NBER WORKING PAPER SERIES

PATENTS AND INNOVATION IN ECONOMIC HISTORY

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Working Paper 21964
http://www.nber.org/papers/w21964

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
February 2016

Prepared for the Annual Review of Economics. I wish to thank the editor Tim Bresnahan, as well as Eric Hilt, Larry White, Megan MacGarvie, and Walker Hanlon for helpful comments and discussions. Much of the research that I describe in this review has been supported by the National Science Foundation through CAREER Grant 1151180, and through a Fellowship at the Center for Advanced Study (CASBS). The views expressed herein are those of the author and do not necessarily reflect the views of the National Bureau of Economic Research.

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NBER Working Paper No. 21964
February 2016
JEL No. K0,K21,L51,N0,O30,O31,O34

ABSTRACT

A strong tradition in economic history, which primarily relies on qualitative evidence and statistical correlations, has emphasized the importance of patents as a primary driver of innovation. Recent improvements in empirical methodology – through the creation of new data sets and advances in identification – have produced research that challenges this traditional view. The findings of this literature provide a more nuanced view of the effects of intellectual property, and suggest that when patent rights have been too broad or strong, they have actually discouraged innovation. This paper summarizes the major results from this research and presents open questions.

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PATENTS AND INNOVATION IN ECONOMIC HISTORY[1]

Abstract:
A strong tradition in economic history, which primarily relies on qualitative evidence and statistical correlations, has emphasized the importance of patents as a primary driver of innovation. Recent improvements in empirical methodology – through the creation of new data sets and advances in identification – have produced research that challenges this traditional view. The findings of this literature provide a more nuanced view of the effects of intellectual property, and suggest that when patent rights have been too broad or strong, they have actually discouraged innovation. This paper summarizes the major results from this research and presents open questions.

Keywords: Technical change, intellectual property, patents, science, creativity.

JEL Codes: O3, O34, N0, L51, K00

Innovation is commonly viewed as the primary driver of sustained improvements in human welfare and economic growth. The creation of intellectual property institutions, particularly patents, has been motivated by a desire to stimulate innovation, and support economic growth. Yet the connections between patents and innovation are difficult to identify empirically, and the predictions of economic theory are somewhat ambiguous. For example, basic models of patent laws (in the spirit of Nordhaus 1969) predict that extensions in the length of patents encourage innovation by granting inventors stronger property rights in their ideas. Yet alternative models suggest that stronger patents can discourage innovation if they reduce the payoffs to later innovators who rely on previous inventions as an input for their work (e.g., Scotchmer 1991, Bessen and Maskin 2007).

[1] Prepared for the *Annual Review of Economics*. I wish to thank the editor Tim Bresnahan, as well as Eric Hilt, Larry White, Megan MacGarvie, and Walker Hanlon for helpful comments and conversations. Much of the research that I describe in this review has been supported by the National Science Foundation through CAREER Grant 1151180, and through a Fellowship at the Center for Advanced Study (CASBS).

Economic history plays an important role in research on patent policies because it provides some of the best data, as well as credibly exogenous sources of policy variation. In the nineteenth century, for example, several countries failed to adopt patent systems for significant periods of time, or abolished existing patent laws for political reasons that were unrelated to innovation. In addition, the world technology fairs of the nineteenth century (Moser 2005, 2011, and 2012) create opportunities to examine innovations that were made within and outside of patent systems across countries. The catalogs of these exhibitions enable researchers to observe the rate and direction of technical change in countries without patents, as well as the rate at which innovators use patents when they are available. Both are critical for understanding the effects of patents laws on innovation, and represents a major advantage over much of the literature on modern innovation, which relies primarily on patent data.

The lens of history also allows researchers to examine changes in policy from a distance, which often leads to a more complete understanding of different aspects of intellectual property institutions. This is particularly useful because the design of a well-functioning patent system depends on understanding the tradeoffs associated with many different components of patent policy, including some that are exceedingly difficult to analyze with modern data. For example, a key issue in international debates relates to compulsory licensing, which allows developing countries to license foreign-owned patents to domestic firms - without the consent of foreign patent owners. To devise effective policies to govern compulsory licensing, policy makers must weigh the benefits of compulsory licensing for consumers and firms in developing countries against the potential costs of reducing innovation incentives for foreign firms whose intellectual property rights are violated.

Another example of such tradeoffs are patent pools, which allow competing firms to combine their patents and license them as a bundle to outside non-member firms. Regulators who decide whether or not to allow these arrangements must evaluate the benefits that pools provide for their members against the potentially negative and dynamic effects of pools on future innovation. Pools benefit members and consumers by minimizing litigation risks and facilitating the commercializations of inventions for which competing firms own mutually overlapping patent rights. Yet they may also discourage the creation of new technologies by allowing pool members to cooperate (instead of competing to improve). Moreover, the existence of a pool may increase litigation risks for outside firms, which makes it harder for them to compete with the pool. These effects have thus far been ignored by theoretical models, but they feature prominently in historical data.

More generally, analyses of intellectual property institutions must consider alternative mechanisms, such as secrecy, which inventors can use *instead of patents*. With a few notable exceptions (such as Anton and Yao 2004) theories of intellectual property rights have ignored these alternatives. Yet, their existence allows inventors to opt out of the patent system, which means that changes in patent policies will not have the predicted effects. In part, economic analyses have ignored alternative mechanisms, such as secrecy, because they are intrinsically more difficult to observe. This makes it difficult to evaluate their importance, even though we know intuitively that they exist. Notably, data from world technology fairs indicate that, historically, the great majority of innovations have been created outside of the patent systems (e.g., more than 80 percent of exhibits at the 1851 Crystal Palace).

