? One potential mechanism is a decline in the intensity of competition if pools combine patents by competing firms. If the decline in patenting is a result of reduced competition for pool technologies, the creation of a pool should create differential effects across subclasses with one or more than one pool patents. In subclasses with only one

[25] The increase in patenting immediately before the pool is consistent with two alternative explanations. First, a patent pool may form in response to an increase in the threat of litigation, which results in an increase in strategic patenting (e.g., Hall and Ziedonis 2001). These results are consistent with evidence from non-patent measures of innovation, which show no comparable increase in innovation immediately preceding the creation of a pool (Lampe and Moser 2010). Alternatively, the increase in patent applications may reflect a race to patent technologies to be included in the pool (Dequiedt and Versaevel 2007). Such a race may lead to a wasteful duplication of effort because firms do not take into account the parallel nature of their research (e.g. Loury 1979; Lee and Wilde 1980).

pool patent, the creation of a pool does not affect competition, because a single firm is an active inventor in that technology already. In subclasses with two or more pool patents, however, the formation of a pool may combine patents by two or more firms that innovate to remain competitive.[26]

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 10 years before and after the creation of a pool increases the relative decline. Pool subclasses with more than 2 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

[26] 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 et al. (2005) establish an inverted-U shape relationship in U.K. patents issued to 311 firms between 1973 and 1994.

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 3, column 3).

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 10 years before the creation of a pool to 2.80 patents per year across 10 years afterwards (Figure 6). 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 firms is associated with 0.41 fewer patents (significant at 1 percent, Table 4, column 2), implying a 15.92 percent decline relative to mean of 2.58 patents per year in pool subclasses.

C. 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.[27] 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, or by encouraging firms that could not afford to defend their patents in court from patenting their innovations.[28]

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

[27] 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).

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

Citations-weighted patents$_{ct}$ = *patents by application year 1921-1948*$_{ct}$ + *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 patents granted 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; Figure 7).

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. Subclasses with an additional pool patent produce 1.00 fewer citations-weighted patents after a pool has formed (significant at 1 percent, Table 5, column 2), implying a 7.71 percent decline in citations-weighted patents after the creation of a pool.

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, Figure 8). 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).[29]

Citations-weighted counts also confirm that the decline in patenting is strongest for subclasses where the pool combines patents by competing firms.[30] 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 4). 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 4). 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 competing firms. Subclasses where pool patents were owned by more than one firm produce 1.35 fewer citation-weighted patents after the creation of a pool (significant at 1 percent, Table 4, column 4), implying a decline of 10.47 percent.

D. Robustness checks

[29] With the caveat that citations are subject to a large amount of measurement error, the fact that estimated effects are slightly smaller for citations-weighted patents suggests that the creation of a pool may lead to a slight increase in the average quality of innovations that pool members and outside firms choose to patent. For example, the creation of a pool that reduces litigation risks for members and increases litigation risks for outside firms (e.g., Lampe and Moser 2010 and 2012) may reduce the need for members to strategically patent minor inventions and discourage outside firms from patenting anything except their most significant inventions. Consistent with this idea, we find that patents for which members apply after a pool forms are more likely to be cited. A large portion of the observed increase may, however be due to the fact that more recent patents are more likely to be cited. 606 pool patents that members filed until a pool formed received an average of 2.93 citations, while 1,554 pool patents that members filed after a pool formed received an average of 3.90 citations.

[30] 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.

A series of robustness checks estimates the main specifications with alternative definitions of the control group, without pool patents, as Poisson regressions, 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. 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"). 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).

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.[31] 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

[31] 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.

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).[32] These estimates imply that subclasses with one additional pool patent produce 8.42 percent fewer raw patents and 7.13 percent fewer citation-weighted patents after the creation of a pool (significant at 1 percent, Table 6, columns 7 and 8).[33]

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

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[32] 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.

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

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 7).[34] 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 7).

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.[35] 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

[34] 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.
[35] *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).

$9,000, roughly $150,000 dollars in 2011.[36] 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 of outside firms (Lampe and Moser 2010, 2011).

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.

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

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[36] 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).

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).[37]

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 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

[37] 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.

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.

