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Patent Laws and Innovation: Evidence from Economic History
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ABSTRACT

What is the optimal system of intellectual property rights to encourage innovation? Empirical evidence from economic history can help to inform important policy questions that have been difficult to answer with modern data: 1) Does the existence of strong patent laws encourage innovation? And 2) May patent laws influence the direction – as opposed to the rate – of technical change? Economic history can also help to shed light on the effectiveness of policy tools that are intended to address problems with the current patent system: 3) How do patent pools, as a mechanism to mitigate litigation risks, influence the creation of new technologies? 4) Will compulsory licensing, as a mechanism to improve access to essential innovations in developing countries, discourage innovation in the developing countries? This essay summarizes results of existing research and highlights promising areas for future research.

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What is the optimal system of intellectual property rights to encourage innovation? In the most basic theoretical models, patents pose a tradeoff between the social benefits from stronger incentives for invention and losses in consumer welfare as a result of monopoly pricing (Nordhaus 1969). But providing stronger patents for early generations of inventors may also weaken incentives to invest in research and development for later generations (for example, Scotchmer 1991 in this journal), so that the overall effects of stronger patents on innovation are difficult to predict. Negative incentive effects are particularly severe if the boundaries of intellectual property are poorly defined, so that later generations of inventors place themselves at risk of ruinous litigation. Litigation risks are exacerbated when incumbents build “thickets” of strategic patents that cover little innovative progress and instead serve as a legal weapon to protect incumbents’ profits (Shapiro 2001; Hall and Ziedonis 2001). Recent patent wars over smart phones and tablet computers have moved these issues to the forefront of policy debates, but the underlying tensions are substantially more general. Empirical analyses that exploit a wealth of historical datasets and exogenous variation, when done carefully, can help to improve our understanding of these tensions and inform contemporary patent policy.

Empirical analyses of historical data have emphasized the role of patent laws in creating incentives to invent, promoting innovation, and encouraging economic growth (for example, Khan and Sokoloff 1993; Lamoreaux and Sokoloff 1999; Khan 2005). In the absence of economy-wide data on the quantity of innovations, patent counts have become the standard measure of innovation (for example, Schmookler 1962, 1966; Sokoloff 1988; Moser and Voena 2012), fuelled in part by the creation of National Bureau of Economic Research dataset of US patents and citations between 1976 and 2002 (Hall, Jaffe, and Trajtenberg 2001), and more recently by the availability of historical patent data since 1920 through a collaboration between the United States Patent and Trademark Office and Google Patents.

Patent data may, however, fail to capture innovation that occurs *outside* of the patent system—for example, in countries without patent laws or in industries in which inventors rely on alternative mechanisms to protect their intellectual property. In fact, survey data for the late twentieth century indicate that commercial research and development labs in most industries deem alternative mechanisms, such as secrecy and lead-time (being the first firm to offer a new product) to be more effective than patents (Levin, Klevorick, Nelson, and Winter 1987; Cohen, Nelson, and Walsh 2000). Historical accounts also indicate that innovation often occurs independently of patents as a result of knowledge sharing (Allen 1983; Nuvolari 2004; Thomson 2009) or cultural attitudes that encourage risk taking (Landes 1969) and scientific experimentation (Mokyr 2009).

Historical events—including a series of prominent technology exhibitions that started with the 1851 Crystal Palace world's fair in London—have created rich archival records on innovation within *and outside* of the patent system, which offer opportunities to measure the share and the characteristics of innovations that occur outside of the patent system. Data on exhibits and prizes that international juries awarded to the most innovative exhibits make it possible to examine innovation in countries without patent laws, and thus to exploit a large amount of credibly exogenous variation in patent laws to investigate the effects of patent laws on innovation. Patent laws that were in force in the mid-nineteenth century had largely been adopted *ad hoc* according to idiosyncratic allegiances of national rulers (Penrose 1951, p. 13) and before interest groups from individual industries had learned to lobby for stronger patents. Scientific breakthroughs that reduced the effectiveness of alternative mechanisms to protect intellectual property created exogenous shifts towards patenting, which make it possible to examine the role that patents play, for example, in the diffusion of ideas. Historical events, such as the creation of the first patent pool in 1856 and the compulsory licensing of enemy-owned US patents as a result of World War I, create opportunities to examine the effects of policies that strengthen or weaken the monopoly power of patents.

To use historical evidence to guide patent policies today, one must carefully compare historical and modern institutions, political conditions, and changes in the technological characteristics of industries over time. Empirical evidence from economic history, however, can help to inform important policy questions that have proven difficult to answer with modern data. For example, does the existence of strong patent laws encourage innovation? What proportion of innovations is patented? And is this share constant across industries and over time? How does patenting affect the diffusion of knowledge? And how effective are prominent mechanisms, such as patent pools and compulsory licensing, that have been proposed to address problems with the patent system?.[1]

[1] In addition to patents, innovation policy includes other types of intellectual property rights, such as copyrights, which protect books, music, and software. National governments have also begun to increasingly use prizes as an alternative mechanism to encourage innovation. More generally, the ability to attract high-skilled scientists and

Have Patent Laws Increased the Rate of Innovation?

In 1474, the Venetian Republic began to offer exclusive rights to inventors and entrepreneurs who had invented or brought new technologies to Venice. Intended to attract skilled artisans, the Republic's rudimentary patent system was copied by other European rulers to promote economic development and, more frequently, reward political and financial support (David 1994, p. 134; Boldrin and Levin 2008, p. 43-44). In 1623, Britain's Statute of Monopolies transferred the right of granting monopolies from King James I to Parliament. North and Thomas (1973) argue that this shift, which replaced a royal prerogative to sell monopolies by a legal property rights in ideas, played a critical role in encouraging Britain's Industrial Revolution. In 1797, the first article of the U.S. Constitution instructed Congress to "promote the Progress of Science and useful Arts, by securing for limited Times to Authors and Inventors to the exclusive Right to their respective Writings and Discoveries." This provision established the foundation for the world's first modern patent system, which Khan and Sokoloff (1998 and 2001) argue was instrumental in encouraging technological progress and economic growth in the United States.

