How Do Patent Laws Influence Innovation? Evidence from 19th-Century World Fairs

Petra Moser

MIT and NBER
December 28, 2004

Studies of innovation have focused on the effects of patent laws on the number of innovations but ignored effects on the direction of technological change. This paper introduces a new data set of close to fifteen thousand innovations at the Crystal Palace World's Fair in 1851 and at the Centennial Exhibition in 1876 to examine the effects of patent laws on the direction of innovation. The paper tests the following argument: if innovative activity is motivated by expected profits, and if the effectiveness of patent protection varies across industries, then innovation in countries without patent laws should focus on industries where alternative mechanisms to protect intellectual property are effective. Analyses of exhibition data for twelve countries in 1851 and ten countries in 1876 indicate that inventors in countries without patent laws focus on a small set of industries where patents were less important, while innovation in countries with patent laws appears to be much more diversified. These findings suggest that patents help to determine the direction of technical change and that the adoption of patent laws in countries without such laws may alter existing patterns of comparative advantage across countries.

I wish to thank David Autor, Steve Broadberry, Robert Gibbons, Bronwyn Hall, Joshua Lerner, David Mowery, Tom Nicholas, Christina Romer, Ken Sokoloff, and two anonymous referees for helpful comments and discussions.

Studies of innovation have focused on the effects of patent laws on levels of innovative activity, but ignored effects on the direction of technical change. This omission is critical if differences in the direction of innovation help to determine patterns of comparative advantage and international differences in economic growth (Simon Kuznets 1963, Nathan Rosenberg 1974). This paper introduces a new source of cross-country, economy-wide data on innovations with and without patents, which makes it possible to examine the effects of patent laws on the direction of innovation. I have collected such data for close to fifteen thousand innovations from the catalogues of two 19th-century world fairs, the Crystal Palace Exhibition in London in 1851 and the American Centennial Exhibition in Philadelphia in 1876. Exhibition data provide economy-wide data on innovation with and without patents for twelve countries in 1851 and ten countries in 1876.

The empirical analysis tests the following argument: if innovative activity is motivated by expected profits and if the effectiveness of patent protection varies across industries, then innovation in countries without patents should focus on industries with strong alternative mechanisms to protect intellectual property. Exhibition data indicate that inventors in countries without patent laws focus on a small set of industries where patents are less important, while innovation in countries with patent laws appears to be much more diversified. These findings suggest that patents serve to expand the set of industries where innovation is attractive to inventors. But they also indicate that patents may help to determine the direction of innovation and that the adoption of patent laws in countries without such laws may alter existing patterns of comparative advantage across countries.

A necessary condition for patent laws to influence innovation is that innovation, or a significant share of it, must be responsive to profit incentives. A long tradition of empirical studies has established this fact. As early as 1883, surveys of inventors have suggested that inventive effort is motivated by expected profits (*Procès-Verbal du Congres Suisse*…1883, S.C. Gilfillan 1930, Joseph Rossman 1931). Zvi Griliches (1957) corroborates these findings in a pioneering empirical study of geographic patterns in the adoption of hybrid corn, which proves that the diffusion of innovations is responsive to market size. Jacob Schmookler (1966) constructs further evidence for the importance of profit incentives as he shows that the number of U.S. patents for railway equipment increases with a short lag after sales of railway equipment. Kenneth Sokoloff (1988) and Zorina Khan and Sokoloff (1998) present further evidence for the responsiveness to demand from 19th-century patent data and the behavior of "great inventors".

William Nordhaus (1969) and later studies of innovation have emphasized the role of patent laws in determining the incentives to invent. Nordhaus identifies the trade-off between strong incentives to inventors through long-lived patents and the deadweight loss from a monopoly distortion caused by long-lived patents. Paul Klemperer (1990) and Richard Gilbert and Carl Shapiro (1990) add the breadth of patent grants as a further policy instrument, thus capturing the range of technologies that are covered by each patent. In a study of Japanese patents after the reform of 1988, Mariko Sakakibara and Lee Branstetter (2001) find little evidence that patent breadth increases the incentives to invent. Suzanne Scotchmer (1991) provides a potential explanation based on the cumulative nature of innovation, whereby strong patent rights may reduce the number of inventions, if exclusivity to early generations of inventors weakens the incentives for later generations.[1]

[1] See Joel Mokyr (2002) for a historical analysis of the cumulative nature of innovation. More generally, William Baumol (1990) and Kevin Murphy, Andrei Shleifer, and Robert Vishny (1991) show that individuals are more likely to chose socially productive activities (such as inventing) if property rights protect the returns from such activities.

Although previous studies have recognized the importance of patent laws for determining the incentives to invent, they have neglected the influence of patent laws on the direction of technical change. Yet, the importance of the direction of innovation for economic growth has long been recognized. Kuznets observed in 1963 that innovation at any given time tends to concentrate in a small sector of industries and countries and argued that such differences help to determine differences in rates of economic growth across countries. Economic history supports these claims: Germany's focus on chemical innovations is widely understood to have enabled Germany to replace Britain as the industrial leader in the late 19th-century. Edwin Rothbarth (1946), H.J. Habakkuk (1962) and Rosenberg (1972) argue that America's growth rates overtook Europe's at the beginning of the 20th century because American innovations focused on labor-saving innovations in machinery.[2] Although the United States is generally recognized as the country with the most advanced patent system in the 19th century, the influence of patent laws on the direction of innovation has never been considered.

This paper proposes to extend the standard accounts of the effects of patent laws on innovation by examining their influence on the direction of technical change. Similar to the classic approach in Nordhaus (1969), it supposes that the incentives to invent increase with the strength of monopoly rights that are granted to successful innovations. This paper then relaxes the assumptions of the classic models by allowing for alternative mechanisms, in addition to patent grants, to create incentives to invent. For example, inventors may be able to achieve conditions similar to patent monopolies by keeping innovations secret, by beating competitors to

[2] Peter Temin (1966) counters these arguments with a standard two-goods neoclassical model, which shows that resource abundance does not necessarily lead to greater capital intensity and mechanization since both capital and labor are scarce. The discussion of the Habakkuk-Rothbarth hypothesis and the labor-saving nature of American technologies continues with Gavin Wright (1990), Nathan Rosenberg (1972), David A. Hounshell (1985), Daron Acemoglu (1998) and Charles Jones (2004).

the market, or by maintaining tight control over assets that are complementary to the innovation. Surveys of 634 American R&D labs in 1983 by Richard Levin, Alvin K. Klevorick, and Richard Nelson (1987), and of 1,478 firms in 1994 by Wesley Cohen, Richard Nelson, and John Walsh (2000) suggest that secrecy is particularly valuable as an alternative mechanism to protect intellectual property.

Exhibition data create a unique opportunity to evaluate the importance of patenting across industries and countries. Mid 19th-century patent laws had been adopted in a relatively *ad hoc* manner, depending on legal traditions rather than economic considerations (Edith Penrose, 1951). Large differences in patent systems existed across countries, and patentees depended on domestic patent laws since patenting abroad was prohibitively expensive and countries discriminated heavily against foreign patentees (John Coryton 1855, Richard Godson 1840). As a result, domestic patent laws played a more important role in creating incentives for domestic invention than at any later stage in history. Moreover, data from 19th-century world fairs grant a rare opportunity to study the patenting decisions of inventors who presented innovations both with and without patents at the fairs.

Data from the Crystal Palace Exhibition on more than six thousand British and American innovations with and without patents make it possible to measure differences in the propensity to patent across industries and across countries. Such data indicate that inventors' propensity to patent varies strongly across industries but not across countries. In Britain one in nine innovations appears to have been patented, compared to one in eight in the United States. The propensity to patent, however, varies strongly across industries in both countries, suggesting significant sectoral differences in the usefulness of patent protection. Patenting rates, calculated as the share of innovations that are patented, range from seven percent in textiles, eight percent in food processing, and less than ten percent in scientific instruments to more than twenty percent in manufacturing machinery, engines, and other types of machinery. Differences across industries are almost identical for the British and American data, despite the fact that British patenting rates are constructed from references to patents in the exhibition data, while American rates are constructed by matching exhibits with entries in the lists of all patents in the *Annual Reports of the United States Patent Office* between 1841 and 1851. These parallels in patenting behavior are especially remarkable considering the vast differences between the British and the American patent system, at a time when patent applications were 60 times more expensive in Britain than in the United States. In addition to comparisons across nations' patent laws, inter-industry differences in the propensity to patent are robust to comparisons across rural and urban areas, and adjustments for the quality of innovations.

If the relative effectiveness of patents varies across industries, the payoffs for invention in countries without patent laws should be highest in those industries where alternative mechanisms are prominent relative to patenting, and innovation in patentless countries should focus in those industries. Exhibition data indicate that innovations in the patentless countries concentrated on two industries with low patenting rates: scientific instruments and food processing. At the Crystal Palace, every fourth exhibit from a country without patent laws is a scientific instrument, while no more than one seventh of other countries' innovations occur in this industry. Countries without patent laws also have significantly larger shares of their overall innovations in textiles, especially dye stuffs, and in food processing. After the Netherlands abolished its patent system in 1869, the share of Dutch innovations in food processing increased from 11 to 37 percent. At the same time, the patentless countries have smaller shares of innovation in machinery, especially in machinery for manufacturing and agriculture; in these industries innovations appear to have depended crucially on patents.

The remainder of this paper presents these comparisons in more detail. Section I describes the exhibition data and discusses potential sources of bias. Section II compares estimates for the propensity to patent across industries, section III examines the direction of innovation across countries, and section IV concludes.

I. The Data

The Crystal Palace exhibition in 1851 was the first world fair that effectively allowed inventors and firms to exchange information on technological innovations across countries. At a time when London had less than two million inhabitants, it attracted more than six million people; its companion, the American Centennial Exhibition of 1876 drew ten million visitors (Table 1; see Evelyn Kroker, 1975 p. 146). Even those who stayed at home could read about the fairs in weekly updates in trade and general interest journals, such as *Scientific American* and the *Illustrated London News*, and peruse detailed reports by their national committees (e.g., *Bericht*, 1853). In 1851, the Crystal Palace was the largest enclosed space on earth; its exhibition halls covered 772,784 square feet, an area six times that of St. Paul's Cathedral in London, and housed a total of 17,062 exhibitors from 25 countries and 15 colonies. In 1876, a visitor would have to walk more than 22 miles, the equivalent of a three day stroll, to see all 30,864 exhibitors from 35 countries (see *Bericht III*, 1853 p. 674; Kretschmer, 1999 p. 101). From the catalogues that guided visitors through these fairs, the reports of national commissions, the diaries of committee members such as Edgar Alfred Bowring (1850), and many letters of exhibitors and visitors to the fairs, I have collected detailed information on each of close to 15,000 exhibits, including brief descriptions of the innovation, its industry of use, its exhibitor's name and location, its patent status and whether the exhibit received an award for exceptional inventiveness and usefulness.