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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	Grant-back Rules	Patents at Dissolution	Licensees	Foreign Countries	Prior Litigation
High Tension Cables	1930-48	2	6	73	Yes	294	0	I, S	-
Water Conditioning	1930-51	3	4	4	Yes	130	0	UK, F, G	-
Fuel Injection	1931-42	4	4	22	Yes	171	0	G, UK, F	Yes
Pharmaceuticals	1932-45	2	2	5	Yes	110	0	G	-
Railroad Springs	1932-47	2	3	6	Yes	13	9	-	-
Textile Machines	1932-50	2	2	39	-	218	0	-	-
Hydraulic Oil Pumps	1933-52	2	2	3	Yes	44	0	-	-
Machine Tools	1933-55	5	5	3	Yes	9	0	-	-
Phillips Screws	1933-49	2	2	2	Yes	26	28	-	-
Color Cinematography	1934-50	2	2	59	Yes	162	0	-	-
Dry Ice	1934-52	4	4	36	Yes	58	0	-	-
Electric Generators	1934-53	2	2	30	Yes	222	0	G	-
Lecithin	1934-47	5	5	36	Yes	63	1	G, D	-
Variable Condensers	1934-53	3	3	60	Yes	74	3	-	Yes
Aircraft Instruments	1935-46	2	18	92	Yes	272	0	C, G, UK, I, F, S, J	-
Stamped Metal Wheels	1937-55	3	3	90	-	189	11	-	Yes
Wrinkle Paint Finishes	1937-55	2	2	20	-	77	200	-	Yes
Fuse Cutouts	1938-48	2	2	2	-	2	10	-	-
Ophthalmic Frames	1938-48	4	4	21	-	22	14	-	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)	2.644	2.506	2.576
1 pool patent (n=287)	2.321	2.354	2.337
2 pool patents (n=43)	2.823	2.942	2.881
More than 2 pool patents (n=46)	4.526	3.046	3.778
Control			
Cross-reference subclasses (n=730)	2.854	3.102	2.978
In the same main class (n=549)	2.888	3.156	3.021
All other subclasses in the same class (n=65,071)	0.992	1.110	1.056
Citations-weighted patents			
Pool subclasses (n=376)	10.248	15.605	12.907
1 pool patent (n=287)	9.245	15.019	12.109
2 pool patents (n=43)	11.779	18.122	14.877
More than 2 pool patents (n=46)	15.143	16.922	16.042
Control			
Cross-reference subclasses (n=730)	12.288	20.325	16.301
In the same main class (n=549)	12.218	20.756	16.457
All other subclasses in same class (n=65,071)	4.078	7.563	5.959

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**	
	(0.105)	(0.127)	
Pool * 1 pool patent			-0.094
			(0.156)
Pool * 2 pool patents			0.045
			(0.471)
Pool * more than 2 pool patents			-1.713**
			(0.580)
Constant	2.015**	2.015**	2.015**
	(0.080)	(0.080)	(0.080)
Subclass fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Linear and quadratic trends	-	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	0.549

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 – PATENT OWNERSHIP (FIRM-LEVEL DATA)
DEPENDENT VARIABLE IS PATENTS PER SUBCLASS AND YEAR

	Raw patents		Citations-weighted patents	
	(1)	(2)	(3)	(4)
Pool * pool patents	-0.411**		-0.995**	
	(0.127)		(0.305)	
Pool * pool patents * pool patents owned by more than 1 firm		-0.410**		-1.351**
		(0.114)		(0.346)
Constant	2.015**	2.015**	6.576**	6.576**
	(0.080)	(0.081)	(0.432)	(0.360)
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	30,968	30,968
R-squared	0.550	0.545	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 5: OLS – DEPENDENT VARIABLE IS CITATIONS-WEIGHTED PATENTS

	(1)	(2)	(3)
Pool * pool patents	-1.419**	-0.995**	
	(0.317)	(0.305)	
Pool *1 pool patent			-0.198
			(0.999)
Pool * 2 pool patents			1.047
			(2.975)
Pool * more than 2 pool patents			-4.768*
			(2.145)
Constant	6.576**	6.576**	6.576**
	(0.432)	(0.432)	(0.432)
Subclass fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Linear and quadratic trends	-	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	0.474	0.474	0.474