Recent interpretations, however, content that patents played no major role in encouraging technological development and economic growth during Britain's Industrial Revolution (Clark 2006; Mokyr 2009; Allen 2009). Mokyr (2009), for example, emphasizes the importance of a shift towards science-based experimentation during the Enlightenment in setting the stage for Europe's Industrial Revolution. Alternative accounts of U.S. innovation have emphasized the importance of relative factor prices, and in particular, the high costs of labor relative to the abundance of natural resources, as an impetus for mechanization, and for the development of a specifically American system of manufacturing (Rothbarth 1946; Habbakuk 1962; Rosenberg 1963, 1969, 1972; Hounshell 1985).

Historical variation in 19th century patent laws — when several countries had not yet adopted patent laws or abolished them for political reasons — offers unique opportunities to

workers is likely to be a key factor in determining rates of innovation. Economic history also offers rich opportunities to explore the effectiveness of these alternative mechanisms; see for example Li, MacGarvie, and Moser 2012; Moser, Voena, and Waldinger 2012, and Moser and Nicholas 2012.

investigate the effects of patent laws on innovation. Switzerland, for example, had no patents until the country adopted a rudimentary patent system in 1888 and switched towards a full-fledged system in 1907 (Schiff 1971). Denmark provided limited patent protection for up to five years in 1874, but waited until 1894 to enact an official patent law (Agnew 1874, p. 430; Boult 1895, p. 136). The Netherlands abolished its patent system in 1869 after a political victory of the free-trade movement, which reflected a common view of patents as a form of protectionism and rejected them as a restriction on trade (Schiff 1971). Even for countries with patent laws, the strength of patents was far from uniform. In 1876, for example, patents in Denmark and Greece expired after five years, while patents in other countries lasted for a minimum of twelve years (Lerner 2000). Inventors around the world were also heavily dependent on domestic patent laws because patenting abroad was prohibitively expensive and – until the Paris Convention of 1883 – national patent systems discriminated heavily against foreign patentees (Bilir and Moser, 2012).

Analyses of technologies that were exhibited 19th century world's fairs exploit such variation to examine differences in innovation for countries with and *without* patent laws. Exhibition catalogues, which guided visitors through the vast grounds of nineteenth- and early twentieth-century technology fairs, list all exhibits. Collecting these data and matching them with reports on prize-winning innovations, as well with patent data and with geographic information, makes it possible to examine the number and the characteristics of innovations that occurred inside and outside of the patent system - which has been difficult to accomplish with patent counts as the standard source of innovation.

Exhibition data are available for the Crystal Palace Exhibition in London in 1851, the American Centennial Exhibition in Philadelphia in 1876, the World's Columbian Exhibition in Chicago in 1893, and the Panama-Pacific International Exposition in San Francisco in 1915. In 1851, the Crystal Palace, a 1,848-foot long greenhouse of cast-iron and glass, was the largest enclosed space on earth; it housed 17,062 exhibitors from 40 countries. At a time when London had fewer than two million inhabitants, more than six million entry tickets were sold for the Crystal Palace. In 1876, visitors at the U.S. Centennial Exhibition would have had to walk more than the distance of a marathon to see 30,864 exhibitors from 35 countries; almost ten million people visited the fair (Kroker 1975, p. 146). In 1893, the World's Columbian Exposition covered 717 acres of land and water in Jackson Park by Lake Michigan; it attracted 27.5 million visitors. In 1915, San Francisco's Marina and Presidio was converted to a fairground; it welcomed 30,000 exhibitors from 32 countries and 19 million visitors.

Analyses of exhibits 1851 and 1876 reveal a surprising amount of high-quality innovations in countries without patent laws. In 1851, Switzerland and Denmark contributed 110 exhibits per million people, compared with a mean of 55 and a median of 36 per million in population for all countries (Moser 2005). Swiss exhibits were also more likely to win prizes for exceptional novelty and usefulness. In 1851, 43 percent of Swiss exhibits won a prize, compared with a mean of 35 percent and a median of 33 percent for all countries. In 1876, Switzerland contributed 168 exhibits per million in population, compared with a mean of 87 and a median of 61 for all countries (Moser and Zimring 2012). The Netherlands—which had abolished patents in 1869—won more prizes per exhibit than any other country, with 86 percent, compared with a mean of 46 and a median of 45 percent for all countries.

The world's fair data also indicate that only a small share of innovations were patented, calling into question the role of intellectual property rights in encouraging Britain's Industrial Revolution. In 1851, 11 percent of British exhibits were patented. These results are consistent with historical accounts, which emphasize the importance of cultural factors (Clark 2006; Mokyr 2009) as well as systems of collective invention without patents. For example, improvements in Cornish steam engines (Nuvolari 2004) and in blast furnaces in Cleveland's iron industry in the United Kingdom were shared freely within a system of collective invention (Allen 1983), in which patenting was rare.[2]

Data on prize-winning British exhibits help to shed light on the interaction between the quality of inventions and inventors' decision to use patents. Existing theoretical models indicate that firms may decide to keep important innovations secret because patents require disclosure, which is risky if patents are ineffective at blocking competitors from using a patented invention (Anton and Yao 2004; Horstmann, MacDonald, Slivinski 1985). Exhibition data, however, indicate that high-quality innovations are slightly more likely to be patented: In 1851, 15 percent of British exhibits that won prizes for exceptional usefulness and quality were patented, compared with 11 percent of average-quality exhibits.

Exhibition data on the share of innovations without patents make it possible to examine

[2] Inventions within systems of collective invention were predominantly incremental (or micro-, rather than macro inventions, Mokyr 1990), which Landes (1969, p.92) argues "were probably more important in the long run than the major inventions that have been remembered in history books."

how the characteristics of patent institutions influence inventors' use of patents. Khan and Sokoloff (1998, 2001, in this journal) have credited the design and low costs of patenting under the US system with encouraging technical progress and economic growth through the "democratization" of invention. In the mid 19th-century, British inventors faced a drawn-out and expensive process, with exorbitant legal fees and bribes (MacLeod 1988, p. 76) in addition to official fees of $37,000 (in 2000 US dollars, Lerner 2000).[3] By comparison, US inventors could mail in their applications and paid only $618 in fees (in 2000 US dollars, Lerner 2000). By Patenting rates, however, were only slightly higher for US compared with British exhibits—at 15 compared with 11 percent (Moser 2012, p. 54).