Intellectual Property Rights as a Source of Economic Development

The origins of intellectual property rights reach back as far as 1474 when the Venetian Republic begun to offer exclusive rights to entrepreneurs who had invented - or imported – a new technology. The Venetian law was purposefully agnostic about the source of an innovation; Venetian rulers were happy to attract skilled artisans with new inventions, whether they had created that invention or not. Other European countries introduced modified versions of the Venetian system, hoping to promote economic development. But from the beginning, this system proved vulnerable to exploitation (David 1994, p. 134). For example, British monarchs up to King James I used the grant of royal monopolies on technical inventions as a mechanism to extract rents that financed wars or courtly estates. Britain's Statute of Monopolies of 1624 replaced the royal monopolies with a system of legal property rights in ideas. North and Thomas (1973) argue that the creation of this intellectual property institution helped trigger Britain's Industrial Revolution. Well-functioning property rights in ideas allow inventors to keep a large enough share of the fruits of their labor, motivating them to invest in creating socially valuable inventions.

This ideal motivated the creation of "the world's first modern patent institution" (e.g., Sokoloff and Khan 2001, p. 235), the US patent law. Thus Article 1 of the US Constitution instructs 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." In contrast with the early British system, the US patent system combined the twin goals of creating inventions and encouraging their widespread adoption. Importantly, the United States also introduced a system of patent examinations in 1836 (e.g. Khan 2005, p. 55). This system charged patent examiners (ideally technical experts in their field) with the responsibility to establish the novelty of each invention and – at least in principle – refuse patents for inventions covered by previous patents.

European countries began to copy features of the US patent system after they observed American innovations at the Crystal Palace fair in London in 1851. Until the *Great Exhibition of the Works of Industry of all Nations* (as the Crystal Palace was officially called), European observers had ridiculed the United States as a technological backwater. But soon after the fair had opened, droves of visitors began to admire US innovations such as the McCormick grain reaper, which promised enormous productivity gains in agricultural production. Another US invention, Samuel Colt's revolver, demonstrated the potential of the American system of manufacturing, in which the components were made with such uniformity and precision that they could be treated as interchangeable parts (Hounshell 1985).

Soon afterwards, Britain's Parliament established a commission to investigate the US system of manufacturing (Rosenberg 1969, p. 2). In his 1855 report on New York's own Crystal Palace exhibition, which was held on the ground of the current Bryant Park between July 1853 and November 1854, Commissioner Joseph Withworth (1854, pp. 55-68) included a detailed description of the US patent system, emphasizing low fees:

> "It remains to say a few words, in conclusion, on the scale of fees. These are extremely moderate in the case of citizens, and the privileges and protection afforded by letters patent are most properly placed within the reach of all citizen inventors" (Withworth 1854, p. 67)

Since then, economic historians have credited low fees with encouraging broad-based innovation in the United States (e.g., Khan and Sokoloff 1993; 1998; 2001, Lamoreaux and Sokoloff 1999; Khan 2005).

Notably Withworth (1854, p. 67) also describes the dramatically higher fees that the US system levied on foreign, and especially British, inventors.

> "But foreigners labour under great disadvantages, being required, if British subjects, to pay nearly seventeen times as much as a citizen ($500), if any other foreigner, ten times as much as a citizen ($300)."

These fees are interesting for two reasons, which invite empirical analyses of their effects: First, expensive fees probably discouraged foreigners from patenting their inventions in the United States, which made it easier for US nationals to copy them. In spirit, this is reminiscent of modern policies that weaken the patent rights of foreign inventors, such as compulsory licensing (discussed below). Second, it is remarkable that the US system reserved the largest fees for inventors from Britain, who were at the technology frontier. Taken together these featurs suggest that the early US patent system may have encouraged economic development by reducing the costs of copying foreign inventions.

A Continuing Search for Data on Innovation

Following the pioneering analyses of hand-collected data in Schmookler (1962 and 1966), and Sokoloff (1988), patent counts have become the standard proxy for innovation. In recent years, the availability of electronic data sets, such as the NBER's Patents and Citations dataset for 1976 to 2002 (Jaffe, Hall, and Trajtenberg 2001) and optical character recognition (OCR) files of US patents since 1920, has further contributed to the popularity of patents as a focus for research.[2]

Yet it is important to keep in mind that patents are an "imperfect, fallible measure" of the "net accretion of economically valuable knowledge" (Griliches 1990, p. 1670). This is particularly important for analyses of patent laws because we need to understand what types – if

[2] See Moser and Voena (2012), for a detailed description of Google/USPTO patent data since 1920, Moser et al. (2014) for inventor-level data, and Lampe and Moser (2016) for historical data on patent citations since 1920.

any – innovations would be made *in the absence of patent laws*. By construction, patent data fail to capture these innovations.

Studies of individual industries, such as Allen (1983) and Nuvolari (2004), have addressed this issue by collecting independent measures of performance. That is, rather than focusing on counts of patents or their citations, this research has attempted to directly measure improvements of particular products. For example, Lampe and Moser (2010) use data on sewing speeds to observe the rate of innovation in sewing machines. Similarly, Moser, Ohmstedt, and Rhode (2014) compile data on advances in yields, and other biological characteristics of patented corn hybrids, to measure the speed of biological innovation. Yet such performance measures are impossible to construct in a manner that makes them comparable across industries. This feature limits their use in empirical analysis of the *direction* of technical change, and other important questions.

Observing Innovations with and without Patents: Historical Technology Fairs

Historical data on exhibits at world fairs make it possible to observe innovations - irrespective of their patent status - across sectors, across countries, and over time. Starting with the Crystal Palace in London in 1851, the organizers of these fairs systematically collected and displayed technologies from across the world (Moser 2003, 2005, 2011, and 2012). The scale of the fairs was unprecedented, and remains unparalleled today. 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 less than 2 million inhabitants, more than 6 million tickets were sold. The American Centennial Exhibition in Philadelphia in 1876 attracted more than 10 million visitors (Kroker 1975, p. 146). To see all

10,863 exhibits from 35 countries at the Centennial fair, a visitor had to walk the equivalent of a marathon. Another important fair, the 1893 World's Columbian Exposition in Chicago, covered 717 acres in Jackson Park by Lake Michigan; it attracted 27.5 million visitors. Finally, to host the Panama-Pacific International Exposition in San Francisco in 1915, its organizers drained a swampy part of the San Francisco Bay, which later became the Presidio. This fair welcomed 30,000 exhibitors from 32 countries and 19 million visitors.