A. Advantages over Patent Data

Empirical analyses of the effects of patent laws on innovation typically rely on patent data, although patents may not be an ideal measure to study the effects of patent laws. Most importantly, the way in which patent data measure innovation depends on the details of patent laws, and the definition of what constitutes a patentable invention varies considerably across countries. For instance, in the 19th-century U.S., only "first and true" inventors were allowed to patent, while France granted patents to any person importing new technologies (Coryton 1855, pp. 235-264). In the best case, patents measure new ideas that have proven to be feasible at least in theory. But such patents capture an early input in the process of innovation and only a small share of them reach later stages (Griliches, 1990 p. 1669, Harold I. Dutton 1984, p. 6). For the 20th century, for example, firm-level surveys have found that only between 5 to 20 percent of patents become economically useful innovations (Meinhardt, 1950 p. 256). In the 19th century, usefulness was often not even required for a patent grant (Coryton, 1855 pp. 235 and 239).[3]

Even if patent data were a perfect measure of innovation, such data exist only for a handful of countries in the 19th-century, excluding those without patent protection. Moreover, economy-wide patent data are not available when countries exclude specific industries from patenting. In the 19th century, for example, Austria, Belgium, France, and Saxony did not issue patents to inventions in chemicals, foods, and medicines (Coryton, 1855 pp. 241, 244, 249, 266). As a further complication, patents are classified by functional principles and often cannot be assigned to a specific industry of use.[4] As a result, empirical studies based on patent counts had to exclude important innovations such as power plant inventions, electric motors, or bearings, because they could not be assigned to a specific industry (Schmookler, 1972 p. 89). Finally, Griliches (1990 p. 1669) observes that patented inventions differ greatly in quality. Manuel Trajtenberg (1990) addresses this problem by constructing measures of the value of patented inventions based on the number of succeeding patents that refer to them. However, historical citations data are extremely costly to collect and they may underestimate the quality of innovations in those industries where patents undercount inventions.

Exhibition data, as a complement to 19th-century patent data, offer a way to address these concerns. Most importantly, exhibition data measure innovations regardless of whether they were patented or not, whereas patent data count only those inventions which inventors chose to patent. Uniform rules of selecting exhibits ensure that exhibits are comparable across countries, regardless of domestic patent laws. Exhibition data include information on three patentless countries: Switzerland and Denmark in 1851, and Switzerland and the Netherlands in 1876. No other data are available to study innovation in these countries. Exhibition data cover innovations in all industries, including those that were barred from patenting. Depending on an innovation's country of origin, exhibition data either include references to mark patented inventions or can be matched with patent data to distinguish innovations with and without patents. Awards to the most innovative and useful exhibits provide a measure for the quality of innovation.

---

[3] The most prominent alternative to patent data, firms' expenditure on R&D (e.g., Sakakibara and Branstetter 2001), captures an even earlier stage of the innovation process (see Griliches 1990, p.1671).
[4] The functional class "dispensing liquids" includes holy water dispensers along with water pistols, while "dispensing solid" groups tooth paste tubes with manure spreaders (Schmookler, 1972 p. 88).

B. Description of the Exhibition Data

A typical entry in the exhibition catalogues includes the name of the exhibitor, his location, and a brief description of the innovation. For example,

> 32 Bendall, J. Woodbridge, Manu. – A universal self-adjusting cultivator, for skimming, cleaning, pulverizing, or subsoiling land; pat.

This exhibit is classified in the Crystal Palace industry class number 9, "Agricultural and Horticultural Machines and Implements" and in the Centennial class 670, "Agricultural Machinery and Instruments for Tillage." For the Crystal Palace data, a total of 13,876 such exhibits have been classified according to 30 industries of use. For the Centennial data, I have counted 19,076 exhibits in 344 industry classes. I have been able to match all Centennial classes to Crystal Palace classes except for systems of education and exhibits of marine mammals (live, stuffed, and salted), which were exhibited only in Philadelphia. Industry classes span the entire spectrum of production; they range from mining and minerals, chemicals, and food processing, to engines, manufacturing machinery, and scientific instruments.

Based on the original classification scheme of the 1851 catalogue, I aggregate the exhibition data from thirty into seven industry classes: "mining", "chemicals", "food processing", "machinery", "scientific instruments, "textiles", and "manufactures". This creates a system of mutually exclusive and unordered industry classes. For example, Tweedale & Son's "superfine Saxony and fine twilled cricketer's flannel", Britain's exhibit number 4 in "wool", could also be classified under "clothing" in the original system. Combining the data into broader industry classes addresses the problem of overlap between the original classes and also the related issue of treating discretely a choice between "woolens" and "flax" (closely related industries in the textiles sector), and a choice between "woolens" and "scientific instruments".

Aggregating in this way also increases the number of exhibits in each class and thereby avoids the problem that classes with exceptionally small numbers of exhibits receive a disproportional weight in tests of the equality of distributions.

A uniform system of selecting exhibits ensured that all participating countries chose exhibits according to the same criteria of "novelty and usefulness" (*Bericht*, 1853 p. 50). Countries valued the exhibitions to showcase their technologies, and often competed to demonstrate their technical supremacy in certain industries (*The Times*, October 20, 1849). National commissions delegated the authority to select exhibits to local branches. For example, Britain's national commission for the Crystal Palace nominated 65 local commissions to select exhibits at the local level. Local committees typically consisted of two to ten academics and business people, representing the area's main industries (*Bericht*, 1852 pp. 37 and 90). In their applications to their local commission, all potential exhibitors were required to report "what is novel and important about the product, how its production shows special skillfulness and proves an original approach" *(Bericht*, 1853 pp. 50 and 117).

Awards to the most innovative exhibits helped to enforce the selection criteria. International panels of between six and twelve researchers and businessmen ranked all exhibits according to their "novelty and usefulness" and awarded prizes to the top 30 percent. All exhibits were included, and no one could excuse himself from the jury's evaluation. Signs such as "Not entered in the competition" were explicitly prohibited (*Bericht*, 1853 pp. 29, 50, 98 and 111). At the Crystal Palace, 5,438 exhibits received awards (*Bericht*, 1853 p. 707; Utz Haltern, 1971 p. 155). Juries awarded Council Medals, the highest honor, to 1 percent of all exhibits, Prize (or silver) Medals to 18 percent, and Honorable Mentions to 12 percent of all exhibits

(*Bericht*, 1853 p. 707; Haltern, 1971 p. 155). These award-winners can be matched with the entries from the exhibition catalogues to construct a measure for the quality of innovations.

C. Potential Weaknesses of the Exhibition Data

There are however potential sources of bias in the exhibition data. Space restrictions and transportation costs appear to be the most important potential sources of bias for the number of innovations that countries brought to the fairs. At the Crystal Palace, Britain's Central Commission allocated exhibition space according to their subjective perception of each country's relative importance. Space restrictions, however, appear to have been flexible: when the United States Commission to the Crystal Palace thought that U.S. 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 exhibition show that countries built additional exhibition space on the Centennial grounds: Australia, Brazil, Canada, Egypt, Germany, Great Britain, Japan, Morocco, Spain, Sweden, and Turkey constructed temporary structures to house further exhibits.[5]

Heavy and fragile innovations, which would otherwise have been under-represented due to transportation costs, could be exhibited as models or as blueprints. Of 194 British exhibits in class 7, "Civil Engineering, Architecture, and Building Contrivances", 88 exhibits, or 45 percent, were represented by models. For example, T. Powell of Monmouthshire, Britain, exhibited a "Model for apparatus used for shipment of coals from boats or waggons at Cardiff dock"; A.Watney of Llanelly, Wales, exhibited "Models of anthracite blast furnaces." Among the engineering exhibits there was a model of the suspension bridge that was being constructed across the river Dnieper in Kiev. Robert and Alan Stevenson (grandfather and uncle to Robert Louis Stevenson) displayed models of lighthouses for the Bell Rock and for Skerryvore (see L.T.C. Rolt, 1970 p. 157).

Perhaps the most important weakness of the exhibition data is that they may underreport innovations that are easy to copy, if such innovations were not displayed for fear of imitation. Exhibition data may therefore be biased against innovations that are omitted from the patent counts. Contemporary records indicate that imitation was a more serious concern if the host country to the exhibition did not have patent laws. Yet even in these countries only a few exhibitors decided to withdraw their innovations from the fairs:

> In a meeting of the Central Commission for the Swiss Exposition in Lucerne, they had declared that they would not exhibit at Zurich unless Switzerland would adopt patent laws…It is a fact though, that, despite this false alarm, of the 5000 exhibitors only 50, no more than 1 percent, retracted their applications (*Procès-verbal du Congres Suisse*, 1883 p. 68).

At both fairs, exhibitors found ways to advertise without disclosing the secrets of their innovations. Rather than exhibiting a new piece of machinery, or describing a new process, exhibitors often chose to display samples of their final output. For example, Drewsen & Sons of Silkeborg, Jutland, exhibited "Specimens of paper, glazed by a machine constructed by the exhibitor", instead of the machine itself, which he kept secret (see *Official Catalogue, First Edition*, 1851 p. 210). P. Claussen of London, an inventor and patentee, exhibited "Samples of flax in all its stages, from straw to cloth, prepared by the exhibitor's process" (*Official Catalogue,* 1851 p. 28). In addition, a system of registration, which was available to all exhibitors, acted as a cheap and fast patent system; at the Crystal Palace only 500 of 13,750 exhibitors took advantage of it (*Bericht III*, 1853 pp. 697-701). If exhibition data undercount

[5] *Visitor's Guide* (1875, p. 18). The mean area per exhibitor was approximately equal at both fairs, with 0.00118

innovations that were protected by secrecy they under- rather than overstate the share of innovations without patents.

D. Are Patent Laws Endogenous to Innovation?

All empirical analyses of the effects of patent laws on innovation are plagued with the problem of endogeneity (Adam Jaffe 2000), and this study also must be mindful of the problem. From the mid-19th century onwards, domestic interest groups began to lobby strongly for what they considered the most favorable patent laws. In the 1880s, two of Switzerland's most important industries – chemicals and textiles – opposed the introduction of patent laws (*Procès-Verbal du Congres Suisse*…1883, Penrose 1951) and, as a likely outcome of such pressures, the first patent law in 1888 required inventors to deposit models with the patent office, effectively excluding chemical processes and dyes from patenting (see Penrose, 1951 p. 16; Eric Schiff, 1971 pp. 86, 93). International treaties in the 1880s, which could serve as an instrument for patent laws (Josh Lerner 2002) were influenced by foreign interest groups whose fears of competition reflected international patterns of innovative activity and industry structure (Penrose 1951, pp. 15-17 and 117-124).

Endogeneity, however, is less likely to be a problem for the mid 19th-century than for any later period, even though it cannot be excluded with absolute certainty. Lerner's (2000) observation, that legal traditions and political systems appear to be a primary force in shaping patent laws, is especially true for this period. Historical records indicate that patent systems were initially adopted in a relative *ad hoc* manner, without knowledge or consideration for their

acres (4.7753 square meters) in 1851 and 0.00125 acres (or 5.0586 square meters) in 1876.

effects on specific industries (Penrose 1951, p. 19) and they document that the influence of innovation on patent laws was limited prior to the exhibitions:

> "In 1839 Brougham's Act was amended for a minor technical reason, and in 1844, the Judicial Committee of the Privy Council was empowered to extend patents up to a period of fourteen years. Neither of these changes appears to have resulted from pressure applied by the invention interest." (Dutton 1984, p.57)

Dutton (1984) offers a variety of potential explanations for the limited involvement of 19th-century inventors:

> "Patent laws were technically complex and intrinsically uninteresting. Many inventors were probably too ignorant to offer any interference and few MPs were able or willing to master the subject…Secondly, the invention interest was not sufficiently unified, and remained organized on a local basis only, right through to the late 1840s" (Dutton 1984, p.64)

Nevertheless, endogeneity deserves consideration and will be addressed in detail later using a variety of robustness checks. The following section combines exhibition and patent data to measure the importance of patenting across industries.