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 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		Excluding all pool-owned patents; control is all cross-reference subclasses		Conditional fixed-effects Poisson; control is all cross-reference subclasses	
	Raw patents (1)	Citation-weighted (2)	Raw patents (3)	Citation-weighted (4)	Raw patents (5)	Citation-weighted (6)	Raw patents (7)	Citation-weighted (8)
Pool*pool patents	-0.413**	-1.042**	-0.437**	-0.874**	-0.389**	-1.004**	-0.088**	-0.074**
	(0.127)	(0.305)	(0.122)	(0.307)	(0.125)	(0.296)	(0.017)	(0.017)
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	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Linear and quadratic trends	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Standard errors clustered at the subclass level; ** significant at 1 percent, * significant at 5 percent.							
N (# subclasses * 28 years)	25,900	25,900	1,852,956	1,852,956	30,968	30,968	30,968	30,968
R-squared / Log-likelihood	0.526	0.454	0.516	0.393	0.553	0.474	-56631	-220419

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 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: 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

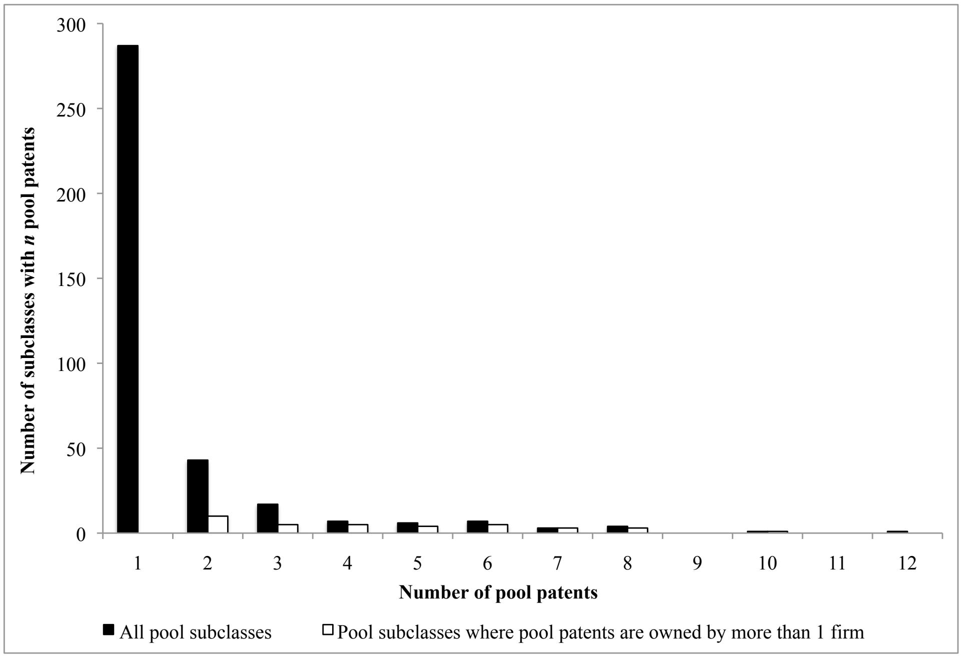
	Machine Tools	Phillips Screws	Color Cinema.	Dry Ice	Electric Gen.	Lecithin	Variable Cond.
Pool*pool patents	-0.410**	-0.409**	-0.428**	-0.403**	-0.403**	-0.414**	-0.366*
	(0.127)	(0.127)	(0.130)	(0.132)	(0.128)	(0.128)	(0.151)
Constant	2.018**	2.018**	2.105**	2.011**	2.020**	2.107**	1.981**
	(0.080)	(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.