US courts have also always been more likely to uphold the patent rights of early generations of inventors, while British courts tended to be more anti-patent (Dutton 1984; Khan 2005). This pro-patent bias may, however, have *discouraged* U.S. rates of innovation as early as the mid-19th century, anticipating problems with the current system (Bessen and Meurer 2008). In 1846, for example, the US Patent and Trademark Office issued patent 4,750 to Elias Howe for an *Improvement in Sewing Machines*. Howe's patent was broad enough to cover most commercially viable sewing machines at the time. Like a twenty-first century "patent troll," Howe used his patent to threaten litigation, instead of commercializing his invention. In 1852, a District Court upheld Howe's patent, and he began to collect license fees of $25 per machine, roughly one-fifth the average price of a sewing machine (Lampe and Moser 2012). When other firms sued based on their own patents, and production came to a near halt in the 1851–1856 "sewing machine wars" (Bissell 1999, p. 84)..By 1867, Howe had received $2 million in license fees (Parton, 1867), roughly $27.8 million in 2011 dollars.[4]

Did the Creation of Plant Patents in 1930 Encourage Innovation?

Throughout the early twentieth century, living organisms such as livestock, bacteria, and plants could not be patented. After World War I, however, concerns about food security

[3] Reforms of the British and other European patent systems during the "Patent Controversy" (1855-1873) may have been triggered by the Crystal Palace exhibition and the unexpected quality of US innovations (Machlup and Penrose 1950; Rosenberg 1969, p. 2).
[4] Using the GDP deflator, conversions based on Officer and Williamson 2011.

motivated the creation of intellectual property rights for plants that propagate asexually (through roots rather than seeds) in the US Plant Patent Act of 1930. Breeders of food crops had argued that, in the absence of effective alternative mechanisms, they were heavily dependent on patent rights to recover large development costs. The Stark Brothers Nursery, for example, had built a large cage, armed with a burglar alarm, to prevent competitors from stealing cuttings of the first Golden Delicious apple tree, as shown in Figure 1. By creating plant patents, Congress hoped to encourage domestic innovation and the development of a domestic US plant breeding industry.

Nearly half of all US plant patents between 1930 and 1970, however, were for roses, suggesting that the 1930 legislation may have missed its target of establishing food security (Moser and Rhode 2012, pp. 418–420). Anecdotal evidence indicates that the creation of plant patents may have facilitated the development of a research-based U.S. rose breeding industry. Similar to pharmaceutical R&D today, it took up to twelve years to develop a new rose, and fewer than one in 1,000 seedlings typically proved commercially successful (Robb 1964, p. 389; Stewart 2007, p. 131). Once a new rose had been developed, it was easy for competitors to copy and propagate through cuttings, so that original breeders could not rely on secrecy or being first to recuperate their costs of R&D. Until World War II, U.S. nurseries had depended on imported nursery stock from Europe, but in the 1940s roughly a decade after the Plant Patent Act, commercial nurseries, which account for the majority of plant patents, began to build mass hybridization programs for roses in the 1940s.

Data on registrations of newly-created roses between 1916 and 1970, as an alternative measure of innovation, however, suggest that the impact of plant patents was limited. Registration data suggest that U.S. breeders created *fewer* new roses after 1931. Moreover, less than 20 percent of new rose varieties registered after 1930 were patented (Moser and Rhode 2012, pp. 429-434). In fact, information on lineage indicates that most roses that are commercially successful today descended from the breeding efforts of public-sector plant scientists that preceded the creation of plant patents. Instead, historical records suggest that the US rose industry received a boost when World War II cut off rose supplies from European competitors and US breeders began to produce their own nursery stock based on licensed European roses.

Patents, Secrecy, and the *Direction* of Technical Change

Exhibition data also indicate that the share of innovations that inventors chose to patent varied strongly across industries. For example, fewer than 5 percent of Britain's chemical exhibits in 1851, 10 percent of scientific instruments, and 8 percent of exhibits in food processing were patented, compared with 20 percent of manufacturing machinery (Moser 2012). Remarkably, U.S. inventors appear to have relied on patents –and avoided patents – in the same industries despite vast differences between the British and the American patent system.

Historical accounts suggest that variation in the effectiveness of secrecy, as an alternative to patents, was instrumental in determining variation in the use of patents. Secrecy was an effective mechanism to protect mid-nineteenth-century improvements in chemicals, because science had not yet evolved enough to allow competitors to reverse engineer them. With crude analytical tools, valuable dyes such as indigo and madder red proved impervious to industrial espionage until the late nineteenth century (Haber 1958, p. 83). Secrecy was also effective in protecting improvements in the production of scientific instruments, such as the rectangular prisms of Swiss glassmaker T. Daguet of Soleure and the optical instruments of Danish makers (*Bericht I*, 1852 pp. 813–19, 930–41). Watchmakers in the Swiss Valleé de Joux, for example, maintained tight secrecy surrounding an improved mechanism to measure minutes by agreeing not to take apprentices between 1823 and 1840 (Jaquet and Chapuis, 1945 p. 165).

But if inventors' dependence on patents varies across industries, patent laws may influence the *direction* of technical change (Moser 2005): In countries without patent laws, inventors depend entirely on secrecy, lead time, and other alternatives to patents to protect their intellectual property. As a result, investments in R&D may be most attractive in industries in which secrecy is effective enough to guarantee exclusive rights that are strong enough to allow inventors to recuperate their investments. In countries *with* patent laws, inventors can use legal protection to establish exclusivity in any industry, so that factors other than the effectiveness of secrecy determine the direction of technical change.

Cross-country comparisons of exhibition data confirm that innovation in countries without patent laws focused on a narrow set of industries, in which secrecy was effective. At the Crystal Palace, one-fourth of exhibits from countries without patent laws were scientific instruments, compared with one-seventh of exhibits from other countries (Moser 2005).

Countries without patent laws also had larger shares of innovations in textiles, especially dyes, and in food processing.

In food processing, the history of margarine illustrates the effectiveness of secrecy relative to patents. The French chemist Mège Mouriès, for example, believed his invention to be protected by a patent, and disclosed the process of producing margarine from suet to two Dutch entrepreneurs Jurgens and van den Bergh. Jurgens and van den Bergh began to manufacture margarine in 1871—two years after the Netherlands had abolished patent laws in response to a victory of the free-trade movement. After a falling-out, van den Bergh kept his improvements secret, and Jurgens was unable to reverse-engineer the superior taste of van den Bergh margarine (which allowed for its commercialization) until 1905 (Schiff 1971).