Exhibits were recorded in catalogues that helped visitors navigate the fairs. Many of these catalogues became significant reference works for the current state of technology. For example, Britain's *Official Catalogue of the great exhibition of the work of industry of all nations (1851)* became a "book of reference to the philosopher, merchant, and manufacturer" (Auerbach 1999, p. 94) to an exhibition that was a "veritable acting industrial encyclopaedia" (Tallis 1852, p. 234; *The Times*, December 5, 1850). Catalogue entries include the exhibitor's name, location, and a description of the exhibit:

> 406, Fourdrinier, E. N., 38 Barclay St., Sunderland, Patent safety apparatus, for preventing loss of life and destruction of property when a rope or chain breaks in shafts of mines and collieries.

In addition to the prize-winning reaper and Colt's revolver, examples of exhibits included power-loom lathes, and the first sewing machines.

As a means of quality control, exhibits were subject to a systematic and careful process of selection.[3] Commissioners for the Crystal Palace Fair visited cities and rural areas to set up local selection committees and to ensure broad-based representation (Bericht 1853, pp. 40 and 64, Auerbach 1999, p. 55 and 87). National papers, such as the British *Times*, *Economist*, and *Sun*,

[3] By comparison, selection processes at smaller regional fairs in the US and Britain and even at later world's fairs was substantially more haphazard (e.g., Khan 2014), and exhibits at these fairs may not be a good proxy for innovation.

and the US *Scientific American* advertised the fairs in regular features (e.g., *The Times*, November 14, 20, December 6, 9, and 30, 1850). In Britain, 65 local commissions formed more than 300 sub-commissions (Auerbach 1999, p. 32). Local committees selected exhibits in the first round; their submissions competed at the national level. Among these selections, national committees chose the most promising innovations to represent their country in a hard-fought international "contest of industries" (Kretschmer 1999, pp. 46-48; Auerbach 1999, pp. 68-69, 78 and 189). Less than 30 percent of applicants were admitted to the fair (Bericht 1853, pp. 50 and 117). After the fair, universities, scientists, and museums competed to purchase exhibits (Auerbach 1999, p. 105, 120).

A concern with exhibition data is that transportation costs may have influenced the selection of exhibits and that exhibits from host countries were over-represented. For example, three-fourths of the 13 acres in Machinery Hall were taken up with American machines in 1876, including the colossal Corliss steam engine, which provided power to the fair (Andrews 1894, p. 73). The influence of transportation costs was mitigated because heavy, large, or fragile inventions were presented by models. In 1851, for example, 88 of 194 British exhibits in "Civil Engineering, Architecture, and Building Contrivance," were represented by models, including a 770-meter long chain suspension bridge across the Dnepr in Kiev (Rolt 1970, p. 157). Similarly, T. Powell of Monmouthshire, Britain, exhibited a "Model for apparatus used for shipment of coals from boats or waggons at Cardiff dock" at the Crystal Palace, and A.Watney of Llanelly, Wales, exhibited "Models of anthracite blast furnaces."[4]

[4] Another potential source of bias stems from restrictions on exhibition space, which were set by the host country. Anecdotal evidence, however, indicates that such restrictions may not have been binding. For example, when the US commission to the Crystal Palace thought that US exhibitors would be short on exhibition space, it asked the British commission for more room and was granted its request (Haltern 1971, p. 150). Floor plans for the Centennial

Many Important Innovations Occur Outside of the Patent System

Although prominent accounts have emphasized the importance of patents in stimulating innovation (e.g., Sokoloff and Lamoreaux 1999), exhibition data show that the majority of 19th-century innovations occurred *outside of the patent system*. In 1851, for example, only 11 percent of British exhibits were patented. Such low patenting rates are more consistent with alternative explanations that emphasize a culture of entrepreneurship (Landes 1969), the free exchange of knowledge (Allen 1983, Nuvolari 2004), and investments in science (Arora and Rosenberg 1998; Mowery and Rosenberg 1998) as potential sources for innovation.[5]

In addition to capturing innovation without patents, exhibition data also make it possible to control for the quality of innovations through prizes that were granted to a small share of exceptional inventions. These data raise a question for empirical and theoretical research: Are inventors more or less likely to patent high-quality inventions? Existing theories of innovation predict that firms are more likely to use secrecy if innovations are important. Patents require disclosure, which is risky if patents cannot effectively prevent competitors from using a patented invention (Anton and Yao 2004; Horstmann, MacDonald, and Slivinski 1985). Exhibition data, however, show that high-quality exhibits were slightly more likely to be patented. In 1851, 15 percent of Britain's prize-winning exhibits were patented, compared with 11 percent of average-quality exhibits. Notably, the prize data also show that the large majority of prize-winning

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exhibition show that 11 countries, including Germany, Britain, Spain, and Sweden, built additional exhibition space on the Centennial grounds.

[5] Low patenting rates are particularly remarkable considering that exhibition data may be biased towards recording patented inventions, if inventors were reluctant to exhibit inventors that were protected by secrecy. To address this problem, the U.K. government created a registration system to offer "Protection from Piracy to Persons exhibiting new Inventions." Only 600 exhibitors (less than 3.3 percent) took advantage of this system. Instead exhibitors advertised the finished product, rather than the machines that had made it, to maintain secrecy surrounding the machine. For example, Drewsen & Sons of Silkeborg, Jutland, exhibited "Specimens of paper, glazed by a machine constructed by the exhibitor," instead of their paper-making machine (Official Catalogue 1851, p. 210).

inventions were not patented, which calls into question the importance of patents as a driver of high-quality invention.

Patent Laws Were not Necessary for Innovation

The 19th century offers a unique setting to examine the effects of patent laws on innovation because no other period had a comparable amount of exogenous variation in national laws. In 1851, the statutory length of a patent varied from no protection in Denmark and Switzerland to 14 years in Britain and the United States, and 15 years in Bavaria, Belgium, and the Netherlands. Much of this variation was in place because countries had adopted patent laws according to idiosyncratic allegiances of national rulers (Penrose 1951, p. 13). Another benefit of the empirical setting is that it precedes the period of intense lobbying from interests that dominate debates today.