II. Cross-Industry Variation in the Importance of Patent Protection

Moser (2004) uses exhibition data to measure inventors' propensity to patent across industries and countries. Two different methods are used to distinguish innovations that are patented. For Britain's innovations, patented innovations are identified from references to patents in the descriptions of exhibits in the catalogues. For example, J. Bendall, introduced "A universal self-adjusting cultivator,…; pat.". Patenting rates are constructed by dividing the number of exhibits with references to patents by the total number of exhibits.[6] For American

[6] References to patents will be most accurate if exhibitors report patents truthfully. As an approximation, this seems reasonable: exhibitors benefited from reporting the patents that they owned and jurors carefully checked all exhibits, so that fraudulent references faced a real risk of discovery.

innovations, patented exhibits are identified by matching all 549 American exhibitors at the Crystal Palace with patents granted between 1841 and 1851 from the *Annual Report of the Unites States Patent Office*. For example, "U.S. patent No. 4387; Otis, Benjamin H.; Dedham, Mass; Mortising machine; granted Feb. 20, 1846", from the *Annual Report* for 1846, and "U.S. exhibit 23; Otis, B.H.; Cincinnati, Ohio; Boring and mortising machine" from the *Official Catalogue* (1851), identify a match.

Comparisons of American and British patenting rates reveal remarkable similarities in patenting behavior, despite important differences between the American and the British patent laws. Although the upfront costs of patenting were extremely high in Britain (at the equivalent of 37,000 current U.S. dollars, Lerner 2000) but modest in the U.S. (at 618 U.S. dollars), the share of innovations that were patented was similar in Britain and in the U.S.: 11.1 percent in Britain compared to only 14.2 percent in the U.S. (Table 3). Moreover, British and American inventors chose to patent (and not to patent) in the same industries. In Britain and the U.S., innovations in machines, such as new types of engines, manufacturing machinery or agricultural tools, were patented more frequently than innovations in any other industry. Table 3 shows that one third of American innovations in engines, manufacturing machinery, and agricultural machinery were patented, compared to one seventh across all industries. In Britain, these same industries had the highest patenting rates, despite significant differences in patent laws. One fifth of British innovations in these industries refer to patents, compared to less than one ninth of British innovations economy-wide. In contrast, inventors chose to patent between three and ten percent of innovations in scientific instruments, food processing, chemicals, textiles, and mining.

These inter-industry differences in patenting are robust to quality adjustments. For 1,803 British innovations that received awards for inventiveness, the proportion of patent holders is only slightly higher than in the overall population of British innovations: approximately 10 percent of British award-winners refer to patents, compared to 11.2 percent of all British innovations. Moreover, the patenting behavior of award-winning innovations corroborates the patterns of cross-industry variations in the overall data, as patenting rates are close to 20 percent for machinery, but significantly lower in other industries, such as instruments, chemicals, and food processing.

Aggregating the data into larger industry classes may lead to underestimating inter-industry differences in the propensity to patent. The industry class "textiles", for example, includes dye stuffs innovations, that were extremely difficult to reverse-engineer, as many dyes remained inimitable for more than 100 years, along with advances in weaving and other types of innovations that are copied with much greater ease. Similarly, the class "instruments" includes telegraphs and improvements to the pianoforte along with optical and scientific instruments. Half of all telegraphs are patented, compared to 14 of 101 British inventions in optical instruments and watches. A large share of telegraphs in the British data may cause an upward bias in the propensity to patent instruments compared to the potential patenting rates in countries without patent laws, where innovation focused on optical and scientific instruments.

Contemporary industry reports, letters from inventors, and government surveys attest to the importance of alternative mechanisms to protect innovations, especially in instruments and food processing.[7] Eugène Jaquet and Alfred Chapuis (1945) relate many instances when Swiss watchmakers went through great troubles to keep new production processes secret. For example,

[7] The analysis concentrates on secrecy, which appears to be the most important alternative mechanism, but it could be easily extended to include others, such as lead time or complementary assets. The central issue is that alternatives to patent laws exist, and that their effectiveness relative to patents varies across industries.

> Many of Geneva's watchmakers – Lovousy, Latard, Boureaux, Geneqund, Girod, Bagan, Boinche, to name a few – employed their own inventions of new tools, which they did not allow anybody to see. Nobody was permitted to enter their workroom, not even those who brought work to them.[8]

Another group of watchmakers in the Valleé de Joux, who shared the secret of the "sonnerie des minutes", measuring minutes, entered into a verbal agreement not to take any apprentices in order to protect their intellectual property. They succeeded in honoring this agreement from 1823 to 1840 (see Jaquet and Chapuis, 1945 p. 165). Watch-making may have been especially suitable to secrecy because such innovations proved so difficult to imitate. For example, the German Commission reports that Dutch and Swiss inventions in optical instruments, such as the rectangular prisms of Swiss glassmaker T. Daguet of Soleure, or Danish barometers and surgical instruments, proved impossible to reverse-engineer (*Bericht I*, 1852 pp. 813, 819, 930, and 941).

In food processing, the history of margarine illustrates the effectiveness of secrecy relative to patents. Although margarine was first invented and patented in France, it turned profitable in the Netherlands, at a time when this country did not have patent laws. Two Dutch firms, Jurgens and Van den Bergh, began to manufacture margarine in 1871, after the original patent holder, a French chemist by the name Mège Mouriès, freely told them how to produce margarine from suet, considering margarine protected by his patent. Trade secrets protected future improvements: when the Van den Bergh factory succeeded in producing a new and less repulsive type of margarine, they kept this innovation secret. As late as 1905, long after the original patent would have expired, the Jurgens firm had not succeeded in reverse engineering by chemical analysis or by hiring away his rival's workers (Schiff 1971).

In sum, Moser (2004) documents that the effectiveness of patent protection varies across industries. Therefore, if innovation is motivated by expected profits, inventors in countries

[8] Jaquet and Chapuis (1945 p. 170), author's translation. See David Landes (1983) for further examples.

without patents should focus on industries with low patenting rates and strong alternative mechanisms. The following section uses exhibition data to test this hypothesis.

III. Empirical Tests with Exhibition Data

This section uses data on exhibits for two years (1851 and 1876) and twelve countries (Austria, Bavaria, Belgium, Britain, Denmark, France, the Netherlands, Norway and Sweden, Prussia, Saxony, Switzerland, and Württenberg) to examine the relationship between patent laws and the direction of technical change.[9] Together, these countries contribute 10,792 exhibits at the Crystal Palace and 4,143 at the Centennial Exhibition. Although this adds to a total of almost fifteen thousand observed innovations, all variation occurs at the level of countries and industries, which effectively reduces the number of observations to the number of countries times the number of industries. With twelve countries in 1851, ten countries in 1876, and seven industry categories, the analyses are based on 154 observations of exhibits per year, country, and industry. Although exhibition data would be available for almost all 19th-century countries, including the U.S., Russia, China, and Japan (countries for which exhibition data are the only data on innovation), I focus the analysis on Northern Europe because the selection process for these countries is well documented and differences in unobserved characteristics, such as climate, culture, and religious beliefs are relatively small, whereas differences in patent laws are significant.[10]

[9] Table 2 summarizes data on patent length, size, GDP, and levels of education for these countries. An earlier version of this paper also examined the effects of patent laws on the number of innovations and included patent fees as an explanatory variable. Countries without patent laws brought large numbers of innovations to the fairs and received a disproportionate share of awards for high quality innovations. For example, mid-19th century Switzerland, had the second highest number of exhibits per capita in 1851.
[10] Including data for the rest of the world strengthens the measured effects of patent laws, but these effects may be driven by largely unobservable differences across countries, such as geographic location and resource endowments.

For states whose borders are comparable between 1850 and today I use Lerner's (2000, 2002) data on patent laws. These data, constructed from inventors' manuals on patenting in foreign countries, proceed in 25 year intervals, which include 1850 and 1875. For states with border changes, such as pre-unification Germany, I obtain additional information from inventors' guides to international patent laws by Richard Godson (1840), John Kingsley and Joseph Pirsson (1848), and Coryton (1855). In the 19th century, there was a large amount of variation in patent laws even for countries that are unified today. Within Germany, patent lengths varied from 10 years in Württenberg to 15 years and "prolonged at pleasure" in Bavaria. At the same time, Württenberg's patent officers charged fees that were 20 times higher than those demanded by their Prussian counterparts.

The variable "patent length" is defined as the maximal duration of the patent that inventors can be granted at the time of application. For countries without patent laws, I record patent length to equal zero. Denmark, a country which offered only rudimentary protection to certain types of manufacturing processes, is recorded as having patent length zero. Other countries with zero patent length are Switzerland, which did not adopt its patent laws until the 20th century, and the Netherlands after the abolition of patent laws in 1869 (Coryton, 1855 pp. 245, 260). Plots of the patent length variable reveal that patent length clusters around a few values rather than being continuous. To account for the discrete nature of these data, I divide patent length into three categories: no patents, short patents, and long patents. I follow studies of 20th -century patent renewal data such as Ariel Pakes (1986) that chose 10 years as the cutoff point to distinguish short and long patents. Two countries are without patent laws in both 1851 and 1876; one country has short patent grants in 1851 but three have short patents in 1876.

A. Tests for the Equality of Distributions

If patent laws influence the direction of innovation in a similar way to that proposed in section II, the distribution of innovations across industries should differ across countries with widely divergent patent laws and be quite similar for countries with similar patent systems. Chi-square statistics in Table 4 confirm that large differences exist in the distribution of exhibits across industries, especially among countries with different patent laws. For European countries with different patent lengths, the hypothesis that innovations are distributed equally across industries is strongly rejected. Table 4 also provides weaker evidence that countries with equal patent length are more similar to each other. Differences in distributions increase with increases in patent lengths. As Mark Schankerman and Pakes (1986) argue the life cycle of innovations is much shorter than the statutory patent grant for all but a small minority of innovations. Consequently, for long patents, further increases in patent length exert little influence on innovation, whereas for short patents increases in patent length appear to be much more important. In the Crystal Palace data large differences in patent length are associated with large differences in the distribution of innovation, while, for countries without patent laws, chi-square tests narrowly fail to reject the hypothesis (at 1 percent significance) that innovations are distributed identically across industries.

Figure 3 reveals that the patentless countries share a strong focus on a narrow set of innovations. In 1851, one in four exhibits from both Switzerland and Denmark is a scientific instrument, such as an optical lens, an improved watch movement or a watch escapement, a barometer, or a theodolite. Twenty-seven percent of Switzerland's exhibits and 23 percent of Denmark's exhibits at the Crystal Palace are such instruments. At the same time, no other country, regardless of her level of industrialization, has comparable shares of innovations in this class, although instruments are among the key high-tech industries of the 19th century. For Britain, undoubtedly the most technologically advanced country of the mid 19th century, only eight percent of innovations occur in instruments, a share that equals the mean and slightly exceeds the median of six percent across all countries. After Switzerland and Denmark, Bavaria, where patents last up to 15 years, but are ill-enforced, has the third highest share: 14 percent of Bavaria's exhibits are in instruments.

This parallel focus of innovations is even more striking for two countries that differ so strongly in their other natural endowments. Switzerland is land-locked, mountainous and largely isolated, whereas Denmark is an open, flat, and maritime. The following section presents discrete-choice regressions, which control for such non-patent characteristics that may affect the direction of technical change.

B. Discrete-choice Regressions

The aim of this section is to assess the effect of patent laws on an innovator's choice between industries. Innovations are divided into seven distinct industry classes: mining, chemicals, food processing, machinery, scientific instruments, textiles, and manufacturing. This categorization, which I have described in the data section, removes the hierarchies among industry classes, so that the remaining, larger classes are unordered, and mutually exclusive, i.e., each innovation can occur in only one class. Potential inventors choose simultaneously between industries; their choice may be influenced by patent laws, as well as other characteristics of their work environment. Multinomial logit regressions, as introduced by Daniel McFadden (1974), provide the most natural approach to measure such effects.[11]

Results in Table 5 confirm that patent laws have a strong influence on an inventor's choice of industry. The focus of inventive activity on instruments persists even when we control for country size, GDP per capita, and levels of education. Predicted values in Table 6 demonstrate that 1 in 4 innovations from patentless countries are instruments, compared to 1 in 15 innovations from other countries (holding population and GDP per person constant).[12] This strong positive effect is robust to changes in the specifications, to dropping Switzerland from the regressions (column IV), to dropping Britain, and to restricting the data to award-winners only.[13]

Textiles innovations, particularly of dye stuffs, also attract disproportionate shares of inventors in the patentless countries. The variable "no patents" consistently exerts a positive and statistically significant effect on the share of textile innovation in countries without patent laws, even when omitting Switzerland. A closer examination of Swiss textiles at the Crystal Palace reveals that 20 percent of Switzerland's innovations were related to dyes. Turkey red, heavily dependant on specialized knowledge and widely regarded as the most complex dyeing process ever invented, was most prominent among Swiss innovations in dyes.[14] Similarly, predicted shares in another secrecy industry, food processing, are 13.5 percent for countries without patent laws, but only 9 percent for countries with patent laws.