More generally, the share of Dutch innovations in food processing experienced a marked increase after the Netherlands abolished patents in 1869. In 1851, 11 percent of exhibits from the Netherlands were related to food processing. In 1876, 37 percent of Dutch exhibits, including a disproportionate amount of award-winners, originated from this industry (Moser 2005). Many other innovations in the field, including milk chocolate, baby foods, and ready-made soups, were made in Switzerland and the Netherlands when neither country offered patents (Schiff 1971, pp. 52–58).

Survey data for the late 20th-century indicate that the relative effectiveness of secrecy and patents continued to vary across industries. For example, respondents from 634 American research and development labs in 1983 (Levin, Klevorick, Nelson, and Winter 1987), and from 1,478 American firms in 1994 (Cohen, Nelson, and Walsh 2000) report that today secrecy is more effective than patents as a mechanism to protect intellectual property in most industries. Harhoff and Hoisl (2006) present comparable evidence for European countries. Only for pharmaceuticals and chemical inventions, patents are consistently rated as an effective mechanism to protect intellectual property. Compared with mid 19th-century reports, which emphasize the effectiveness of secrecy to protect chemical inventions, these results indicate that the effectiveness of secrecy varies not only across industries, but also over time.

Scientific breakthroughs, which lowered the effectiveness of secrecy, may be one important factor that determines inventors' propensity to patent. In chemicals, for example, analytical advances such as August Kekulé's model of the benzene ring in 1865 and Dmitrii Mendeleev's publication of the periodic table in 1869, transformed chemical analysis in the second half of the 19th- century. As a result of these advances, it became much riskier to protect chemicals through secrecy (Haber, 1958, p. 81). At the same time, these analytical advances had no effects innovations in machinery, which had always been easy to copy.

Moser (2012) exploits this differential shift to examine the effects of exogenous changes in the effectiveness of secrecy on inventors' propensity to patent. Difference-in-differences comparisons reveal a significant shift towards patenting in response to analytical advances: In 1851 and 1876, 0 and 5 percent of US chemical innovations were patented, respectively. In 1893 and 1915, 19 and 20 percent of US chemical innovations were patented, respectively. During the same time, patenting rates in manufacturing machinery—an industry in which secrecy was always ineffective—stayed roughly constant between 44 and 49 percent (Moser 2012, pp. 62-67). These results suggest that scientific breakthroughs, such as the publication of the periodic table in the 19th century or the decoding of the human genome today may not only affect the speed of innovation but also increase inventors' dependency on patents.

Patent Laws and the *Diffusion* of Innovation

This science-driven shift towards patenting makes it possible to explore whether patent rights encourage the geographic diffusion of innovative activity, which in turn has important consequences for cumulative innovation and economic growth. Analyses of patent laws typically focus on incentive effects and have largely ignored diffusion, even though disclosure and teaching a new set firms about the "mysteries" of more advanced technologies was an important goal of early patent systems (David 1994). In fact patents are often considered as a mechanism to prevent rather than encourage the diffusion of patented ideas

> …there is a need to balance the potential private rewards of innovation, which are the incentive for private investment, against the social interest in spreading knowledge and encouraging its widespread and rapid commercial application. The first element calls for protecting the private investor in an exclusive right to exploit the new knowledge he has gained. The second calls for limiting that exclusive privilege to permit diffusion and to support the competitive investments of rivals (Abramovitz 1989, pp. 39-40).

Lamoreaux and Sokoloff (1999), however, link the increase in U.S. patenting in the late 19th century with the emergence of professional patent agents, whose role was to facilitate the trade in patented ideas. The case of Mège Mouriès (the unfortunate inventor of margarine) suggests that inventors may be more willing to disclose technical information to competitors if they feel protected by a patent. In another example from early 19th-century England, the U.K. iron founder Robert Ransome began to advertise his plough-shares to all ironmongers in Norwich and 50 outlets in East Anglia after he received a patent in 1803 (MacLeod 1988, p. 100). By contrast, inventors have fiercely guarded knowledge from spreading to people outside their social network in the absence of intellectual property. For example, silk weavers in seventeenth-century Bologna hanged Ugolino Menzani for sharing the knowledge of a new silk twisting machine with Venetian weavers (Belfanti 2004, p. 581), and mechanics in the nineteenth-century Pennsylvania cotton industry relied on family relations to exchange technical knowledge (Wallace 1986, pp. 211–46).

Moser (2011) exploits the shift towards patenting in the 19th-century chemicals industry to explore whether patenting may, in fact encourage the diffusion of innovative activity: By creating intellectual property rights in ideas, patents may encourage inventors to disseminate knowledge of patented inventions, which in turn facilitates cumulative innovation and learning by doing.[5] A geographic analysis of exhibition data confirms that the shift towards patenting in chemicals was followed by a significant weakening in the geographic localization of inventive activity in chemicals. This decline in geographic concentration cannot be explained by changes in the localization of production: Data from decennial census records for 1840 to 1920 indicate that the localization of chemical production remained relatively stable after 1876. Measuring changes in the diffusion of innovations by a geographic Herfindahl-Hirschmann index and using 1876 as a baseline, geographic concentration decreased by more than 70 percent for chemicals after 1876, compared with roughly 25 percent for manufacturing machinery. Difference-in-differences regressions, which compare changes after 1876 in the geographic concentration of innovations in chemicals and manufacturing machinery, indicate that a 1 percent increase in the share of patented innovations was associated with a 1.3 percent decrease in localization.

Thus, the sum of the historical evidence from exhibition data, plant patents, and other sources indicates that patent laws may influence the direction of technological change and help to encourage the diffusion of knowledge, even though patent laws do not appear to be a necessary or sufficient condition for higher rates of innovation.

[5] See Scotchmer (1991) for a survey of the literature on cumulative innovation.