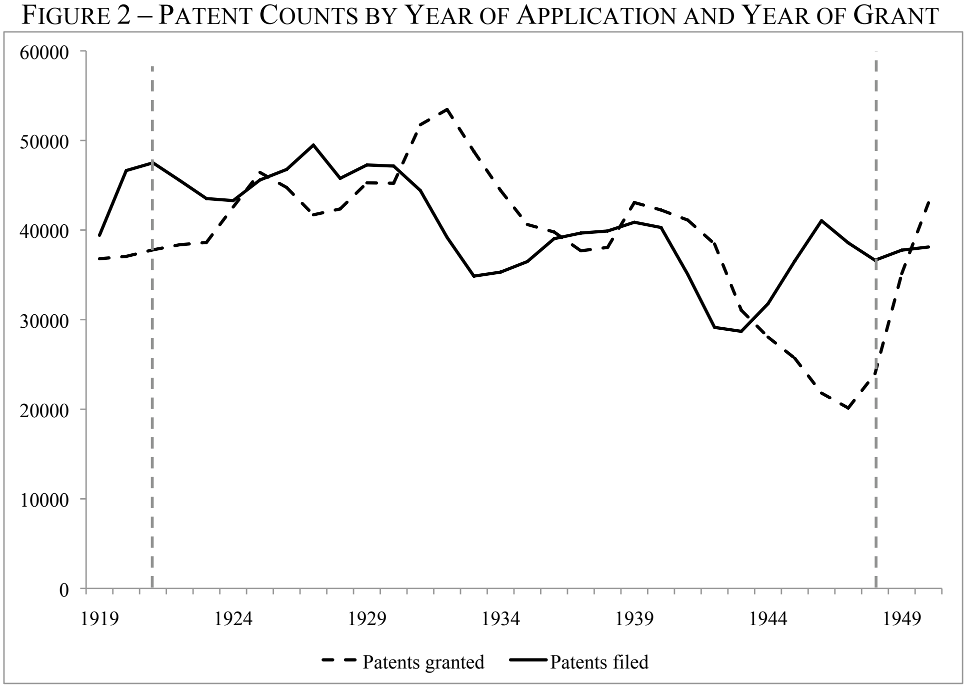
Notes: The dependent variable counts patents per subclass and year. The timing of invention is measured by the application year for granted patents. The variable *pool* equals 1 for years after the pool forms. *Pool patents* counts patents that were included in the initial pooling agreement and list 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.

FIGURE 1 – VARIATION IN THE NUMBER OF POOL PATENTS



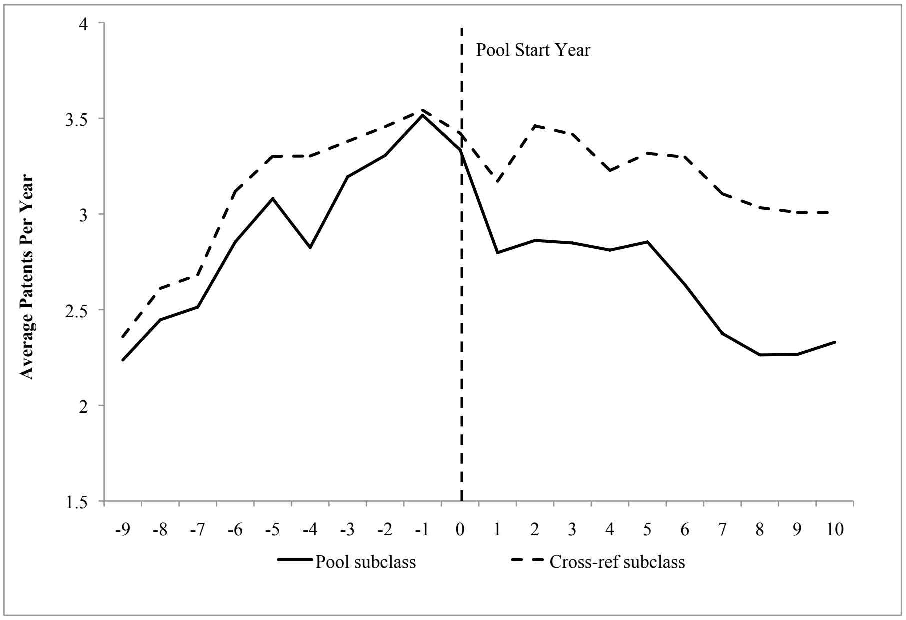
Notes: Data include 376 subclasses listed by at least one pool patents as its primary subclass. The timing of invention is measured by the year of the patent application. *Pool subclasses* are subclasses that include at least one pool patent, which lists the subclass as its (primary) subclass. Thirty-six subclasses include 2 or more pool patents that are owned by 2 or more firms.