---

[11] Alternatively, I have fitted logit models separately for the six pairings of responses (omitting *Manufactures* as the largest class). Parameter estimates obtained in separate fitting of logit models are less efficient than those obtained by simultaneously fitting the multinomial logit, especially when the probability of being classified in the omitted (baseline) category is small, but they are a useful check on the data and results remain largely unchanged.

[12] Predicted values are calculated as $\pi_i (x_{ij}) = \exp (\alpha_i + \beta_i x_j) / [\exp (\alpha_{mining} + \beta_{mining} x_j) + \ldots + \exp (\alpha_{manufactures} + \beta_{manufactures} x_j)]$ from regressions controlling for GDP per person and the logarithm of population.

[13] In the awards regressions, mining and chemicals are combined to raise the number of observations per cell.

[14] The process involved thoroughly cleansing the yarn by boiling with alkali, steeping in rancid oil, soda and sheep dung, mordanting with alum and sumac, dyeing in a batch of madder, ox blood, and chalk and finally washing to brighten the color (Archive of the Society of Dyers and Colourists, 2004).

In contrast, inventors in patentless countries are less likely to focus on machinery innovations that depend on patenting. Predicted shares for machinery are 11.4 percent for countries with patents and only 8.8 percent for countries without patents. While this gap is relatively small, especially considering the pronounced importance of patenting for machinery, it is economically significant when considering other aspects of the data. A closer look at Switzerland's innovations, for example, reveals a strong difference in the composition of innovations within the machinery class relative to countries that have patent laws. British and American innovations concentrate on engines and manufacturing machinery, which are strongly dependant on patent protection, while Swiss inventors focus on innovations that tend not to be patented even in the British and American data. Tools for skilled manufacture, such as J. Erbrau's "turning, pivoting, and depthening tools" (exhibit 4), hunting rifles, such as J. Vannod's "improved fowling piece" (exhibit 69) and agricultural tools, including J.A. Faessler's "milk tubs" (exhibit 229), are most frequent among Swiss inventors. These innovations are not patented. In contrast, innovations in manufacturing machinery and engines are extremely rare in the Swiss data.

For mining innovations, the lack of deposits of iron and coal, not surprisingly, outweighs the influence of patents. Mining innovations have among the lowest patenting rates, and they may therefore serve as a haven to inventors in countries without patent laws. However, Switzerland, Denmark, and the Netherlands all lack significant endowments in iron ore and high quality coal, which would have made such innovations possible (Schiff, 1971 p. 35). Resources wealth also plays a key role in determining the feasibility of chemical innovations, especially at the earlier exhibition. Ideally, the regressions would control for such endowments, but there are no systematic data for the 19th century. Instead, I check that including these resource-intensive industries does not distort effects on other variables. As transportation costs decrease the negative coefficient of mining weakens for countries without patent laws.

Education, population and GDP per capita are other important influences on the distribution of innovative activity across industries. The effects of education are intuitive; countries that invest more in education also have larger shares of their innovations in 19th-century high-tech industries, chemicals and scientific instruments, which were at the vanguard of technological progress in the 19th-century (Mokyr 2002). Size, as measured by population, may allow large economies to develop innovative capacity in sectors where inventive activity depends on large scale to be profitable (Schmookler 1966). Large markets for innovations, proxied by GDP per capita, may create opportunities for specialization and knowledge spillovers among competing firms (Sokoloff 1988 and Michael Kremer 1993).

Table 5 also suggests that the effects of patent laws change with the nature of technological progress. For example, the effects of patent laws on food become stronger as the industry evolves from methods of preservation in 1851 to methods of processing in 1876, including instant meals and mass-produced staple goods, such as margarine. In 1851, innovations in foodstuffs have shares of about two percent in countries without patent laws and four percent in other countries. By 1876, the share of foodstuffs has risen to about one quarter for countries without patent laws and to nearly 16 percent for countries with patent laws. Many important innovations in food processing originated in late 19th-century Switzerland, such as milk chocolate, liquid soup seasoning, bouillon, and baby food (see Schiff, 1971 pp. 54-58, 111-112).

At the same time, the focus on scientific instruments weakens between the exhibitions: In 1851, 27 percent of all exhibited innovations from patentless countries are in scientific instruments compared to 7 percent for other countries. In 1876 these shares have dropped to 19 and 6 percent, respectively. This drop coincides with a shift from specialized skilled manufacture to mechanization and mass production, which relied heavily on progress in manufacturing machinery (Jaquet and Dupuis 1945, David Landes 1983). As the nature of innovation changes, leadership in instrument-making shifts from Switzerland, a country without patent laws, to the United States that had adopted a strong patent system (Khan and Sokoloff 1998).

C. The Netherlands' Abolition of Patent Laws in 1869

Changes in the distribution of innovation between the Crystal Palace and Centennial exhibitions also help to address the problem that the direction of innovation may depend on unobserved country characteristics. While there are too few observations to calculate country-fixed effects, the Netherlands' decision to abandon patent laws creates a situation that resembles a natural experiment for examining the effects of patent laws. According to Penrose (1951) the central reason why the Netherlands abolished patent laws in 1869 was the ideological link between patent laws and protectionism; patent laws were at odds with the Netherlands' commitment to free trade. Innovation may have played only an indirect role in the decision, yet after the Netherlands abandoned patent laws in 1869 the country experienced a strong shift towards food processing, an industry where secrecy was important. The proportion of Dutch innovations in food processing increased from 11 to 37 percent between 1851 and 1876, replacing textiles as the most prominent sector (Figure 2). At a time when the focus of textiles innovation shifted from dyes to manufacturing machinery and mass production, the Netherlands' share of innovations in textiles fell from 37 to 20 percent. Equally, as mechanization and machinery became central to the manufacturing sector, the share of manufactures dropped from 26 to 12 percent. At the same time, the proportion of innovations in scientific instruments stayed constant at 8 percent, while other countries reduced their focus on that industry.

D. Constructing a Synthetic Switzerland with Patent Laws

Another way to address the possibility that pre-existing factors influence the adoption of patent laws is to construct a synthetic country without patent laws from data for countries with patent laws that match the characteristics of patentless countries as closely as possible. Following Alberto Abadie and Javier Gardeazabal (2003), I use a Mahalanobis matching estimator to construct this synthetic country.[15] Abadie and Gardeazabal create a synthetic Basque region (without terrorism) from the characteristics of other Spanish regions to evaluate the effects of terrorism on GDP growth over time; I create a synthetic "Switzerland" with patent laws from the characteristics of other European countries as an additional check for the effects of patent laws on the distribution of innovations across industries.

The synthetic country is created by matching the characteristics of the real Switzerland and Denmark as closely as possible through a weighted average of the characteristics of other European countries with similar characteristics, but *with* patent laws. Let J be the number of available control countries with patent laws and let W be a ($J \times 1$) vector of non-negative weights $(w_1, w_e, \ldots w_J)'$ that sum to one. The scalar w_j represents the weight that country j is given in constructing the synthetic Switzerland. Let X_1 be a $(K \times 2)$ vector of population, GDP per person, and education in Switzerland and Denmark as reported in Table 2, and let X_0 be a $(K \times J)$

[15] Abadie and Gardeazabal (2003) construct a weighing matrix to mimic the growth path of GDP in the Basque country. Similarly, Yi Quian (2004) uses the Mahalanobis estimator to examine the effects of a country's

matrix of the values for these same variables in the set of possible control countries. Let the (K x K) matrix *V* be the inverse sample variance covariance matrix of the matching variables. This is the weighing matrix of the Mahalanobis matching estimator (Rubin 1977, Rosenbaum and Rubin 1983). The vector of weights *W** is chosen to minimize $(X_1\text{-}WX_0)'V(X_1\text{-}WX_0)$. Each country is allowed to be used as a match twice, equivalent to allowing one replacement.[16]

Table 7 and Figure 4 report the results of this estimation, which lends further support to the hypothesis that the absence of patent laws helped to encourage a focus on secrecy industries in countries without patent laws. In a counterfactual Switzerland and Denmark *with* patent laws, the share of innovations that occurred in scientific instruments would have been between 14 and 25 percent lower than it was in the observed countries. Although the effects on food processing and machinery are not significant in the overall data, estimation on a sub-set of high-quality innovations, the award-winners in 1851, indicate a positive treatment effect on food processing and a negative effect on machinery (5 and -5 percent respectively, in column II). Treatment effects on the treated countries suggest that, in addition to reducing the share of machinery innovations, the absence of patent laws strongly reduced the proportion of manufacturing innovations as this industry became increasingly dependant on manufacturing machinery and mechanization (values for 1851 and 1876, with and without awards, rows 3 to 6). The results also indicate that the absence of patent laws increased the share of innovations in mining compared to a counterfactual country with patent laws (treatment effects on the treated, row 4),

---

pharmaceutical patent policy on R&D expenditure in pharmaceuticals and on U.S. patents granted to residents of that country. See Abadie and Guido Imbens (2004) for a comprehensive discussion of the Mahalanobis estimator.

[16] Although including primary education as a third variable would create a closer match, I present results excluding education because matching estimators are not consistent with more than two continuous matching variables. Abadie and Imbens 2004). Including education does not affect the qualitative results. I allow one replacement because matching with replacements produces higher quality matches by increasing the number of possible matches.

lending further support to the hypothesis that patent laws exert a noticeable influence on the direction of innovation.

VI. Conclusions

This paper has introduced new data on innovations at two 19^{th}-century world fairs, which allow an empirical examination of the effects of patent laws on the direction of technical change. The data have been constructed from the catalogues of the Crystal Palace Exhibition in London in 1851 and the Centennial Fair in Philadelphia in 1876. Exhibition data strongly suggest that patent laws influence the direction of innovation. In the 19^{th}-century, the absence of patent laws appears to have guided innovative activity towards industries where mechanisms other than patent laws protected intellectual property. Inventors in countries without patent laws concentrated in industries where secrecy was an effective alternative to patent grants, such as scientific instruments, food processing, and dye stuffs, and countries without patent laws became technological leaders in those industries. At the same time, inventors in the patentless countries tended to avoid innovations in manufacturing and other machinery, which were strongly dependent on patent protection, and the patentless countries lost their early lead in manufacturing industries as machinery and mechanization became more important.

This result may help to resolve a long-standing debate over the relative importance of demand and supply factors in determining the direction of innovation. Schmookler (1966) interpreted variations in the number of annual patents across a small number of industries as evidence for the importance of demand factors, while Rosenberg (1974) argued that an exogenous supply of scientific progress, and government policies encouraging such progress, played an equally important role. The collection of economy-wide international data on innovations has made it possible to examine the relationship between patent laws and the distribution of innovations across industries and across countries. Such data suggests that patent laws help to shape the direction of innovation by influencing the incentives to invent across industries. Patent policies help to determine how inventors respond to differences in the demand for innovations across industries, and, to the extent that knowledge is cumulative as Scotchmer (1991) and Mokyr (2002) suggest, they also help to determine the supply of knowledge.