Exhibition data show that the existence of patent laws was not a necessary condition for high levels of innovation (Moser 2003). Crystal Palace data in Moser (2005, Table 1) include 11,610 exhibits from 12 Northern European countries in 1851. Two of these countries – Switzerland and Denmark - offered no patent protection. Data for the Philadelphia Centennial Exhibition cover 6,482 exhibits from 10 Northern European countries in 1876. Two of them – Switzerland and the Netherlands - offered no patent protection, and 3 had short-lived patents. Notably, the absence of patent protection did not prevent innovation in countries without patent laws. In 1851, for example, Switzerland contributed 110 exhibits per one millions Swiss citizens, which was two times the mean of the average country, and three times compared with the median of 36 exhibits per 1 million people. Switzerland also won a disproportionate number of prizes, with 47 per 1 million people, more than twice the mean value of 20 and more than 4 times the median of 11. Switzerland continued to lead innovation in food processing (e.g., by improving milk chocolate and ready-made meals), all before adopting a full-fledged patent system in 1907.

Even with Low Fees, Most Innovations were not Patented

Most economists understand intuitively that many important innovations - ranging from 19th century dyes and scientific instruments to Ford's conveyer belt and the famously secrective *Coca Cola* – were not patented. Yet, it is difficult to determine how important non-patenting is quantitatively, and whether it varies across sectors and over time.[6] Exhibition data allow researchers to measure such variation across industries, over time, and - importantly - across patent systems.

In 1851, patent fees in Britain ranged between £100 and £120 in Britain "approximately 4 times per capita income in 1860" (Khan 2005, p. 31). In addition, inventors faced a cumbersome process with legal fees and bribes (MacLeod 1988, p. 76; Dutton 1984). In Charles Dicken's "A Poor Man's Tale of the Patent System" (1868, p. 228), the fictional inventor Old John complains:

> "Look at the Home Secretary, the Attorney-General, the Patent Office, the Engrossing Clerk, the Lord Chancellor, the Privy Seal, the Clerk of Patents, the Lord Chancellor's Purse-bearer, the Clerk of the Hanaper, the Deputy Clerk of the Hanaper, the Deputy Sealer, and the Deputy Chaff-was. No man in England could get a patent for an Indian-rubber band or an iron hopp, without feeing all of them. Some of them, over and over again"

By comparison, US patent fees were substantially lower. Moreover, inventors could submit their patent applications by mail, which should have made it much easier for rural inventors to apply

[6] The most complete evidence in modern settings come from survey data (Levin, Klevorick, Nelson, and Winter 1987; Cohen, Nelson, and Walsh 2000), which suggest that chemicals and pharmaceuticals relied strongly on patents, while most other industries relied heavily on secrecy.

for a patent. Khan and Sokoloff (1998 and 2001) have credited the superior design of the US patent system with encouraging the "democratization" of invention in the United States.

> "The British system reflected its origin in royal privilege and effectively limited access to a select class of patentees. In contrast, the United States established the world's first modern patent institution, one that was consciously designed to stimulate participation in invention across a wide spectrum of the population" (Khan and Sokoloff 1998, p. 295)

Yet exhibition data show that US patenting rates were only slightly higher than British patenting rates; the difference was less than five percentage points (Moser 2012, p. 54). These results challenge the view that the design of the US patent system played an important role in stimulating high levels of innovation (Lamoreaux and Sokoloff 1998; Sokoloff and Khan 1998, 2001).

Location data for inventors, however, provide some suggestive evidence in favor of the hypothesis that the US patent system helped democratize innovation. A first test compares variation in patenting rates across urban and rural areas in Britain and the United States. With the caveat that the data include only 574 observations across the United States, there are no noticeable systematic differences in patenting rates across urban and rural areas in the United States (Moser 2012, pp. 13-14, Table 4). By comparison, British patenting rates (for a sample of more than 6,000 exhibits) were significantly higher in London, compared with rural rates. These findings highlight the need for further analyses to examine the role of access costs in determining the effectiveness of patents.

Similar to Today, Litigation Risks were Extremely Damaging

A potential explanation for the low rates at which valuable innovations in the United Sates were patented is that even though the costs of patent applications were low, the costs of patent *enforcement* may have been substantial. Dutton (1984) observes that US courts were more likely to uphold the patent rights of original inventors, while British courts tended to be more anti-patent. Khan (2005) argues that this pro-patent attitude encouraged invention in the United States. The US Patent Act of 1793 specified that "simply changing the form or proportion of any machine…shall not be deemed a discovery." It was, however, often left to the courts determine the boundaries between the original inventor's patent and the next invention that was sufficiently novel to merit a new patent. Eli Whitney, for example, patented a saw gin in 1793 that could be used to remove seeds from short staple upland varieties of cotton (Olmstedt and Rhode, 2008 p. 1130, Lakwete 2003, p. 67-68). Whitney's patent remained subject to litigation until December 1807, one month after it had expired. The knowledge of such cases may have led inventors to incorporate litigation risks into the expected costs of patenting, and avoid patents whenever possible.

Litigation risks were particularly high when US courts enforced overly broad patents that had been issued by the US Patent and Trademark Office (USPTO). 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 21st-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 2014). When other firms sued based on their own patents, production came to a halt during the 1851–1856 "sewing machine wars" (Bissell 1999, p. 84). By 1867, Howe had received $2 million in license fees (Parton, 1867), roughly $30 million in 2014 dollars.

Patent Pools Discouraged Innovation

To resolve litigation, Elias Howe, the Singer Company, and two other manufacturers formed the first patent pool, the Sewing Machine Combination in 1856. Like contemporary pools, the Combination allowed its members to use each others' patents, and license all pool patents together as a bundle to outside firms. Litigation data confirm that the creation of a pool reduced litigation risks for members (Lampe and Moser 2010, p. 900). The pool also reduced license fees from $25 per machine for Howe's patent to $5 for the bundle of patents for members and $15 for outside firms. Patenting, however, declined after the pool formed and increased again only after it dissolved in 1877, with the expiration of the last broad patent (Lampe and Moser 2010, p. 913). A comparison with Britain's sewing machine industry, which had no patent pool, suggests that this decline in innovation was limited to the United States. In Britain, sewing machine patents continued to increase gradually as a share of all patents until the early 1870s and experienced no increase after 1877.