FIGURE 2 – PATENT COUNTS BY YEAR OF APPLICATION AND YEAR OF GRANT



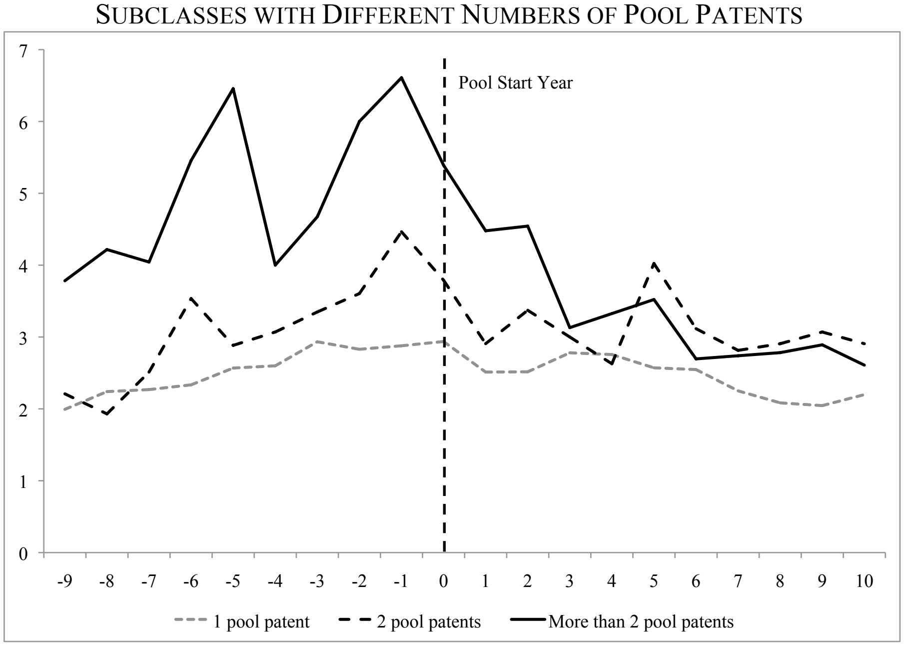
Notes: Patent counts by year of application and by year of grant are for granted patents. We collected data on filing years through an automated search of patent grants between 1920 and 75, available at www.google.com/patents. The empirical tests use data on applications between 1921 and 1948; patent applications before 1921 are subject to truncation bias. The average lag between a patent application and the grant is 2.7 years in this data set; the standard deviation is 1.9 years.

FIGURE 3 – AVERAGE PATENTS BY SUBCLASS AND YEAR



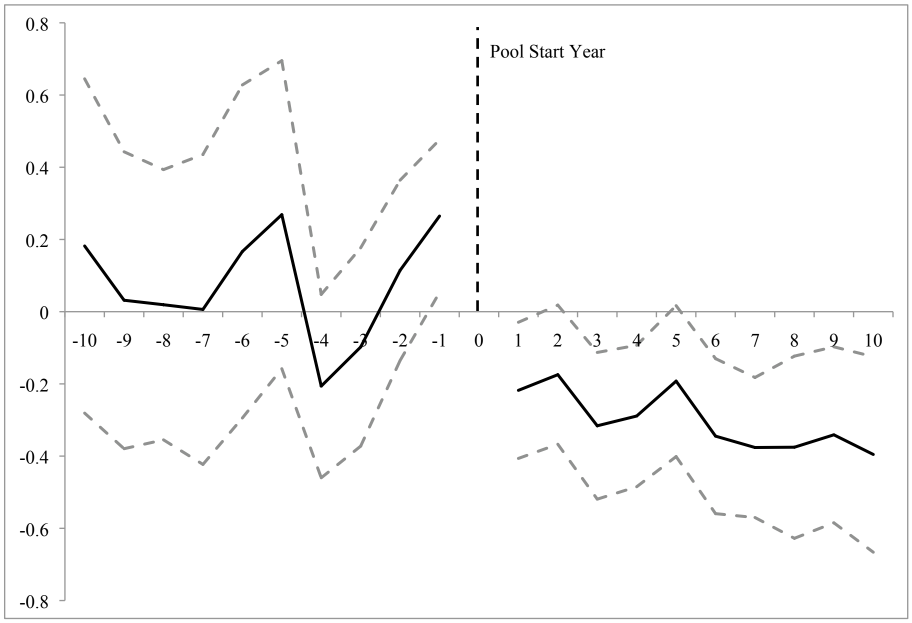
Notes: Pool subclasses include at least one pool patent that lists this subclass as the primary subclass. *Cross-reference subclasses* are subclasses without pool patents that patent examiners identified as related technologies for pool patents. There are 376 pool subclasses and 730 cross-reference subclasses. The timing of invention is measured by the year of the patent application; t=0 denotes the year when the pool formed.