These findings suggest an important consideration for international patent policies: The introduction of strong patent laws may trigger changes in the direction of innovative activity in developing countries and initiate significant changes in international patterns of comparative advantage. In the 19th-century, a focus on manufacturing machinery allowed the U.S. to evolve from a backwater of Europe to the world's most technologically advanced and fastest growing economy. While the focus on machinery innovations has been explained by the scarcity of labor (Rothbarth 1946, Habbakuk 1962, Rosenberg 1969), the results of this paper suggest that the decision to adopt strong patent laws at the beginning of the 19th century may have played an important role in encouraging the American focus on manufacturing machinery that spurred economic growth towards the end of the century.

Unlike the case of the 19th-century U.S., the introduction of patent laws to developing countries today may slow rather than accelerate economic growth if patent laws lead them to compete more directly with innovations from developed countries. Alan Deardorff (1992) and Elhanan Helpman (1993) argue that patent laws which work well in industrialized countries may prove detrimental to developing economies. Strong patent laws benefit developing countries only if they encourage technologies that differ from those invented in developed countries (Ishac Diwan and Dani Rodrik 1991). The results of the current paper, however, suggest that the introduction of uniform patent laws across the world may reduce rather than increase variation in the direction of innovation between developing and developed countries.

REFERENCES

Abadie, Alberto and Gardeazabal, Javier. "The Economic Costs of Conflict: a Case-Control Study for the Basque Country." *American Economic Review*, March 2003, pp. 113-132.

Abadie, Alberto and Guido W. Imbens. "Simple and Bias-Corrected Matching Estimators for Average Treatment Effects." National Bureau of Economic Research (Cambridge, MA) Working Paper No. 0283, October 2002.

Acemoglu, Daron. "Why Do New Technologies Complement Skills? Directed Technical Change and Wage Inequality." *Quarterly Journal of Economics*, November 1998, *113*(4), pp. 1055-89.

Baumol, William. "Entrepreneurship: Productive, Unproductive and Destructive." *The Journal of Political Economy*, October 1990, *98*(5), pp. 893-921.

Berichterstattungs-Kommission der Deutschen Zollvereins-Regierungen, *Amtlicher Berich über die Industrie-Austellung aller Völker zu London im Jahre 1851.* Volumes I-III. Berlin, Prussia: Verlag der Deckerschen Geheimen Ober-Hofbuchdruckerei, Volumes I and II, 1852, and Volume III, 1853.

Bowring, Edgar Alfred, *Journal.* London, England, 363 pages, in *Rare Books and Special Collections*, Duke University, Durham, N.C., 1850.

Cohen, Wesley; Nelson, Richard R. and Walsh, John P. "Protecting Their Intellectual Assets: Appropriability Conditions and Why U.S. Manufacturing Firms Patent (or Not)." National Bureau of Economics Research (Cambridge, MA) Working Paper No. 7552, February 2000.

Coryton, John. *A Treatise on the Law of Letters-Patent; For the Sole Use of Inventions in the United Kingdom of Great Britain and Ireland; Including the Practice Associated with the Grant; To Which is Added a Summary of the Patent Laws in Force in the Principal Foreign States.* Philadelphia: T. & J.W. Johnson, 1855.

Deardorff, Alan, V. "Welfare Benefits of Global Patent Protection." *Economica*, February 1992, *59* (233), pp. 35-51.

Diwan, Ishac and Rodrik, Dani. "Patents, Appropriate Technology, and North-South Trade." *Journal of International Economics*, February 1991, *30*(1,2), pp. 27-4.

Dutton, Harold, I. *The Patent System and Inventive Activity During the Industrial Revolution, 1750- 1852.* Manchester, England: Manchester University Press, 1984.

Gilbert, Richard and Shapiro, Carl. "Optimal Patent Length and Breadth." *RAND Journal of Economics*, Spring 1990, *21*(1), pp. 106-112.

Gilfillan, S.C. "Inventiveness by Nation: A Note on Statistical Treatment." *Geographical Review*, April 1930, *20*(2), pp. 301-304.

Godson, Richard. *A Practical Treatise on the Law of Patents for Inventions and of Copyright: Illustrated by Notes of the Principal Cases; with an abstract of the laws in force in foreign countries.* Second Edition, London: Saunders and Benning, Law Booksellers, 1840.

Griliches, Zvi. "Patent Statistics as Economic Indicators." *Journal of Economic Literature*, December 1990, *28*(4), pp. 1661-1707.

_______. "Hybrid Corn: An Exploration in the Economics of Technological Change," *Econometrica*, October 1957, *25*(4), pp. 501-522.

Habakkuk, H.J. *American and British Technology in the Nineteenth Century: the Search for Labour-Saving Inventions*. Cambridge, England: Cambridge University Press, 1962.

Haltern, Utz. *Die Londoner Weltaustellung von 1851. Ein Beitrag zur Geschichte der bürgerlich-industriellen Gesellschaft im 19. Jahrhundert.* Münster: Aschendorff, 1971.

Helpman, Elhanan. "Innovation, Imitation, and Intellectual Property Rights." *Econometrica*, November 1993, *61*(6), pp. 1247-1280.

Hounshell, David. *From the American System to Mass Production, 1800-1932: The development of manufacturing technology in the United States*. Baltimore: Johns Hopkins University Press, 1985.

Jaquet, Eugène and Chapuis, Alfred. *La Montre Suisse*. Bale and Olten: Editions Urs Graf, 1945.

Jones, Charles, "The Shape of Production Functions and the Direction of Technical Change", National Bureau of Economics Research (Cambridge, MA) Working Paper No. 10457, May 2004.

Khan, Zorina and Sokoloff, Kenneth. "Patent Institutions, Industrial Organization and Early Technological Change: Britain and the United States 1790-1850," Berg, Maxine and Bruland, Kristine (eds.), *Technological Revolutions in Europe: Historical Perspectives*. Cheltenham, UK: Edward Elgar, 1998.

Kingsley, John L. and Pirsson, Joseph P. *Laws and Practice of All Nations and Governments Relating to Patents for Inventions; with Tables of Fees and Forms, also an Editorial Introduction with Explanations of Practice and Proceedings used in Procuring Patents Throughout the World.* New York: Kingsley and Pirsson, 1848.

Klemperer, Paul. "How Broad Should the Scope of Patent Protection Be?" *RAND Journal of Economics,* Spring 1990, *21*(1), pp. 113-130.

Kremer, Michael. "Population Growth and Technological Change: One Million B.C. to 1990." *Quarterly Journal of Economics*, August 1993, *108*(3), pp. 681-716.

Kretschmer, Winfried. *Geschichte der Weltausstellungen*. Frankfurt: Campus Verlag, 1999.

Kroker, Evelyn. *Die Weltausstellungen im 19. Jahrhundert: Industrieller Leistungsnachweis, Konkurrenzverhalten und Kommunikationsfunktion unter Berücksichtigung der Montanindustrie des Ruhrgebietes zwischen 1851 und 1880.* Göttingen, Germany: Vandhoeck Ruprecht, 1975.

Kuznets, Simon. "The Meaning and Measurement of Economic Growth." Supple, Barry (ed.), *The Experience of Economic Growth, Case Studies in Economic History*. New York: Random House, 1963.

Landes, David. *Revolution in Time: Clocks and the Making of the Modern World.* Cambridge: The Belknap Press of Harvard University Press, 1983.

Lerner, Josh. "Patent Protection and Innovation Over 150 Years", National Bureau of Economics Research (Cambridge, MA) Working Paper No. 8977, June 2002.

_______. "150 Years of Patent Protection." National Bureau of Economics Research (Cambridge, MA) Working Paper No. 7478, January 2000.

_______. "150 Years of Patent Protection." *American Economic Review,* May 2002, *92*(2), pp. 221-225.

Levin, R.C.; Alvin K. Klevorick, A.K. and Richard Nelson. "Appropriating the Returns from Industrial R&D." *Brookings Papers on Economic Activity,* 1987, *3*, pp. 783-820.

Maddison, Angus. *The World Economy: A Millennial Perspective*. Paris: Development Centre of the Organization for Economic Co-operation and Development, 2002.

_______. *Monitoring the World Economy, 1820-1992*. Paris: Development Centre of the Organization for Economic Co-operation and Development, 1995.

McFadden, Daniel. "Conditional Logit Analysis of Qualitative Choice Behavior," in *Frontiers of Econometrics,* ed. by P. Zarembka. Academic Press, New York. 1974.

Meinhardt, Peter. *Inventions, Patents and Monopoly*. London: Stevens & Sons, Ltd., 1946.

Mokyr, Joel. *The Gifts of Athena, Historical Origins of the Knowledge Economy*, Princeton: University Press, 2002.

Moser, Petra. "What Do Inventors Patent?" Unpublished working paper, Massachusetts Institute of Technology, August 2004.

Murphy, Kevin M.; Shleifer, Andrei and Vishny, Robert W. "The Allocation of Talent: Implications for Growth." *The Quarterly Journal of Economics,* May 1991, *106*(2), pp. 503-530.

Nordhaus, William D. "An Economic Theory of Technological Change" *The American Economic Review,* May 1969, *59*(2), pp. 18-28.

L'Office permanent de l'institut international de statistique. *Annuaire International de Statistique, 1916, vol. 1, Etat de la population (Europe),* La Haye, 1916.

Pakes, Ariel. "Patents as Options: Some Estimates of the Value of Holding European Patent Stocks." *Econometrica*, July 1986, *54*(4), pp. 755-784.

Penrose, Edith Tilton. *The Economics of the International Patent System.* Baltimore: John Hopkins University Press, 1951.

Procès-Verbal du Congres Suisse *de la Proprieté Industrielle tenu à Zurich dans la salle du Grand Conseil les 24 et 25 Septembre 188*3, Zurich: Impremierie Zurcher & Furcher, 1883.

Rolt, L.T.C. *Victorian Engineering.* Harmondsworth, UK: Penguin Books, 1970.

Rosenbaum, Paul, and Donald Rubin. "The Central Role of the Propensity Score in Observational Studies for Causal Effects." *Biometrika*, April 1983, *70*(1), pp. 41-55.

Rosenberg, Nathan. "Science, Invention and Economic Growth." *The Economic Journal*, Mar. 1974, *84*(333), pp. 90-108.

_______. *Technology and American Economic Growth.* New York: Harper, 1972.

_______. *The American System of Manufactures*. Edinburgh: Edinburgh University Press, 1969.

Rossman, Joseph. "The Motives of Inventors." *Quarterly Journal of Economics*, May 1931, *45*(3), pp. 522-528.

Rothbarth, Edwin. "Causes of the Superior Efficiency of U.S.A. Industry Compared with British Industry." *The Economic Journa*l, 1946, *56*, pp. 383-90.

Royal Commission. *Official Catalogue of the Great Exhibition of the Work of Industry of All Nations 1851*, Third Corrected and Improved Edition, London: Spicer Brothers, 1851.

Rubin, Donald. "Assignment to Treatment Group on the Basis of a Covariate," *Journal of Educational Statistics*, 1977, *2*(1), pp. 1-26.

Sakakibara, Mariko and Branstetter, Lee G. "Do Stronger Patents Induce More Innovation? Evidence from the 1988 Patent Reforms." *RAND Journal of Economics,* Spring 2001, *32*(1), pp. 77-100.

Schankerman, Mark and Ariel Pakes. "Estimates of the Value of Patent Rights in European Countries During the Post-1950 Period." *The Economic Journal*, December 1986, *96*(384), pp. 1052-1076.

Schiff, Eric. *Industrialization without National Patents*. Princeton: Princeton University Press, 1971.

Schmookler, Jacob. *Patents, Invention and Economic Growth - Data and Selected Essays,* Grilliches, Zvi and Hurvicz, Leonid (eds.), Cambridge: Harvard University Press, 1972.