Mechanisms to Modify Patent Laws: Patent Pools

How can economic policy modify existing patent systems to make them more effective? A major problem with any patent system lies in the difficulty of defining the boundaries of the technology space that is covered by a patent. As a result, patent examiners may issue patents that cover overlapping areas of the technology space, such that two or more firms own blocking patents for the same technology. This in turn leads to infringement litigation, which impedes the production of new technologies and may discourage innovation.

Patent pools, which allow a group of firms to combine their patents, have emerged as a prominent mechanism to resolve blocking patents and prevent or resolve patent wars. In the 1990s, four pools formed in the information technology industry: the MPEG-2 pool, the 3G platform and two DVD pools (Merges 1999). More recently, Google launched an open-source video format pool to counter MPEG LA's pool for the H.264 video coding standard, and MPEG LA has announced plans for a pool to cover kits for diagnostic genetic testing.

Although patent pools may weaken the intensity of competition, as they allow a group of firms to combine their individually held patents, regulators and courts have allowed pools arguing that "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]). Another argument in favor of pools is that, at least in theory, pools that combine complementary patents may reduce license fees for outside firms as they eliminate "n-marginalization," which occurs when firms that own patents for part of a product charge license fees that are too high compared with the profit-maximizing fee for the complete product (Lerner and Tirole 2004; Shapiro 2001, p.134).

This positive view of patent pools is consistent with the early history of a pool that formed in the US aircraft industry to encourage the production of planes during World War I. In 1917, patent litigation between the Orville and Wilbur Wright Company and their competitor, the Curtiss Company had brought the US production of planes to a halt. A committee under Franklin Roosevelt, then Assistant Secretary of the Navy, recommended that Wright and Curtiss form a patent pool. After the pool had formed, US output of aircraft increased from 83 in 1916 to

11,950 in 1918 (Bittlingmayer 1988; Stubbs 2002). The aircraft pool remained in effect until 1975, when the US Department of Justice decided to dissolve the pool, arguing that it had "lessened competition in research and development" (Federal Register 40(142), July 23, 1975, p. 30848). This decision exemplifies the tension between the potential benefits and costs of patent pools.

In theoretical models, the predicted effects of patent pools on innovation are ambiguous. The prospect of a pool may motivate firms to enter a race to patent the technologies that will form the pool; this race could be productive, or it may be socially wasteful if it encourages duplicative research and strategic patenting (Dequiedt and Versaevel 2012). The creation of a pool may also encourage investments in research and development by reducing litigation risks for members and thereby increasing expected profits from research and development (Shapiro 2001), but it may also lead pool members to cut their own investments in research and development because they hope to be able to free-ride on the investments of other members (Vaughn 1956, p. 67). Incentives to free-ride are particularly strong for pools that include "grant-back provisions," which require members to offer all new patents to the pool, and innovative members may abandon the pool to protect their patents (Aoki and Nagaoka 2004). Grant-back provisions may, however, also encourage innovation by reducing the potential for hold-up (Lerner, Strojwas, and Tirole 2007).

Empirical evidence on the effects of modern pools on innovation is limited so far. Qualitative evidence indicates that innovation increased in response to a pool for CDs, but declined in response to a pool for disk drives (Flamm 2012). In the open source software industry, the creation of a pool was followed by a modest increase in the number of new open source software products per year for technology fields in which IBM contributed patents to the pool (Ceccagnoli, Forman, and Wen 2012).[6]

Economic history offers opportunities to investigate pools across a broad range of industries and regulatory settings (Gilbert 2004) starting with the first pool in US history, the Sewing Machine Combination (1856–1877). This pool shared key characteristics of pools that are predicted to encourage innovation today: It combined nine complementary patents, which were necessary to build a commercially viable sewing machine, and it resolved the sewing

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[6] Earlier empirical analyses have focused on the determinants of pool participation (Layne-Farrar and Lerner 2010) and on rules that govern interactions between pool members (Lerner, Strojwas, and Tirole 2007).

machine patent war between Elias Howe, the Singer Company, and two other manufacturers, which had delayed commercialization. Litigation data confirm that the creation of a pool lowered litigation risks for members (Lampe and Moser 2010, p. 900). The pool also reduced license fees from $25 for Howe's patent to $5 for the bundle of patents for members and $15 for outside firms, confirming theoretical predictions.

Patenting, however, declined after the pool formed and only increased again after the pool dissolved in 1877 (Lampe and Moser 2010, p. 913). A comparison with the British sewing machine industry, which had no patent pool, suggests that this decline in innovation was a purely American phenomenon (Figure 2). In Britain, sewing machine patents continued to increase gradually as a share of all British patents until the early 1874 and experienced no increase after 1877.

To investigate whether this decline in patenting reflected a decline in *innovation*, we collected additional data on objective improvements in the performance of sewing machines. Articles on sewing machines in 19^{th}-century magazines, such as the *Scientific American* and the *Lady's Home Journal* suggest that the key characteristics that consumers valued in a sewing machine were low weight, little noise, and most importantly, a high speed of sewing, measured as the number of stitches per minute that a machine could perform. Data on improvements in sewing speed, which we collected from company records and trade journals in the Smithsonian Institution Library, indicate that improvements slowed soon after the pool had been established and did not recover until it had dissolved (Figure 3 and Lampe and Moser 2010, pp. 916–17).

Whether these results are generalizable to other industries and modern pools is an open question. The unambiguous decline in innovation for sewing machines, however, highlights the need for additional empirical—and theoretical—analyses to guide antitrust policy towards pools. Theoretical models of effects on price are well developed (Shapiro 2001; Lerner and Tirole 2004), but effects on innovation are equally important and less well understood. Existing theoretical models also focus almost exclusively on member firms, but ignore effects on *outside* firms. Patent data, however, indicate that outside firms produced the large majority of patents across industries (Lampe and Moser 2012a), suggesting that their response to the creation of a pool is essential to understanding the welfare effects of pools.

A better understanding of the mechanism by which pools influence the rate and direction of innovation is particularly important as the use of pools expands to innovative research fields with high social value, such as biochemistry, medicines, or energy. The case of the sewing machine industry suggests that the creation of a pool may soften the intensity of competition for member firms, which tend to be larger and more established, at the expense of outside firms, which tend to be smaller and younger than pool members. For example, the sewing machine pool appears to have exacerbated litigation risks for outside firms, even as it reduced such risks for members (Lampe and Moser 2010, p. 907). The pool also created differential license fees that favored pool members, even though it reduced license fees (as theory predicts). Current antitrust guidelines allow pools to charge differential license fees, unless they have been shown to have direct anti-competitive effects. The experience of the sewing machine pool, however, indicates that differential license fees, which make it harder for outside firms to offer the pool technology at a competitive price, diverted the research investments of outside firms towards technologically inferior substitutes for the pool technologies (Lampe and Moser 2012b), suggesting that – in the absence of effective regulation – patent pools may influence not only levels, but also the direction of technical change.