Did the decline in US patenting represent a decline in innovation? Here again the difference between patents and innovation is important: Patenting may decline because inventors no longer have to create "patent thickets" (Shapiro 2001) to protect themselves from litigiation. With a little bit of detective work, economic history can answer this question. Articles on sewing machines in 19th-century magazines, such as the *Scientific American* and the *Lady's Home Journal,* suggest that contemporary customers valued sewing machines that were light, quiet, and, most importantly fast. Sewing speed is measured as the number of stitches per minute that a machine could perform, and it is reported on contemporary trade cards and catalogues, which we were able to access in the records of the Smithsonian Institution. These data indicate that improvements in sewing speed slowed soon after the pool had been established and increased again after it had dissolved (Lampe and Moser 2010, pp. 916–17).

The experience of the sewing machine industry also suggests another important policy implication of patent pools for the *direction* of technical change. Data on patents and firm entry indicate that the creation of a patent pool diverted innovation away from the pool technology towards a substitute technology that was already understood to be inferior (Lampe and Moser 2014). As long as the pool created a significant wedge between license fees for members and outsiders, outsiders entered with the substitute because they needed to avoid licensing and litigation. Data on firm survivals show that firms that entered with the substitute were significantly more likely to fail compared with other entrants, suggesting that the shift towards the substitute technology was socially wasteful.

Whether these results are generalizable to other industries and modern pools is an open question. A companion study of pools that formed across a broad range of 20 industries in the 1930s, however, unambiguously confirms the decline in patenting (Lampe and Moser 2014). In the absence of effective antitrust, dominant firms used a pool to further limit and discourage competition by outside firms. We find that this reduction in competition was associated with a significant decline in innovation.

These results highlight the need for additional empirical and theoretical analyses of patent pools. Theoretical models of the price effects of pools are well developed (Shapiro 2001; Lerner and Tirole 2004), but a pool's effect on innovation is less well understood. Importantly, existing theoretical models focus almost exclusively on pool members and ignore effects on outside firms. Yet, outside firms account for more than 90 percent of all patents in industries with patent pools (Lampe and Moser 2014), which suggests that ignoring them can bias theoretical predictions.

Compulsory Licensing Encouraged Innovation

Another prominent mechanism of intellectual property policies is “compulsory licensing,” which allows government agencies to license foreign-owned patents inventions to domestic firms - without the consent of foreign patent owners. This policy is a central concern in international debates. WTO rules allow developing countries to use it if negotiations with foreign patent owners fail, and countries such as Brazil and Thailand have used compulsory licensing to improve access to foreign-owned pharmaceuticals, including drugs to treat HIV/AIDS.

While it is impossible to predict the effects of such interventions on innovation, historical episodes of compulsory licensing create opportunities for empirical analysis. In 1917, the US Trading with the Enemy Act (TWEA) empowered government agencies, such as the Chemical Foundation, to license German-owned patents to US firms. The Act’s primary goal was to place all enemy property, including patents, “beyond the control or influence of its former owners” (Alien Property Custodian 1919, p. 13 and 17). By February 22, 1919, the U.S. Alien Property Custodian (1919, p. 7), A. Mitchell Palmer announced that “practically all known enemy property in the United States has been taken over by me.” In 1919, the US Chemical Foundation began to issue nonexclusive licenses for enemy-owned patents to US firms.

In one of the first analyses of the USPTO/Google bulk data patent files, Moser and Voena (2012, p. 404) show that compulsory licensing of German-owned patents in organic chemistry led to a 20 percent increase in US invention for affected technologies. Their baseline estimates compare changes in patent grants per year after 1918 for 336 technologies with compulsory licensing with changes in patent grants for a control group of 7,248 technologies without licensing in the same industry. Lee and Moser (2015) extend these results to an economy-wide analysis during World War II.

Methodologically, the analysis exploits 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, control for variation in the use of patents across technologies and over time. This approach makes it possible to control for unobservable factors, such as improvements in education or protectionist tariffs, which may have encouraged US innovation in chemicals regardless of compulsory licensing.

Firms under threat of compulsory licensing today argue that it will weaken their incentives to invest in R&D. The historical records, however, suggests the opposite. Baten, Moser, and Bianchi (2015) collect and analyze firm-level data on German patents to examine invention by German firms that were differentially affected by compulsory licensing under the TWEA. This analysis indicates that compulsory licensing was associated with a 28 percent increase in patenting by German inventors. Controlling for variation in the quality of patents (through renewal data) indicates that some of the observed increase was due to an increase in lower quality patents, possibly as firms built a "thicket" of strategic patents around technologies that were now threatened by entry. But even with quality controls, we find that compulsory licensing led to a 17 percent increase in high-value German patents.

Patents Have been Useful in Some Industries – but Not in Others

Does this mean that intellectual property rights always hold back innovation? Probably not, but to answer the question economists must understand when inventors use and don't use patents. Exhibition data reveal a great deal of variation in the use of patents across industries and over time. In 1851, for example, fewer than 5 percent of Britain's chemical exhibits were patented, 10 percent of scientific instruments, and 8 percent of exhibits in food processing, compared with 20 percent of manufacturing machinery (Moser 2012, p. 46). The data also show that – despite the most substantial differences in national patent systems – US inventors appear to have relied on patents, and avoided them in the same industries as British inventors (Moser 2012 p. 58). Echoing results on low overall patenting rates in the United States, these findings suggest that the institutional features of the US patent system did not significantly affect patenting behavior.

What determines variation in the use of patents across industries? Qualitative evidence points to variation in the effectiveness of secrecy, as an alternative to patents. With crude tools of chemical analysis, secrecy was an effective mechanism to protect mid-19th-century improvements in chemicals, because competitors could not yet reverse-engineer improvements. Commercially valuable dyes, such as indigo, proved immune to reverse-engineering, despite considerable efforts in industrial espionage until the late 19th century (Haber 1958, p. 83). Secrecy was also effective in protecting improvements in scientific instruments, such as the rectangular prisms of Swiss glassmakers and the optical instruments of Danish makers (*Bericht I*, 1852 pp. 813–19, 930–41). Scientific breakthroughs, such as Dmitrii Mendeleev's publication of the periodic table in 1869, increased the risks associated with the use of secrecy, as they transformed chemical analysis in the second half of the 19th century (Haber, 1958, p. 81).