_______. *Invention and Economic Growth*. Cambridge: Harvard University Press, 1966.

_______. "Economic Sources of Inventive Activity." *Journal of Economic History*, March 1962, *22*(1), pp. 1-20.

Scotchmer, Suzanne. "Standing on the Shoulders of Giants: Cumulative Research and the Patent Law." *Journal of Economic Perspectives*, Winter 1991, *5*(1), pp. 29-41.

Sokoloff, Kenneth. "Inventive Activity in Early Industrial America: Evidence from Patent Records, 1790-1846." *Journal of Economic History,* December 1988, *48*(4), pp. 813-850.

Temin, Peter "Labour Scarcity and the Problem of American Industrial Efficiency in the 1850's." *Journal of Economic History*, Sept. 1966, *26*, pp. 277-298.

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

United States Centennial Commission. *International Exhibition 1876 Official Catalogue, Second and Revised Edition*, Philadelphia: John R. Nagle and Company, 1876.

United States Patent Office. *Annual Report of the Commissioner of Patents,* Washington: Government Publication Office, 1841to 1851.

Wright, Gavin. "The Origins of American Industrial Success", *American Economic Review*, Sept. 1990, *80*(4), pp. 651-68.

Quian, Yi, "Do Additional National Patent Laws Stimulate Domestic Innovation in a Global Patenting Environment? A Cross-Country Analysis of Pharmaceutical Patent Protection: 1978-1999." Unpublished working paper, Harvard University, November 2004.

TABLE 1 – STATISTICS ON THE WORLD FAIRS OF 1851 AND 1876

	EXHIBITION	
	Crystal Palace	Centennial
Location	London	Philadelphia
Year	1851	1876
Countries		
Total	40	35
N. Europe	12	10
Exhibitors		
Total	17,062	30,864
N. Europe	11,610	6,482
Visitors	6,039,195	9,892,625
Area (in acres)	25.7	71.4

Sources: *Bericht III* (1853) and Kretschmer (1999).

TABLE 2 – COUNTRY CHARACTERISTICS

Country	Patent Length		Population		GDP		Primary Education	
	1851	1876	1851	1876	1851	1876	1851	1876
Austria	15	15	3,950	4,730	6,563	9,395	389	426
Bavaria	15	-	4,521	-	6,673	-	-	-
Belgium	15	20	4,449	5,303	8,042	14,849	549	582
Britain	14	14	25,601	30,662	60,479	107,661	555	680
Denmark	0	5	1,499	1,973	2,549	4,008	-	-
France	15	15	36,350	38,221	60,685	84,014	515	737
Germany	-	15	-	24,023	-	-	-	732
Netherlands	15	0	3,095	3,822	5,844	52,805	541	639
Prussia	12	-	16,331	-	24,105	-	730	-
Saxony	12	-	1,894	-	2,796	-	-	-
Norway & Sweden	15	-	4,875	-	5,993	-	615	-
Norway	-	3	-	1,803	-	2,650	-	658
Sweden	-	3	-	4,363	-	8,006	-	568
Switzerland	0	0	2,379	2,750	1,986	5,787	-	759
Wurttemberg	10	-	1,745	-	2,575	-	-	-

Notes: Patent lengths measures the maximal duration of patent grants (Lerner 2000 and Coryton 1855). Data from population and GDP (in million 1990 dollars) are drawn from Maddison (1995 and 2002). Population data for Bavaria, Prussia, Saxony, and Württenberg from the *Annuaire Statistique* (1916). Primary education is measured as the number of children in primary education per 1,000 persons between the age of 5 and 14 (Lindert 2001).

TABLE 3 – PATENTING RATES ACROSS INDUSTRIES IN 1851

	Patenting Rate	
Industry of Use	Britain	US
Mining	5.0%	5.8%
Chemicals	5.1%	4.0%
Food Processing	7.9%	4.3%
Machinery	20.4%	36.4%
Scientific Instruments	9.7%	14.9%
Textiles	6.9%	6.0%
Manufactures	10.1%	13.5%
Total	11.1%	14.2%

Notes: Patenting rates measure the share of exhibits that are patented. For Britain, innovations with patents are identified as exhibits whose inventors refer to at least one patent. For the U.S., innovations are matched with patent counts from the United States Patent Office (USPTO) Patent Gazette. *Official Catalogue* 1851, *Patent Gazette* 1841 to 1851.

TABLE 4 – CHI-SQUARE TEST OF THE HOMOGENEITY OF DISTRIBUTIONS

	1851		1876	
Industry categories	Seven	Ten	Seven	Ten
No patent protection	18.22 (6)	23.46 (9)	68.15 (6)	78.51 (9)
Short and medium patent lives	89.16 (12)	91.09 (18)	55.70 (12)	67.59 (18)
Patent length exceed 12 years	768.83 (54)	802.68 (36)	237.27 (24)	265.91 (36)
All countries	1349.99 (66)	1395.22 (99)	639.72 (54)	693.50 (81)

Notes: The categorization into seven industries distinguishes innovations in mining, chemicals, food processing, machinery, instruments, textiles and manufactures. For ten industries, machinery innovations are further separated into engines, manufacturing machinery, civil and military engineering, and agricultural machinery. Degrees of freedom are reported in parentheses.

TABLE 5 – MULTINOMIAL LOGIT REGRESSIONS

	(1) 1851 and 1876	(2) 1851 and 1876	(3) 1851 Only	(4) 1876 only	(5) 1851 and 1876	(6) (excl. Switzerland)
MINING						
No Patent Laws	-1.8171	-1.5864	-2.1358	-1.1898	-1.2505	-1.8636
	(0.4996)	(0.4058)	(0.7379)	(0.4971)	(0.4024)	(0.6289)
ln Population	-0.4344	-0.2004	-0.2558	-0.2369	-0.0823	-0.4348
	(0.0575)	(0.0444)	(0.0697)	(0.0620)	(0.0388)	(0.0576)
GDP per Person	0.6960	0.5682	1.0752	0.2117	…	0.6970
	(0.0931)	(0.0896)	(0.1566)	(0.1206)		(0.0931)
Education	0.0031	…	…	…	…	0.0031
	(0.0006)					(0.0006)
Crystal Palace	-0.0368	-0.4213	…	…	-0.4977	-0.0389
	(0.1048)	(0.0813)			(0.0793)	(0.1046)
Constant	-0.4759	-0.4307	-1.3793	0.6829	-0.3307	-0.4677
	(0.4299)	(0.3851)	(0.5522)	(0.5644)	(0.3787)	(0.4299)
CHEMICALS						
No Patent Laws	0.4573	0.2674	0.0441	0.4981	0.2916	0.4094
	(0.3272)	(0.2591)	(0.6315)	(0.3085)	(0.2528)	(0.3819)
ln Population	0.0071	0.0265	0.0937	0.0091	0.0314	-0.0039
	(0.0701)	(0.0482)	(0.0899)	(0.0592)	(0.0457)	(0.0703)
GDP per Person	0.0617	0.0252	-0.3926	0.0537	…	0.0578
	(0.1010)	(0.0971)	(0.1879)	(0.1116)		(0.1013)
Education	0.0010	…	…	…	…	0.0011
	(0.0007)					(0.0007)
Crystal Palace	-1.5264	-1.6426	…	…	-1.6442	-1.5101
	(0.1231)	(0.0897)			(0.0895)	(0.1232)
Constant	-1.7836	-1.2523	-2.7001	-1.1568	-1.2468	-1.7597
	(0.4924)	(0.4510)	(0.7981)	(0.5663)	(0.4485)	(0.4925)
FOOD PROCESSING						
No Patent Laws	1.6874	1.4607	0.4947	1.7711	1.1626	1.9918
	(0.2499)	(0.1805)	(0.4687)	(0.2334)	(0.1723)	(0.2813)
ln Population	0.0297	0.0705	0.0724	0.0636	0.0035	-0.0252
	(0.0556)	(0.0393)	(0.0758)	(0.0486)	(0.0380)	(0.0552)
GDP per Person	-0.4960	-0.5016	-0.7290	-0.5166	…	-0.5554
	(0.0949)	(0.0891)	(0.1658)	(0.1059)		(0.0975)
Education	0.0012	…	…	…	…	0.0020
	(0.0005)					(0.0005)
Crystal Palace	-1.7268	-1.9538	…	…	-1.9380	-1.6327
	(0.1010)	(0.0771)			(0.0770)	(0.1002)
Constant	-0.5366	-0.0741	-1.5780	0.0132	-0.4469	-0.4228
	(0.4033)	(0.3706)	(0.6703)	(0.4701)	(0.3720)	(0.4037)

TABLE 5 (CONTINUED)

	(1) 1851 and 1876	(2) 1851 and 1876	(3) 1851 Only	(4) 1876 only	(5) 1851 and 1876	(6) (excl. Switzerland)
MACHINERY						
No Patent Laws	0.6709	0.5385	0.1055	0.8235	0.9710	0.3944
	(0.2565)	(0.1893)	(0.3073)	(0.2570)	(0.1850)	(0.3089)
ln Population	0.0836	0.1890	0.2070	0.0803	0.3367	0.0869
	(0.0474)	(0.0380)	(0.0581)	(0.0532)	(0.0342)	(0.0476)
GDP per Person	0.8619	0.8201	1.3817	0.3905	…	0.8644
	(0.0675)	(0.0654)	(0.1059)	(0.0909)		(0.0675)
Education	0.0016	…	…	…	…	0.0015
	(0.0005)					(0.0005)
Crystal Palace	0.1289	-0.0920	…	…	-0.2050	0.1239
	(0.0851)	(0.0622)			(0.0604)	(0.0853)
Constant	-4.3031	-4.1753	-5.6702	-2.1330	-3.7859	-4.3061
	(0.3986)	(0.3592)	(0.5251)	(0.5134)	(0.3443)	(0.3986)
INSTRUMENTS						
No Patent Laws	2.4863	2.3773	2.2218	2.5962	2.3000	1.2958
	(0.2560)	(0.1733)	(0.2275)	(0.2677)	(0.1667)	(0.3687)
ln Population	0.2778	0.2325	0.1878	0.2646	0.2099	0.3174
	(0.0557)	(0.0440)	(0.0580)	(0.0687)	(0.0418)	(0.0570)
GDP per Person	-0.0976	-0.1420	0.0667	-0.4003	…	-0.0467
	(0.0860)	(0.0833)	(0.1118)	(0.1336)		(0.0858)
Education	0.0002	…	…	…	…	-0.0004
	(0.0005)					(0.0005)
Crystal Palace	-0.1229	-0.0794	…	…	-0.0733	-0.2043
	(0.1017)	(0.0754)			(0.0753)	(0.1034)
Constant	-3.8866	-3.2276	-3.3038	-2.9822	-3.3033	-3.9462
	(0.4851)	(0.4169)	(0.5221)	(0.6853)	(0.4198)	(0.4852)
TEXTILES						
No Patent Laws	1.3350	1.1660	0.9741	1.3625	1.0243	0.7340
	(0.2194)	(0.1440)	(0.1881)	(0.2224)	(0.1397)	(0.2856)
ln Population	-0.0342	-0.0216	-0.0132	-0.0208	-0.0677	-0.0282
	(0.0350)	(0.0272)	(0.0342)	(0.0453)	(0.0250)	(0.0351)
GDP per Person	-0.1762	-0.2312	-0.3201	-0.0525	…	-0.1636
	(0.0603)	(0.0581)	(0.0737)	(0.0885)		(0.0603)
Education	0.0012	…	…	…	…	0.0011
	(0.0003)					(0.0003)
Crystal Palace	0.2214	0.0965	…	…	0.1117	0.2060
	(0.0670)	(0.0535)			(0.0534)	(0.0670)
Constant	-0.2653	0.5422	0.7365	0.1565	0.5077	-0.2648
	(0.2862)	(0.2446)	(0.2956)	(0.4323)	(0.2457)	(0.2861)
Exhibits	14,221	14,935	10,792	4,143	14,935	14,025
Countries	16	22	12	10	22	15