Compulsory Licensing

An alternative mechanism to modify patent systems is compulsory licensing, which weakens the monopoly power of patents by licensing them to competing firms without the consent of patent owners. This policy has moved to the forefront of international trade debates, as international treaties, such as the Agreement on Trade Related Aspects of Intellectual Property Rights (TRIPS) have strengthened foreign-owned patents in developing countries, reducing access to life-saving drugs, and other essential innovations (Deardorff 1992; Grossman and Lai 2004; Chaudhuri, Goldberg, and Jia 2006). To address this issue, Article 31 of TRIPS allows national governments to issue compulsory licenses of foreign-owned patents in cases of national emergencies. The World Trade Organization Doha Declaration of 2001 (WT/MIN(01)/DEC/1, Art. 5.b) further specifies that national governments have “the freedom to determine the grounds upon which such licenses are granted.” Thailand and Brazil, for example, have used compulsory licensing to procure antiretroviral drugs for millions of patients with HIV/AIDS, and India has used the threat of compulsory licensing to procure vaccines for swine flu (Kremer 2002; Galvão 2002; Gostin 2006; Steinbrook 2007).

Immediate access to foreign-owned inventions may, however, come at the cost of discouraging domestic invention in the licensing country if it displaces domestic research and development. But compulsory licensing may also encourage domestic research and development that is complementary to foreign-owned inventions, and the ability to produce foreign-owned inventions may create opportunities for cumulative innovation (Scotchmer 1991 and learning by doing (Arrow 1962). As a result, the effects of compulsory licensing on domestic invention are theoretically ambiguous. Empirical analyses are complicated by the fact that governments are more likely to use compulsory licensing if demand for foreign-owned inventions is high and if domestic production capacities are advanced enough to produce them; both factors may increase domestic invention irrespective of compulsory licensing.

An episode of compulsory licensing under the US Trading with the Enemy Act (TWEA) as a result of World War I creates a unique opportunity to identify the effects of compulsory licensing on invention. Passed on November 17, 1917, the TWEA was intended to "dislodge the hostile Hun within our gates" and to place all enemy property "beyond the control or influence of its former owners, where it cannot eventually yield aid or comfort to the enemy" (Alien Property Custodian 1919, p. 13 and 17). In March 28, 1918, the TWEA was amended to grant the Alien Property Custodian, Mitchell Palmer, the power to sell enemy property, including all enemy-owned patents "as though he were the owner thereof" (Alien Property Custodian 1919, p. 22). By February 22, 1919, Palmer announced that "practically all known enemy property in the United States has been taken over by me" (Alien Property Custodian 1919, p.7). In 1919, the US Chemical Foundation began to issue nonexclusive licenses of enemy-owned patents to US firms.

Moser and Voena (2012) exploit this event to examine the effects of compulsory licensing on the patenting activity of US inventors in organic chemistry. Baseline estimates compare changes after 1918 in patent issues per year for 336 technologies with compulsory licensing, with changes for a control group of 7,248 technologies without licensing. Methodologically, the analysis takes advantage of the USPTO's detailed classification system to distinguish narrowly-defined technologies (measured at the level of USPTO subclasses) that were differentially affected by compulsory licensing. Technology fixed effects (at the level of USPTO subclasses) and year fixed effects, as well as technology-specific trends make it possible to control for variation in the inventors' use of patents across technologies and over time. The difference-in-differences analyses of comparing narrowly defined technologies (at a unit of analysis much below the industry level) allows us to control for unobservable factors, such as improvements in education, the creation of protectionist tariffs, or the temporary absence of German competitors during the war, which may have encouraged US invention across all types of chemical technologies regardless of compulsory licensing.

Baseline estimates indicate a 20 percent increase in domestic patenting in response to compulsory licensing (Moser and Voena 2012, p. 404). Estimates of time-varying effects indicate that this increase set in with a lag of eight to nine years and remained large and statistically significant throughout the 1930s (Moser and Voena 2012, p. 409).

These results suggest that compulsory licensing may help to *increase* innovation in the licensing countries, even though this increase occurs with some delay if the licensing country lags behind the technology frontier. At the time of the TWEA, the United States lagged behind Germany in the field of organic chemistry and needed "time to learn" (Arora and Rosenberg 1998, p.79), even though other branches of U.S. chemical invention were well-developed. For example, the hopes of duplicating German dyes seemed slim for U.S. firms in 1919. Du Pont's initial runs of indigo (which had been developed and patented by the German chemical firm BASF) turned out green (Hounshell and Smith 1988, p. 90). Similarly, countries such as Brazil and India, which are technologically advanced in many fields, seek to license foreign technologies in fields where domestic invention is weak, and may require some time to catch up to the frontier in these fields.

Learning from patent documents is particularly difficult if information in patent documents is incomplete or obscure. The German BASF, for example, had "effectively bulwarked its discovery [of the Haber-Bosch process of nitrogen fixation] with strong, broad patents which detailed meticulously the apparatus, temperatures and pressures, but cleverly avoided particulars as to the catalysts employed or their preparation" (Haynes 1945, pp. 86–87). "A prolonged learning experience was necessary [for US firms] to understand the two sides of catalysis, the chemical side and the engineering and design side" (Mowery and Rosenberg 1998, p. 75).

In the case of compulsory licensing, these problems are exacerbated because licensees typically cannot access the un-codified knowledge that is embodied in skilled workers and scientists who developed the original improvement. Thus, the US Winthrop Chemical Company, which had acquired all of the German company Bayer's production machinery in addition to its patents "could not figure out how to make the sixty-three drugs that were supposed to be [its] stock-in-trade…The former German supervisors having been jailed or deported, nobody knew how to run the machines; …the patents, which were supposed to specify manufacturing processes, were marvels of obfuscation" (Mann and Plummer 1991, pp. 52–53).