FIGURE 4 – AVERAGE PATENTS BY SUBCLASS AND YEAR FOR POOL SUBCLASSES WITH DIFFERENT NUMBERS OF POOL PATENTS



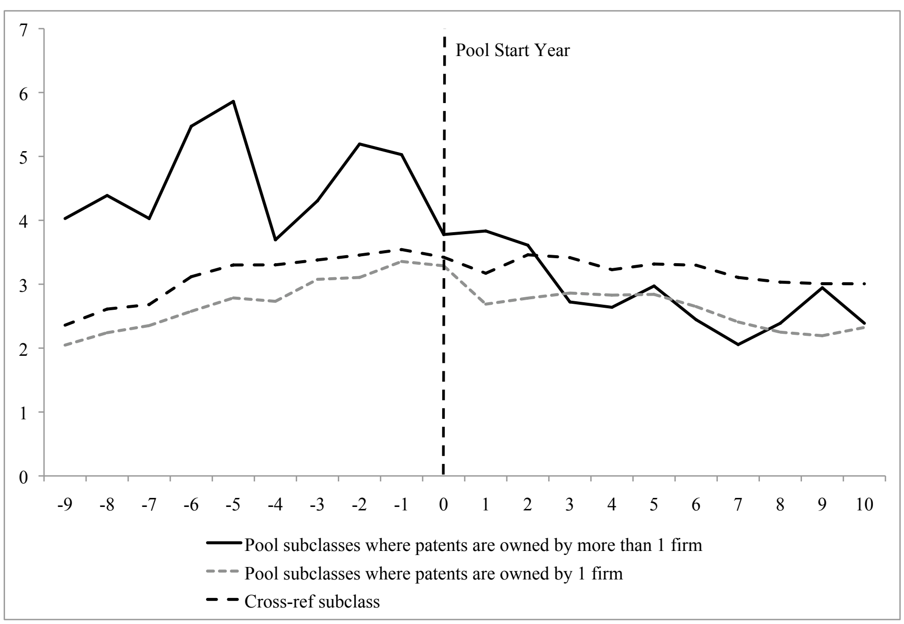
Notes: Subclasses with *1 pool patent* include a single pool patent; subclasses with *2 pool patents* include 2 pool patents (which can be owned by two separate firms); subclasses with *more than 2 pool patents* include 3 or more pool patents. We distinguish these subclasses because the creation of a pool does not affect the ownership structure of patents in pool subclasses with a single pool patent, while the creation of a pool can lead to significant changes in subclasses with more than one pool patent. Data include 376 subclasses in 103 main classes that include at least one pool patent. The timing of invention is measured by the year of the patent application; t=0 denotes the year when the pool formed.