TABLE 6 – PREDICTED VALUES

	1851 and 1876		1851 only		1876 only	
Patent Laws	No	Yes	No	Yes	No	Yes
Mining	0.0101	0.0764	0.0062	0.0575	0.0133	0.0932
	(0.0023)	(0.0239)	(0.0014)	(0.0170)	(0.0008)	(0.0246)
Chemicals	0.0334	0.0554	0.0114	0.0274	0.0557	0.0935
	(0.0206)	(0.0350)	(0.0008)	(0.0034)	(0.0029)	(0.0039)
Food Processing	0.1374	0.0904	0.0245	0.0406	0.2425	0.1553
	(0.0889)	(0.0665)	(0.0040)	(0.0081)	(0.0244)	(0.0346)
Machinery	0.0883	0.1139	0.0503	0.0810	0.1197	0.1388
	(0.0288)	(0.0622)	(0.0198)	(0.0524)	(0.0190)	(0.0414)
Instruments	0.2289	0.0685	0.2739	0.0730	0.1849	0.0611
	(0.0176)	(0.0171)	(0.0189)	(0.0128)	(0.0067)	(0.0201)
Textiles	0.3764	0.2988	0.4619	0.3783	0.2965	0.2134
	(0.0943)	(0.0797)	(0.0364)	(0.0459)	(0.0053)	(0.0110)
Manufactures	0.1255	0.2965	0.1718	0.3422	0.0874	0.2448
	(0.0168)	(0.0463)	(0.0012)	(0.0132)	(0.0031)	(0.0047)

Notes: Predicted values are calculated as $\pi_i (x_{ij}) = \exp(\alpha_i + \beta_i x_j) / [\exp(\alpha_{mining} + \beta_{mining} x_j) + \ldots + \exp(\alpha_{manufactures} + \beta_{manufactures} x_j)]$ from multinomial regressions that control for the logarithm of population, GDP per capita, and time (Table 7, columns 2, 3, and 4)

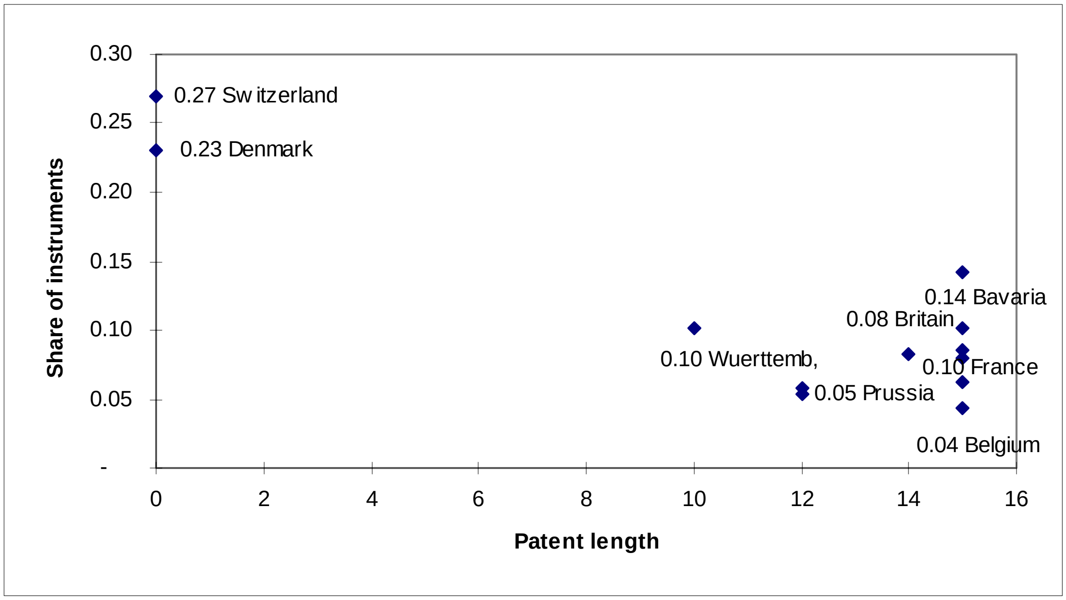
TABLE 7 – MAHALANOBIS NEAREST NEIGHBOR MATCHING

Treatment is "No Patent Laws"
Control variables are population in log form and GDP per person

	ATE			ATT		
Data	1851	Awards in 1851	1876	1851	Awards in 1851	1876
Mining	-0.0379 (0.0336)	-0.0366 (0.0509)	-0.0662 (0.0302)	0.0647 (0.0110)	0.0911 (0.0195)	-0.0422 (0.0107)
Chemicals	-0.0173 (0.0216)	-0.0707 (0.0341)	-0.0612 (0.0210)	-0.0910 (0.0220)	-0.1883 (0.0287)	-0.0457 (0.0171)
Food Processing	0.0310 (0.0484)	0.0515 (0.0254)	-0.0867 (0.1668)	-0.0889 (0.0598)	0.0197 (0.0272)	0.0455 (0.1178)
Machinery	0.0590 (0.0615)	-0.0506 (0.0131)	-0.0449 (0.0241)	0.0014 (0.0599)	-0.0424 (0.0158)	-0.0202 (0.0038)
Instruments	0.1696 (0.0200)	0.2535 (0.0528)	0.2524 (0.1092)	0.1387 (0.0075)	0.1329 (0.0421)	0.1559 (0.0639)
Textiles	-0.0922 (0.1455)	0.0340 (0.1762)	0.1867 (0.1266)	0.1887 (0.1901)	0.4916 (0.2274)	0.0237 (0.0888)
Manufactures	-0.1121 (0.0640)	-0.1811 (0.1103)	-0.1801 (0.0427)	-0.2136 (0.0812)	-0.5046 (0.1295)	-0.1160 (0.0324)
N	12	12	10	12	12	10
N_1	2	2	2	2	2	2

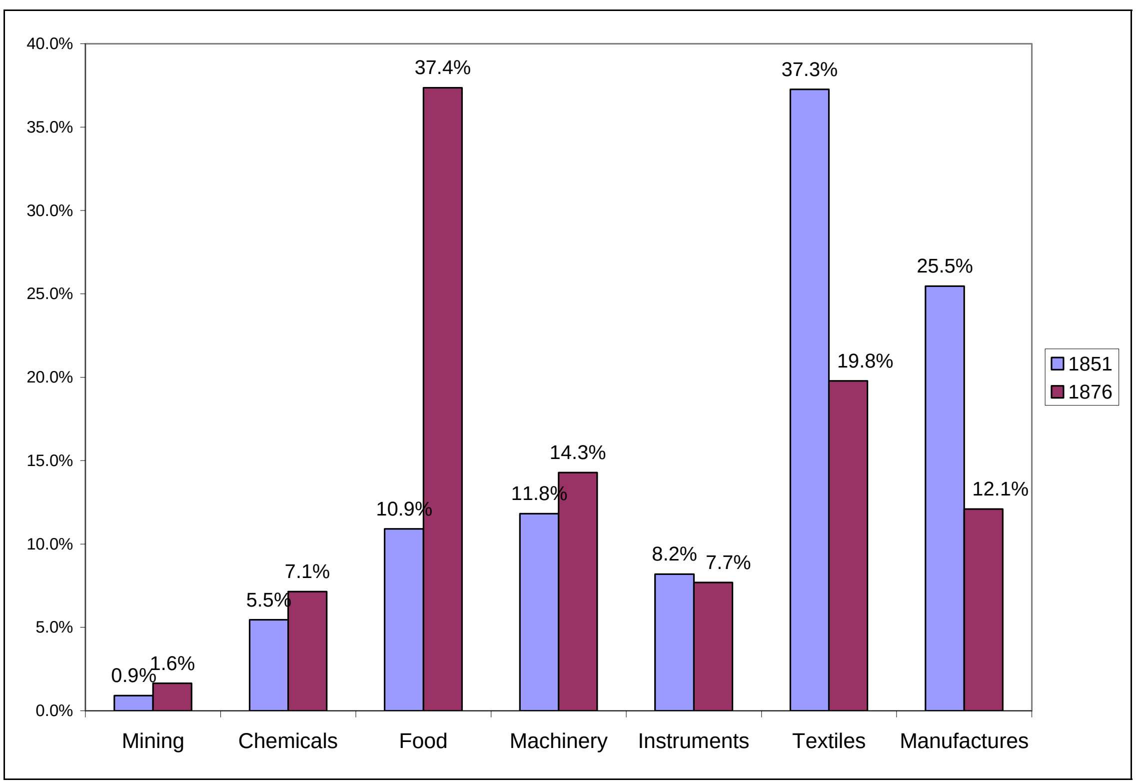
Notes: ATE denotes the Average Treatment Effect for both treated and control observations, and ATT denotes the treatment effect on the treated observations only. Matches are constructed with one replacement; m=2, each observation is allowed to be used as a match two times. N_1 reports the number of observations that receive the treatment. Coefficients are bias-adjusted as discussed in Abadie and Imbens (2004).

FIGURE 1 – SHARES OF EXHIBITS IN SCIENTIFIC INSTRUMENTS AGAINST PATENT LENGTH IN 1851



Sources: Data are from Bericht (1852), Coryton (1855), and Lerner (2000). "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 and at least five years preceding 1851.

FIGURE 2 – DUTCH INNOVATIONS ACROSS INDUSTRIES BEFORE AND AFTER THE ABOLITION OF PATENT LAWS IN 1869



Notes: Calculated from entries in *Official Catalogue* 1851 and United States Centennial Commission 1876