Domestically, regulators have used compulsory licensing as a remedy to restore competition in industries that have become dominated by a small group of firms. For example, Scherer (1977, pp. 47–48) estimates that the US Federal Trade Commission and the US Department of Justice had made thousands of patents available by 1977, in industries ranging from glassware (in the 1946 breakup of the Hartford Empire pool) to copy-machines (in the 1975 decision against Xerox). As a mechanism to address anticompetitive patenting behavior in domestic markets, compulsory licensing is expected to increase overall welfare by encouraging competition (Tandon 1982; Gilbert and Shapiro 1990). Survey results and case studies suggest that compulsory licensing may not provoke dramatic changes in rates of patenting and innovation (for example, Scherer 1977, Chien 2003), but more systematic empirical analyses are needed.

Conclusions

Critics of the current patent system argue that a shift towards the strategic use of patents as a "sword" to hold up competitors and extract license fees threatens the effectiveness of patents as a means to encourage innovation.[7] The underlying problems with this system, however, may be much broader and understanding them is critical to the design of patent policies. As early as the 1850s, patentees who did not produce anything were able to hold up entire industries because they had been issued broad patents, which had been affirmed in court.

Historical evidence suggests that in countries with patent laws the majority of innovations occur outside of the patent system. Countries without patent laws have produced as many innovations as countries with patent laws during some time periods, and their innovations have

[7] See, for example, "The Patent, Used as a Sword," *New York Times* October 7, 2012, p. A1.

been of comparable quality. Even in countries with relatively modern patent laws, such as the mid-19th century United States, most inventors avoided patents and relied on alternative mechanisms when these were feasible. Secrecy emerged as a key mechanism to protect intellectual property; its effectiveness relative to patents varies with the technological characteristics of innovations across industries and over time. In industries where secrecy was effective, inventors were less likely to use patents. Advances in scientific analysis, which lowered the effectiveness of secrecy, increased inventors' dependency on patents.

Incorporating these basic facts changes the predicted effects of patent laws on innovation. If a substantial share of innovations occurs outside of the patent system, policies that implement even the most drastic shifts towards stronger patents may fail to encourage innovation. If inventors' dependence on patent protection varies across industries, implementing stronger patent rights may alter the direction of technical change. If property rights in ideas encourage inventors to publicize technical information, a shift towards patenting may encourage the diffusion of knowledge.

History also offers a laboratory in which researchers can explore the effectiveness of alternative remedies to problems with the current patent system. For example, patent pools, which allow competing firms to combine their patents, have been proposed as a mechanism to resolve litigation risks as a result of overlapping patent grants, when more than one firm owns patents for the same technology. Historical evidence, however, indicates that pools may discourage and divert R&D by outside firms, if they create differential litigation risks and licensing schemes that favor their members. Another prominent mechanism is compulsory licensing, which allows competitors to produce patented inventions without the consent of the patent-owners. Historical evidence suggests that this policy may encourage innovation by allowing a new set of firms to produce a patented technology, and possibly by increasing competition to improve the technology.

Overall, the weight of the existing historical evidence suggests that patent policies, which grant strong intellectual property rights to early generations of inventors, may *discourage* innovation. On the contrary, policies, which encourage the diffusion of ideas, and modify patent laws to facilitate entry and encourage competition, may be an effective mechanism to encourage innovation. Carefully executed historical analyses can help to shed further light on these pressing issues of patent policy.