Exhibition data show that advances in methods of scientific analysis, which made it possible for the first time to reverse-engineer many types of innovations, intensified inventors' dependency on patents. At the world's fairs of 1851 and 1876, 0 and 5 percent of US chemical innovations were patented. By 1893 and 1915, 19 and 20 percent of US chemical innovations were patented. At the same time, innovations in manufacturing machinery remained unaffected by improvements in scientific methods, because they had always been easy to reverse-engineer. Patenting rates for these innovations stayed roughly constant between 44 and 49 percent for manufacturing machinery (Moser 2012, pp. 62-67). This suggests that the shift towards patenting was due to the reduced effectiveness of secrecy in chemicals, rather than an economy-wide increase in the use of patents.

Intellectual Property Rights for Living Organisms Have Not Encouraged Innovation

A contentious question is whether animals and plants should be subject to patent protection. Until 1930, living organisms could not be patented. In the aftermath of World War I, however, concerns about food security motivated the passage 1930 US Plant Patent Act, which created intellectual property rights for plants that propagate (asexually) through roots rather than seeds. In support of the Act, plant breeders had argued that they needed intellectual property rights to protect their investments in R&D because competitors could easily reproduce an improved plant – which had taken years to develop - by taking a cutting. Stark Brothers Nursery for example, had built a cage with a burglar alarm to prevent competitors from taking cuttings of their improved Golden Delicious apple (Moser and Rhode 2012). Responding to these arguments, Congress hoped to encourage the development of a domestic US plant breeding industry by creating plant patent rights.

Data on US plant patent grants, however, show that nearly half of all US plant patent grants beween 1930 and 1970 were for were roses (Moser and Rhode 2012, pp. 418–420). Had the provision of intellectual property helped to encourage the creation of a research-based US rose breeding industry? Until World War II, US nurseries were dependant on imported nursery stock from Europe. In the 1940s commercial nurseries began to build their own mass hybridization programs. In a striking parallel to pharmaceutical R&D, it takes up to 12 years to develop a new rose, and most attempts to create new roses fail; fewer than 1 in 1,000 seedlings typically lead to a commercially successful new rose (Robb 1964, p. 389). Yet, as soon as a breeder succeeds in developing a new rose, competitors can propagate it by stealing cuttings.

To examine whether the creation of plant patents encouraged innovation, we again construct an alternative (no-patent) measure of innovation in roses. This measure draws on registration records for newly-created rose varieties between 1916 and 1970. Matching registration records with plant patents shows that less than 20 percent of newly registered roses after 1930 were protected by a plant patent (Moser and Rhode 2012, pp. 429-434), again highlighting the fact that most innovations are not patented.

Registration data also indicate that US breeders created *fewer* new roses after 1931. In fact, lineage data show that most roses that are commercially successful today are descendants of roses that public-sector, rather than private-sector, plant scientists developed *before* the creation of plant patents. These results indicate that plant patent played no significant role in encouraging innovation in rose breeding, and they highlight the need for analyses of other sectors.

Patent Laws have Changed the Direction of Innovation

If patents are important in some industries (such as manufacturing machinery) but not in others (such as scientific instruments or chemicals in the 19th century), changes in patent laws may influence the *direction* if not the level of technical change (Moser 2005). These patterns are borne out in exhibition data: Countries without patent laws contribute as many exhibits and prize winners as countries with patent law. But their innovations are disproportionately focused on industries in which secrecy is effective, so that inventors are less dependent on patents. 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 (Figure 2; Moser 2005).

(Figure 1 about here)

After the Netherlands abolished its patent protection – as a result of a political victory of the free-trade party in 1869 – Dutch innovations shifted towards food processing, another industry in which secrecy was effective. Between 1851 and 1876, the share of Dutch innovations in food processing increased from 11 to 37 percent (Moser 2005). Many other innovations in this industry, including milk chocolate, baby foods, and ready-made soups, were made in Switzerland and the Netherlands when neither country had a patent law (Schiff 1971, pp. 52–58).

The case of margarine illustrates the effectiveness of secrecy compared with patents. The French chemist Mège Mouriès disclosed the process of producing margarine to the Dutch entrepreneurs Jurgens and van den Bergh, believing that he was protected by a patent. In 1871, however, while the Netherlands did not have patent laws, Jurgens and van den Bergh began to manufacture margarine there. After the partners argued and split, van den Bergh independently improved the taste of margarine, and Jurgens failed to reverse-engineer van den Bergh's improved margarine until 1905 (Schiff 1971).

Patent Laws Have Changed the Geography of Innovations

One important area for future analyses relates to the role that intellectual property rights play in determining the geography of innovation. Can variation in the use of patents help to explain why some regions – within the same country and the same patent system – are more innovative than others?

Accounts of innovation in Britain and the United States indicate that knowledge sharing without patents laid the foundations for innovation and technical change (Allen 1983; Nuvolari 2004; Thomson 2009). For example, technical performance in the Cleveland (UK) iron-smelting district improved rapidly between 1850 and 1875, as iron producers shared technical details about the construction and performances of blast furnaces (Allen 1983). Yet these benefits appear to be extremely localized.

Anecdotal evidence suggests that the ability to protect ideas through intellectual property rights encourages inventors to talk about them, and allow future generations of inventors to build on their ideas. Many inventors, such as Mège Mouriès, were more willing to disclose technical information when they felt protected by patents. The British inventor Robert Ransome, for example, only began to advertise his plough-shares in Norwich and East Anglia after he received a patent in 1803 (MacLeod 1988, p. 100). Moreover, historical records suggest that, in the absence of patent protection, artisans took fierce measures to prevent the knowledge of new technologies from spreading to outsiders. Thus silk weavers in 17th-century Bologna hanged Ugolino Menzani because he had shared the knowledge of a new silk twisting machine with Venetian weavers (Belfanti 2004, p. 581).