FIGURE 5 – ANNUAL COEFFICIENT ESTIMATES FOR THE EFFECTS OF A POOL ON PATENTING



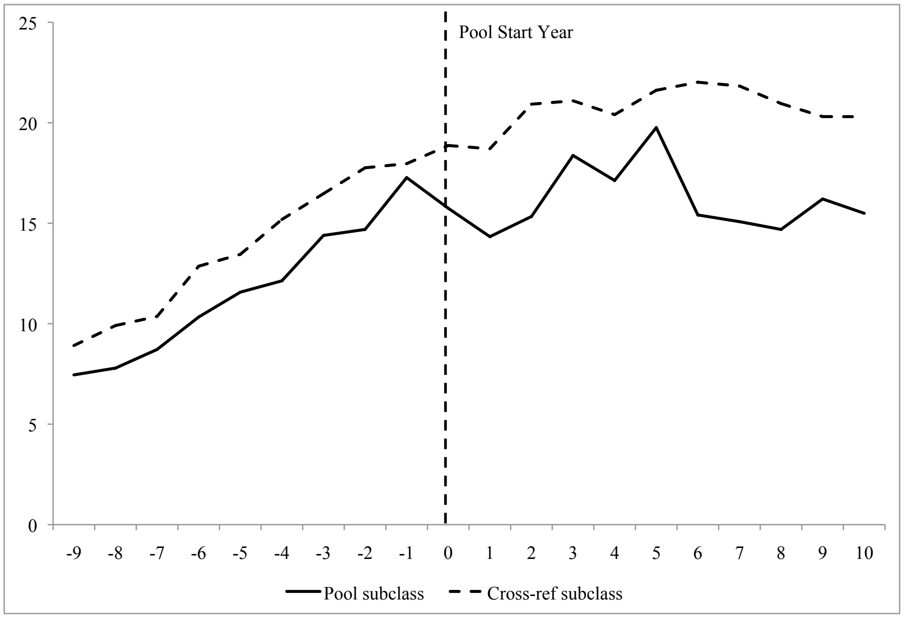
Notes: Coefficient estimates for β_k in the regression $Patents_{ct} = \alpha + \beta_k * Pool\ Patents_c + f_c + \delta_t + \varepsilon_{ct}$ where k =-17, ….17, 18, counts years before and after a pool forms. The timing of invention is measured by the year of the patent application; t=0 denotes the 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 6 – POOL SUBCLASSES WITH MULTIPLE FIRMS



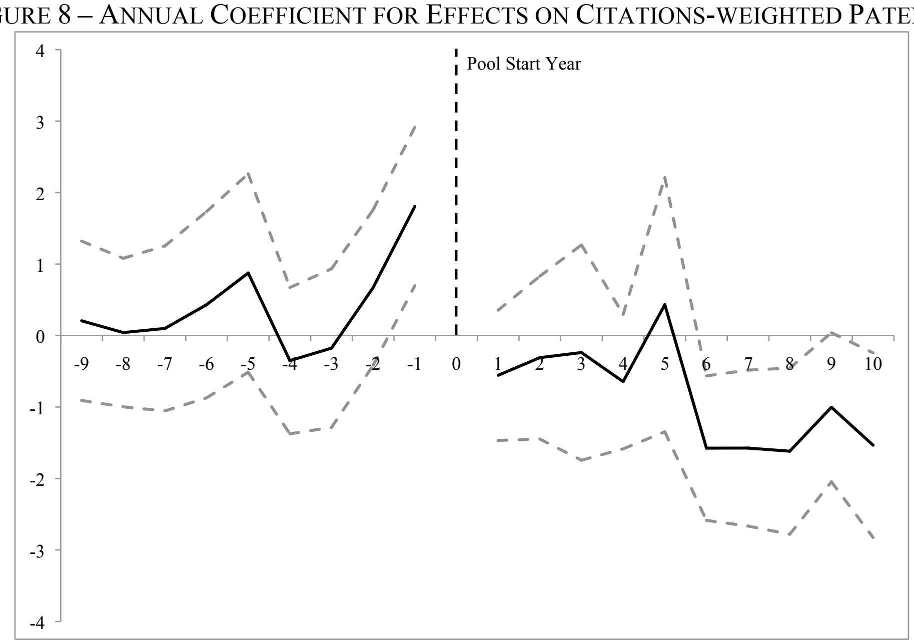
Notes: Data include 376 subclasses in 103 main classes that include at least pool patent. The timing of invention is measured by the year of the patent application; t=0 denotes the year when the pool formed. *Pool subclasses* are listed as the primary subclass by at least one pool patent; pool patents 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.

FIGURE 7 – AVERAGE CITATIONS-WEIGHTED PATENTS BY SUBCLASS AND YEAR



Notes: Citations-weighted patents are constructed as 1+ # of citations by later patents (following Trajtenberg 1990). *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 identified as related technologies for pool patents. There are 376 pool subclasses and 730 cross-reference subclasses. The timing of invention is measured by the year of the patent application; t=0 denotes the year when the pool formed.

FIGURE 8 – ANNUAL COEFFICIENT FOR EFFECTS ON CITATIONS-WEIGHTED PATENTS



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. *Citations-weighted patents* are constructed as 1+ # of citations by later patents (following Trajtenberg 1990). The timing of invention is measured by 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.