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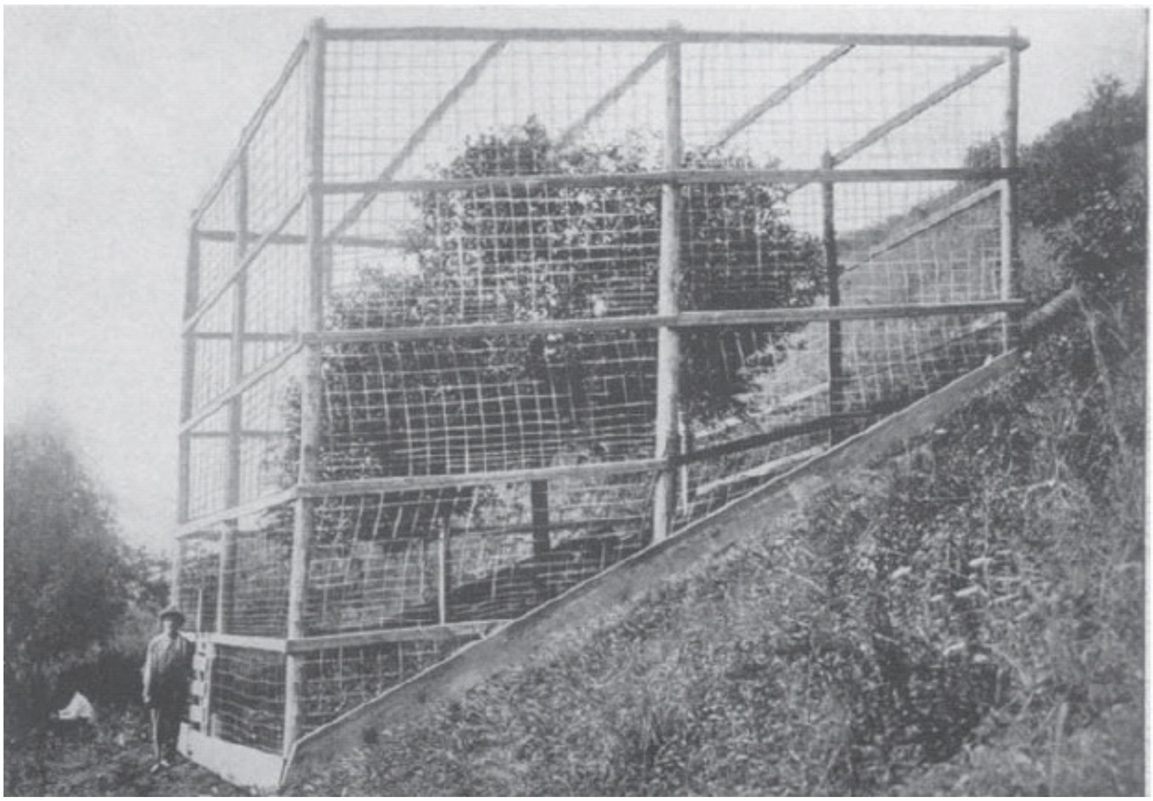
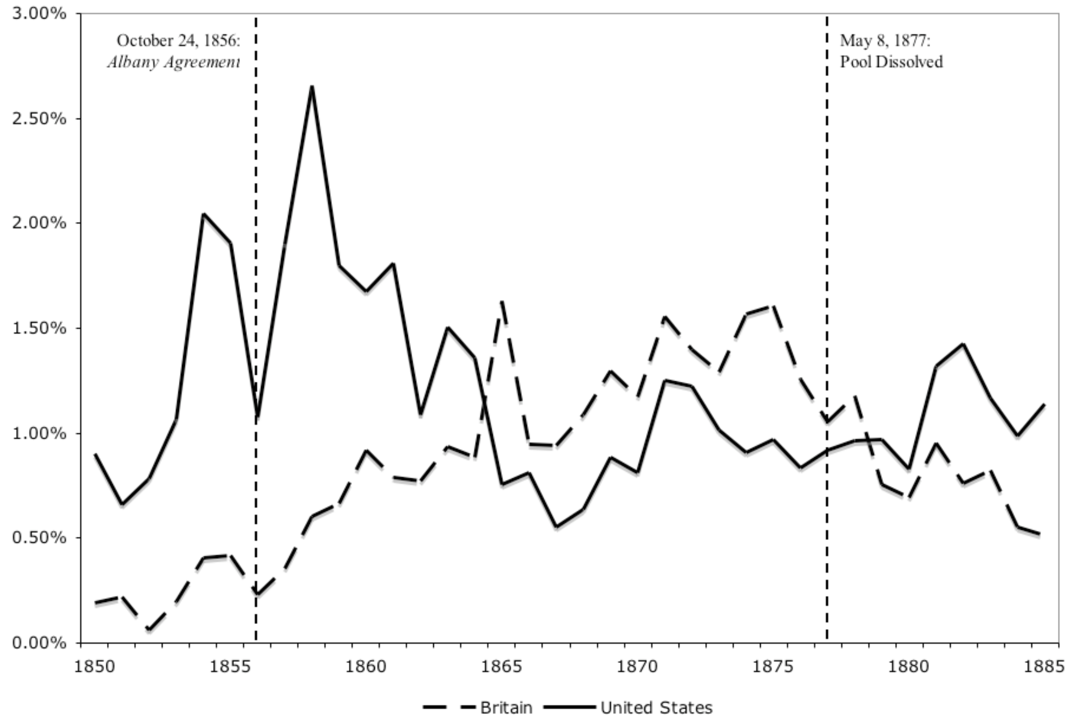
FIGURE 1 – A CAGE THAT STARK BROTHERS BUILT AROUND ITS *GOLDEN DELICIOUS* APPLE



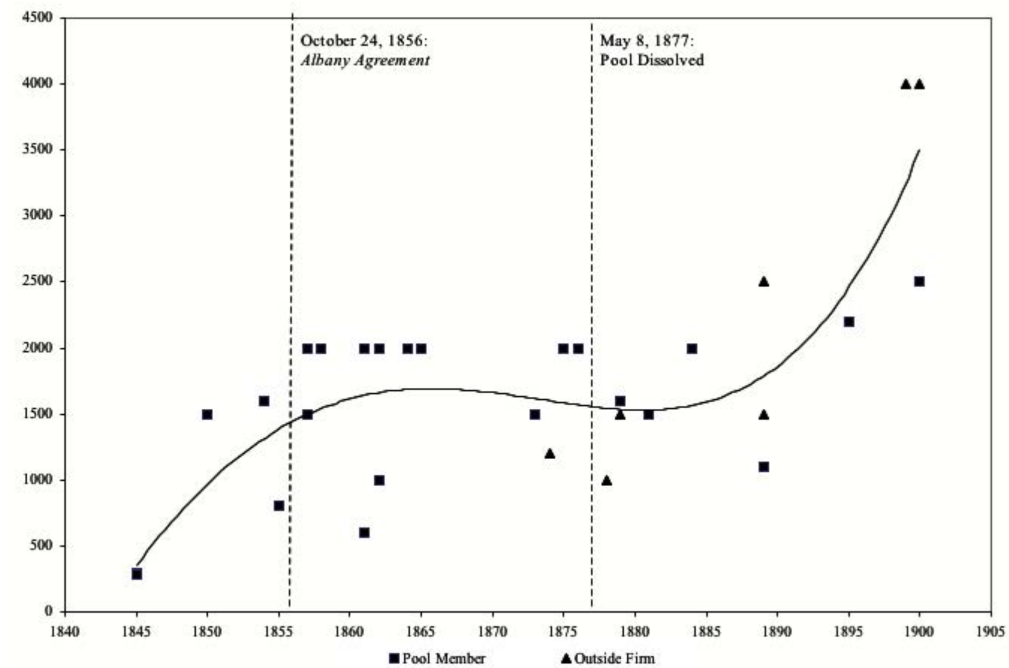
Notes: The cage was built around the Stark Brother's Golden Delicious tree to prevent competitors from stealing shoots of the tree; it was equipped with an alarm. Image from Rossman 1930, p. 395, reproduced in Moser and Rhode (2012, p. 415)

FIGURE 2 – SHARE OF SEWING-MACHINE PATENTS IN ALL PATENTS:
UNITED STATES VERSUS BRITAIN



Notes: U.S. patents granted in USPTO main class 112 (“sewing”) and British patents from *A Cradle of Inventions: British Patents from 1617 to 1894*. Series excludes patents for attachments, tables and stands.

FIGURE 3- STITCHES PER MINUTE



Notes: Data from the *Scientific American* (1846-1869), exhibition catalogues, such as the "United States Commissioners Report to the Universal Exposition in Paris," "The Report of the Twenty-seventh Exhibition of American Manufactures, Held in the City of Philadelphia," ads in contemporary trade publications, including "The Textile American;" and historical industry analysis, such as *Uniting the Tailors: Trade Unionism amongst the Tailoring Workers of London and Leeds, 1870-1939*. The solid line plots a fourth-order polynomial trend.