Thus the availability of intellectual property rights may encourage the diffusion of new ideas, and thereby enable follow-on invention. Although encouraging the diffusion of new technologies is one of the two key goals of the US patent system, there is little systematic empirical evidence on the effectiveness of patents in encouraging diffusion.

The shift towards patenting in chemicals (documented in Moser 2012), however, creates an opportunity to examine whether a shift towards patenting can encourage the geographic diffusion of innovative activity. In chemistry, inventors began to rely more on patents after a series of scientific breakthroughs (including the creation of the periodic table) reduced the effectiveness of secrecy. Geographic data on the location of origins of exhibits show that chemical innovations became significantly more geographically diffused after 1851. By comparison, the localization of innovation in manufacturing machinery (which did not experience a shift towards patenting) remained unchanged. Data from the US Decennial Census between 1840 and 1920 also show that the geographic decentralization of chemical innovations cannot be explained by changes in the localization of production. While chemical exhibits became less localized after 1876, chemical production remained relatively stable.

These results are consistent with the hypothesis that intellectual property rights can encourage the diffusion of innovation, but more empirical evidence is needed to identify these effects.

Narrow Intellectual Property Rights - through Copyrights - as a Promising Alternative

Can economists help to identify alternative mechanisms to protect intellectual property without the shortcomings of patents? One promising alternative are copyrights, which create intellectual property rights that are substantially more narrow than patents. An extremely stylized example helps to illustrate the difference in scope: A copyright for Giacomo Puccini's *Tosca* (1900) protects the specific score and libretto, whereas a patent could in principle protect the idea of an opera about two unlucky artists in love. Because copyrights are so much narrower than patents, they avoid many pitfalls of broad patents, which makes them an appealing alternative to patents for software and many other fields. Moreover, the growing importance of digital content, which is primarily protected through copyrights, highlights the need for understanding the effects of copyrights. Yet – with a few notable exceptions, such as Oberholzer-Gee and Strumpf (2007), Reimers (2014), and Waldfogel (2012) – copyrights are understudied by economists.

In the case of copyrights, the key tradeoff is encouraging the creation of new cultural goods and allowing for their use by consumers and other artists. Initial evidence suggests that basic levels of copyright protection can encourage creativity and innovation. Starting from low levels of existing protection, extensions in copyright length for Romantic Period authors raised the price of books (Li, MacGarvie, and Moser 2014) and increased payments to authors, even though most of the gains accrued to a small number of exceptionally popular authors, such as Sir Walter Scott (MacGarvie and Moser 2014).

The introduction of copyrights also appears to have caused an increase in both the quantity and the quality of operas in 19th century Italy. Italian states that came under Napoleon's rule before 1804 (when France adopted the code civil), adopted the French copyright law of 1793, whereas Italian states that came under Napoleon's rule after 1804 did not get copyrights. Data on the quantity, popularity, and durability of new operas indicate that the introduction of copyrights led to an increase in the quantity and quality of operas (Giorcelli and Moser 2015). These data also show that copyright *extensions* beyond the life of the composer have no effects on creativity.

Copyrights, do, however, come at the cost of restricting access to existing works. These costs may be especially high when copyrights extend beyond the life of the composer and are extremely long, as they are in the United States and Europe today, where copyright length approach 100 years. Broadly speaking, restrictions on access (and higher prices as a result of copyrights) increase the costs of access to existing works, which build the foundation for future generations of what Suzanne Scotchmer (1991) called "cumulative research."

To investigate the effects of copyrights on "cumulative" or "follow-on" science, Biasi and Moser (2015) exploit a historical event of copyright violations under the World War II Book Replication Program (BRP).This program issued temporary, 6-month licenses for German-owned copyrights to US publishers, who then reprinted exact copies of German science books and sold them for a lower price to US libraries and firms.

Citations data indicate that the BRP resulted in a significant increase in new books and publications that built on German science books. A simple model of knowledge production predicts a differential effect of copyrights on human-capital intensive industries, and a comparison of changes for mathematics and chemistry confirms this prediction: Notably, the increase in citations was much more pronounced in mathematics – which was more dependent on human capital – than in chemistry. Intuitively, US mathematicians who now had access to a copy of Courant and Hilbert's "Methods of Mathematical Physics" at their local university library, relied only on their human capital to use methods of mathematical physics in their own research. Chemists, however, were more likely to also require access to physical capital, in the form of laboratory space, to use the knowledge in a BRP book in their own research.

Conclusions and Directions for Future Research

Economic history offers unique data sets and a wealth of exogenous variation to analyze the effects of intellectual property rights to innovation. For example, exhibits at 19th-century world fairs offer a rare alternative (non-patent) measure of innovation to examine the effects of patent laws at a time when several countries had not yet adopted patent laws or abolished them for political reasons. These data indicate that the large majority of historical innovations occurred *outside* of the patent system. Moreover, they reveal that countries without patent laws, such as Switzerland and the Netherlands, were at least as innovative as countries with patent laws. Comparisons across industries also show that the need for patents varies significantly across industries and over time. This need for patents has been strongest when innovations were easy to reverse-engineer, so that inventors could not (or no longer) rely on secrecy to protect their innvoations. At an economy-wide level, such differences have influenced the *direction* of technical change, even when they failed to increase levels of innovation.

More generally intellectual property rights appear to have been most beneficial when they were narrow and short-lived. Compulsory licensing, for example, forces patent owners to license their inventions to new firms, including potential competitors. This policy has encouraged innovation - not only by the firms that benefit from improved access, but by the original owners of licensed patents, who now face more competition. Similarly, patent pools that allow competitors to combine their patents have discouraged innovation, in part by making it more difficult for entrants to compete with incumbents that have formed a pool.

Interestingly, initial results on the effectiveness of copyrights suggest that basic levels of copyrights (which are significantly more narrow than patents) can encourage creativity. But these results also suggest that extensions in the length of copyrights trigger no additional boost in creativity. Such extensions may in fact create significant welfare losses by discouraging the diffusion of cultural goods. These effects are particularly severe for science, a field in which the creation of new knowledge depends critically on access to existing work.