FIGURE 3A – PREDICTED INDUSTRY SHARES IN 1851

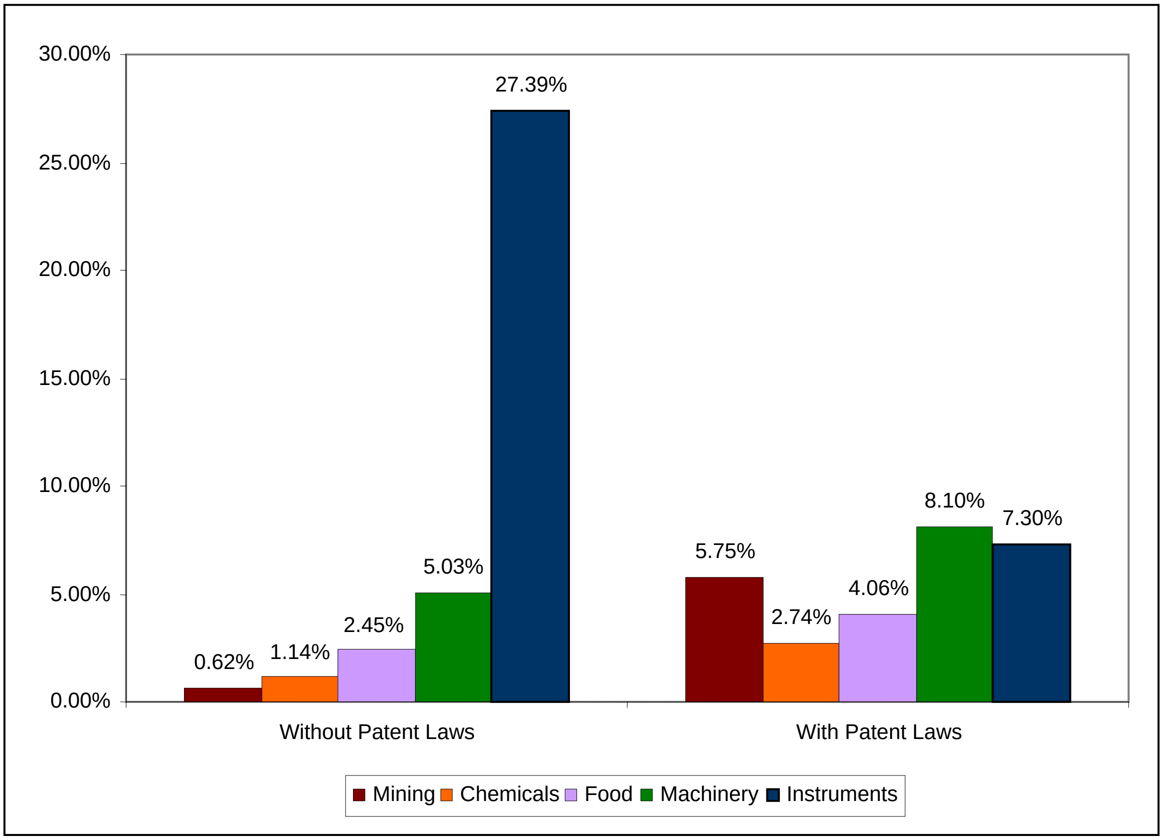
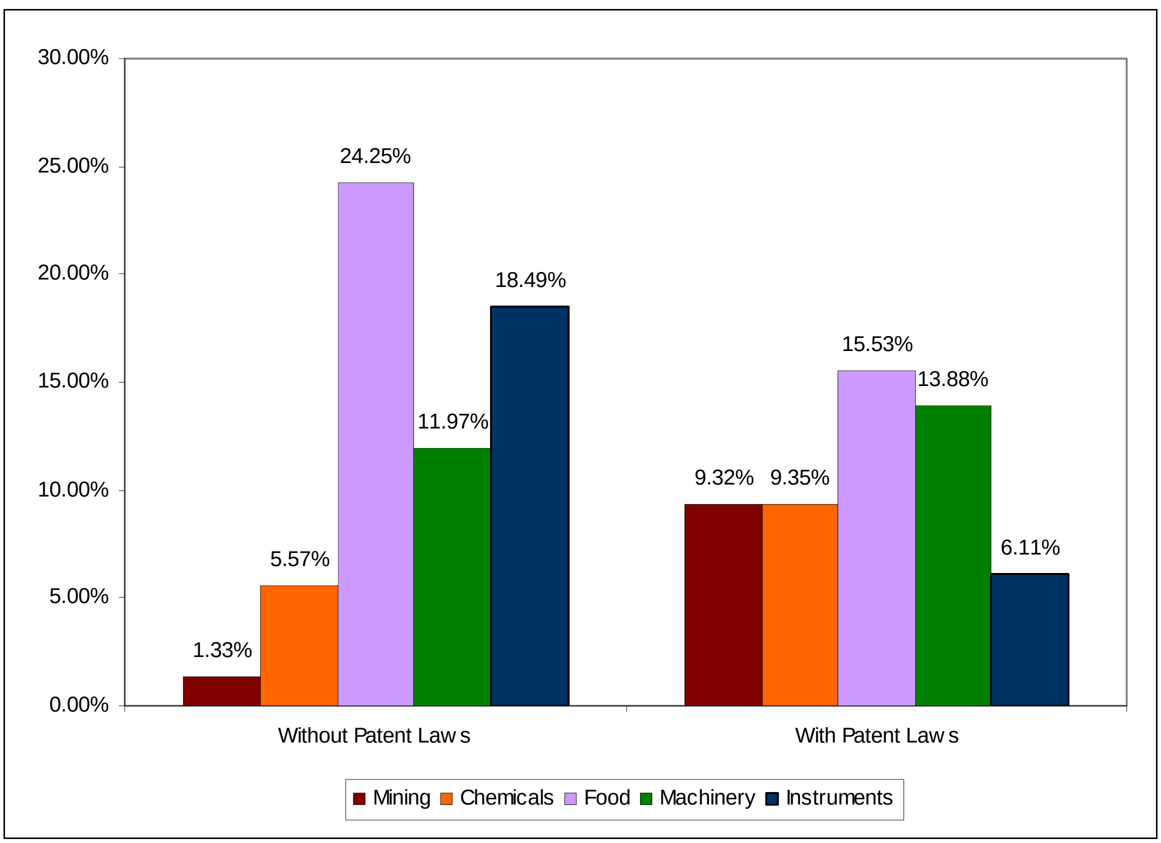
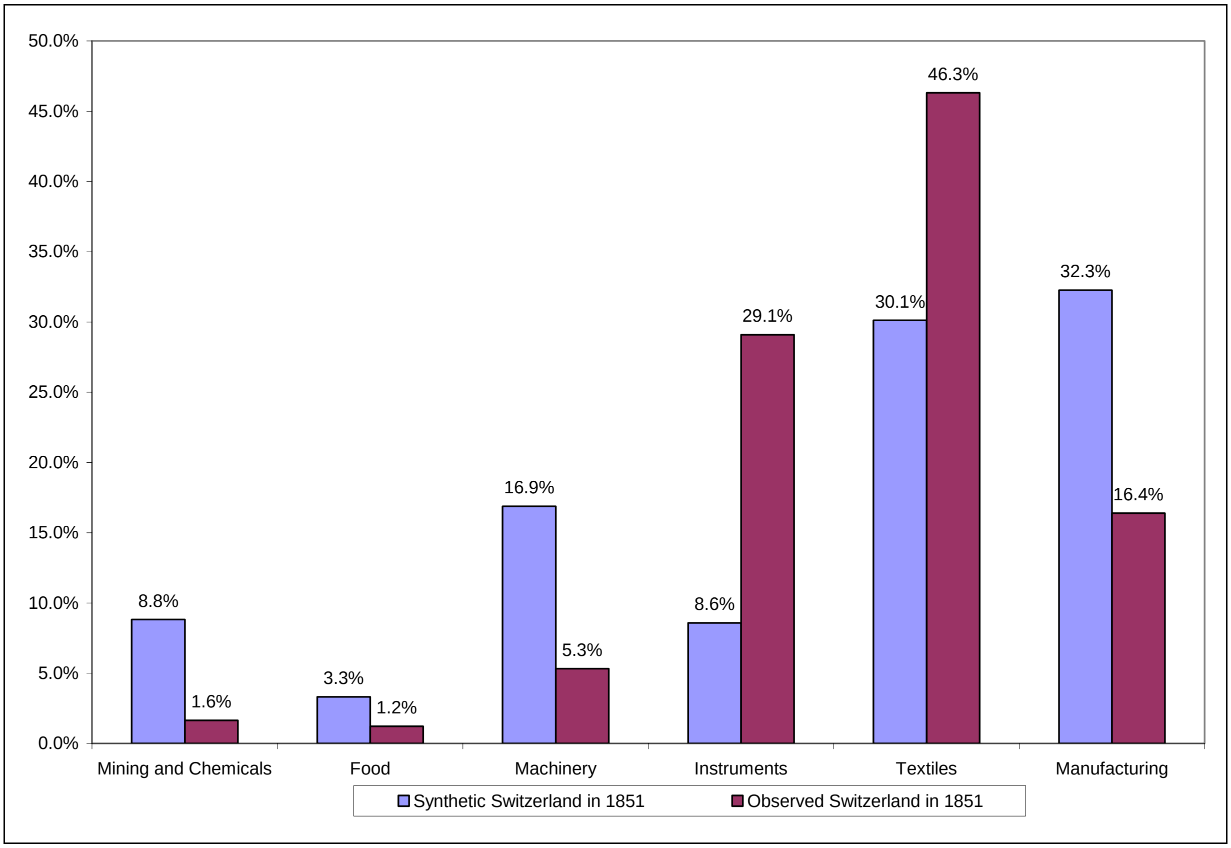


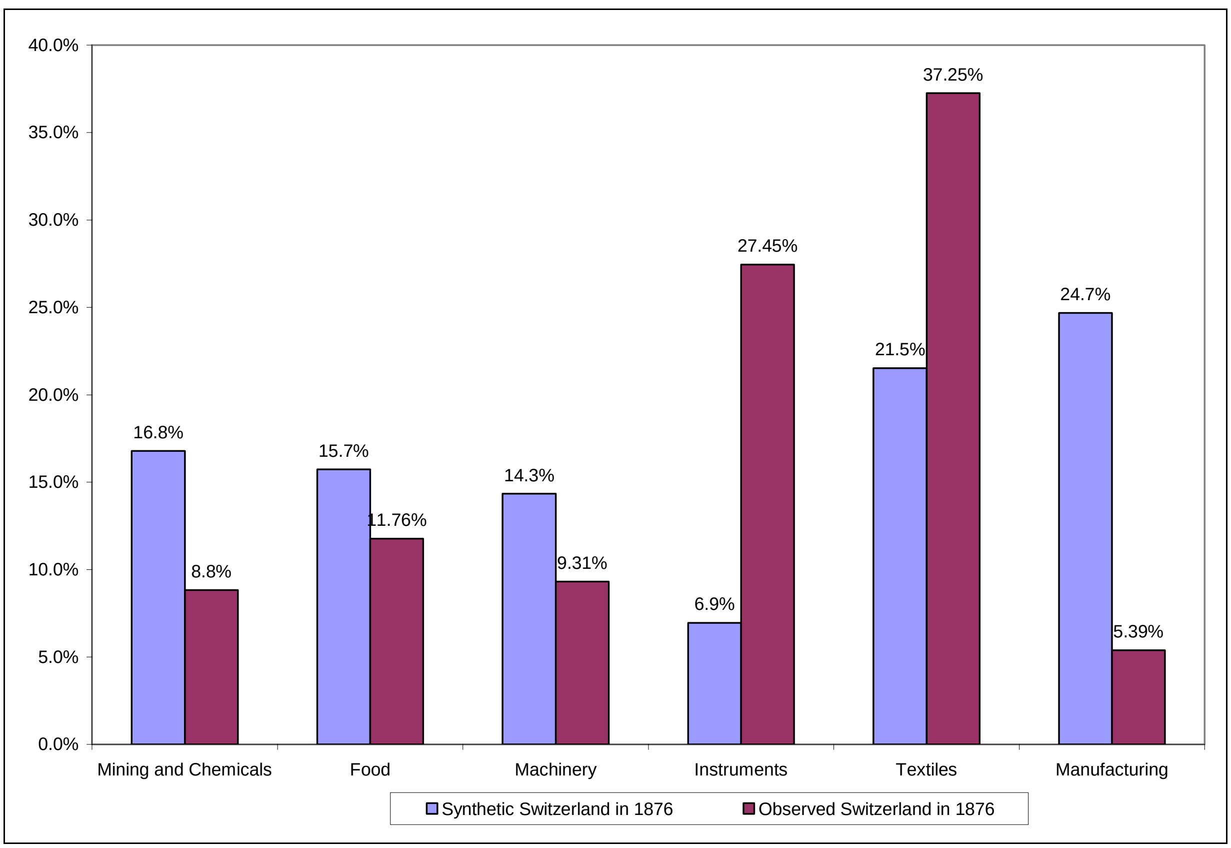
FIGURE 3B – PREDICTED INDUSTRY SHARES IN 1876



Notes: Predicted values are calculated as $\pi_i\ (x_{ij}) = \exp\ (\alpha_i + \beta_i x_j)\ /\ \Sigma\exp\ (\alpha_i + \beta_i x_j)$ from multinomial regressions that control for the logarithm of population and GDP per person (Table 5).

FIGURE 4 – SYNTHETIC VERSUS OBSERVED SWITZERLAND





Notes: Industry shares for the synthetic "Switzerland" are calculated as a weighted average of countries with patent laws that are most similar to the patentless countries in each year. The matching method is Mahalanobis nearest neighbor (Rubin 1977, Rosenbaum and Rubin 1983, Abadie and Imbens 2004).