How Do Patent Laws Influence Innovation? Evidence from Nineteenth-Century World's Fairs

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Studies of innovation have focused on the effects of patent laws on the number of innovations, but have ignored effects on the direction of technological change. This paper introduces a new dataset 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 12 countries in 1851 and 10 countries in 1876 indicate that inventors in countries without patent laws focused 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. (JEL D2, K11, L51, N0, O14)

Studies of innovation have focused on the effects of patent laws on levels of innovative activity, but have ignored the 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 nineteenth-century world's fairs, the Crystal Palace Exhibition in London in 1851 and the Centennial Exhibition in Philadelphia in 1876. Exhibition data provide economy-wide data on innovation with and without patents for 12 countries in 1851 and 10 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 confirm that innovation in countries without patent laws concentrates in 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, sur-

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veys 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 (1993) present further evidence for the responsiveness to demand from nineteenth-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 to invent for later generations.[1]

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-nineteenth 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 twentieth 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 nineteenth 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 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 the market, or by maintaining tight control over assets that are complementary to the commercial exploitation of the innovation. Surveys of 634 American R&D labs in 1983 by Richard Levin et al. (1987) and of 1,478 firms in 1994 by Wesley Cohen et al. (2000) suggest that secrecy is particularly valuable as an alternative mechanism to protect intellectual property.

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

[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).

Exhibition data create a unique opportunity to evaluate the importance of patenting across industries and countries. Mid-nineteenth-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 nineteenth-century world's 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 varies strongly across industries in both countries, however, suggesting significant sectoral differences in the usefulness of patent projection. Patenting rates, calculated as the share of innovations that are patented, range from 7 percent in textiles, 8 percent in food processing, and less than 10 percent in scientific instruments to more than 20 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 was a scientific instrument, while no more than one-seventh of other countries' innovations occurred 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, patentless countries had smaller shares of innovation in machinery, especially in machinery for manufacturing and agriculture; in these industries, innovations appear to have depended crucially on patents.

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 of 1851 was the first world's fair that allowed inventors and firms to exchange information on technological innovations across countries. At a time when London had fewer than two million inhabitants, it attracted more than six million people; its companion, the American Centennial Exhibition, drew ten million visitors in 1876 (Table 1; see Evelyn Kroker, 1975, p. 146). Even those who stayed at home would read about the fairs in weekly updates in trade and general interest journals, such as *Scientific American* and the

TABLE 1—STATISTICS ON THE WORLD'S 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).

Illustrated London News, and peruse detailed reports by their national commissions (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 fifteen thousand 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.

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 mid-nineteenth-century United States, only "first and true" inventors were allowed to patent, while France granted patents to any person importing new technologies (Coryton, 1855, pp. 235–64). 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 twentieth century, for example, firm-level surveys have found that only between 5 and 20 percent of patents become economically useful innovations (Peter Meinhardt, 1946, p. 256). In the nineteenth century, usefulness was often not even required for a patent grant (Coryton, 1855, pp. 235, 239).[3]

Even if patent data were a perfect measure of innovation, such data exist only for a handful of countries in the nineteenth century, excluding those without patent protection. Moreover, economy-wide patent data are not available when countries exclude specific industries from patenting. In the nineteenth 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. For example, 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). As a result of this classification by function rather than industry, empirical studies based on patent counts had to exclude important innovations such as power plant inventions and electric motors, 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

[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).

of innovations in those industries where patents undercount inventions.

Exhibition data, as a complement to nineteenth-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 that 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 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.

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, ranging 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 30 into 7 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 the Crystal Palace class "wool," could also be classified under "clothing." 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 commissions typically consisted of between two and ten academics and businessmen, representing the area's main industries (*Bericht*, 1852, pp. 37, 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, 117).