Many important questions and research opportunities remain. For example, what are the effects of intellectual property rights on the diffusion of innovation? Can basic levels of property rights help to ensure a broad-based participation in processes of creativity and innovation? And are copyrights a useful alternative to patents? Historical analyses can shed light on these questions – with the benefit of distance, new data sets, and careful empirical analyses.

Although the focus of this essay has been on intellectual property rights, the creation of "economically valuable knowledge" (e.g., Griliches 1990) is also vitally dependent on human capital: inventors, scientists, and entrepreneurs. To encourage innovation, economic policies must enable and encourage these individuals to invest in creativity and innovation. A small number of existing studies suggest that basic levels of intellectual property rights can encourage broad-based participation, e.g., by rural inventors (Khan 2005, Moser 2011) and by individuals of modest means who depend on creative work for income (MacGarvie and Moser 2014). Given the enormous welfare implications of getting the most talented individuals to participate in innovation, economic analyses of these issues are critical.

Another topic for future research concerns interactions between intellectual property rights and policies towards science and immigration. Economic history offers a wealth of settings to examine these policies. For example, the United States received an unprecedented inflow of German-Jewish scientists after the Nazi regime took power in 1933. These arrivals helped transform chemical innovation: Research fields in which the United States received an émigré experienced a 31 percent boost in domestic patenting (Moser, Voena, and Waldinger 2014). The importance of émigrés is also confirmed in preliminary analyses of 19th century operas in Italy (Giorcelli and Moser 2015), where a large share of the observed increase in creativity in states with copyrights was due to émigrés.

Finally, the supply of scientists, inventors, and entrepreneurs is grounded in individual-level differences, that are not typically amenable to economic research. Historical biographies reveal exceptional traits of resilience and optimism among creative individuals, ranging from Charles Goodyear (who developed vulcanized rubber) to Sir Walter Scott (the author of *Ivanhoe*). Anecdotal evidence also suggests a link between certain types of mental disorders (such as bipolar disorder) and creativity. Preliminary analyses confirm the existence of such links in modern data, and suggest that they have responded positively to medical innovations (e.g., Biasi, Dahl and Moser 2015). Like other research in this essay, these findings highlight the enormous social gains from identifying sources of creativity and innovation.

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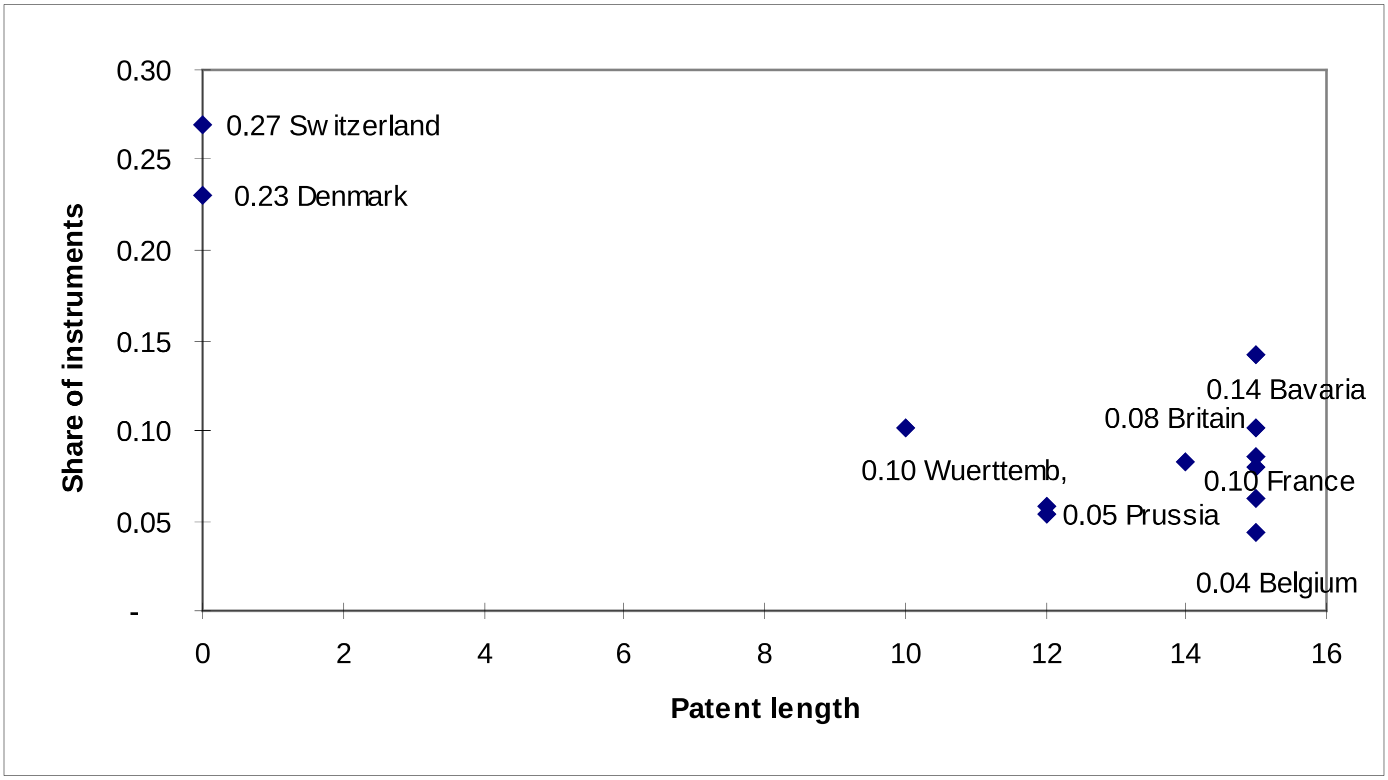
Figure 1 – Shares of Exhibits in Scientific Instruments against Patent Length in 1851



Sources: From Moser (2005). "Share of instruments" measures the proportion of a country's exhibits that occur in the industry class "scientific instruments." Patent length measures the maximum duration of a patent grant in 1851.