Awards to the most innovative exhibits helped to enforce the selection criteria. International panels of between 6 and 12 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, 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.[4]

Heavy and fragile innovations, which would otherwise have been underrepresented 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 Monmouthsire, 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 5,000 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

[4] *Visitor's Guide* (1875, p. 18). The mean area per exhibitor was approximately equal at both fairs, with 0.00118 acres (4.7753 square meters) in 1851 and 0.00125 acres (5.0586 square meters) in 1876.

innovations that were protected by secrecy, they understate, 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, and this study also must be mindful of the problem. From the mid-nineteenth century onward, 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, 2002b), were influenced by foreign interest groups whose fears of competition reflected international patterns of innovative activity and industry structure (Penrose, 1951, pp. 15–17, 117–24).

Endogeneity, however, is less likely to be a problem for the mid-nineteenth 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 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 nineteenth-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.[5] 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 innovations, I identified patented exhibits by matching all 549 American exhibitors at the Crystal Palace with lists of all patents granted between 1841 and 1851 and recorded in the *Annual Report of the United States Patent Office.* For example, "U.S. patent No. 4387; Otis, Benjamin H.; Dedham, Mass; Mortising machine; granted

[5] 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.

[6] This means that patenting rates are defined as patents per innovation, which may be preferable to the common use of the term "patenting rates" to denote patents per year.

TABLE 2—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 description in the *Official Catalogue* (1851) refers to at least one patent. For the United States, innovations are matched with lists of all patents reported in the *Annual Report of the United States Patent Office* between 1841 and 1851.

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), constitute a match between a patent and a Crystal Palace innovation.

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 United States (at 618 U.S. dollars), the share of innovations that were patented was similar in Britain and in the United States: 11.1 percent in Britain compared to only 14.2 percent in the United States (Table 2). Moreover, British and American inventors chose to patent (and not to patent) in the same industries. In Britain and the United States, innovations in machines, such as new types of engines, manufacturing machinery, and agricultural tools, were patented more frequently than innovations in any other industry. Table 2 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 3 and 10 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 14 percent of British award-winners refer to patents, compared to 11.1 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, which were extremely difficult to reverse-engineer and therefore less dependent on patent protection, along with advances in weaving and other types of innovations, which were copied with much greater ease. Similarly, the class "instruments" includes telegraphs and improvements to the pianoforte which were easy to imitate, along with optical and scientific instruments, which could be protected by secrecy. Half of all telegraphs are patented, compared to 14 of 101 British inventions in optical instruments and watches.

Contemporary industry reports and letters from inventors 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 trouble 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 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). Watchmaking may have been especially suitable to secrecy because innovations were 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, 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 the 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 developed 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 its 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 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 13 countries (Austria, Bavaria, Belgium, Britain, Denmark, France, the Netherlands, Norway, Sweden, Prussia, Saxony, Switzerland, and Württemberg) 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 12 countries in 1851, 10 countries in 1876, and 7 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 nineteenth-century countries, including the United States, Russia, China, and Japan (countries for which exhibition data are the only source of 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]

For states whose borders are comparable between 1850 and today, I use Lerner's

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

[9] Table 3 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-nineteenth-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.

TABLE 3—COUNTRY CHARACTERISTICS

	Patent length		Population		GDP		Primary education	
Country	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
Württemberg	10	—	1,745	—	2,575	—	—	—

Notes: Patent length measures the maximal duration of patent grants (Lerner, 2000; Coryton, 1855). Data on population and GDP (in million 1990 dollars) are drawn from Maddison (1995, 2001). Population data for Bavaria, Prussia, Saxony, and Württemberg 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, 2004).

(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 Godson (1840), John Kingsley and Joseph Pirsson (1848), and Coryton (1855). This adjustment is important because there was a large amount of variation in mid-nineteenth-century patent laws for countries that are unified today. Within Germany, patent lengths varied from 10 years in Württemberg to 15 years, and "prolonged at pleasure" in Bavaria. At the same time, Württemberg'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 that 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 twentieth century, and the Netherlands, after the abolition of patent laws in 1869 (Coryton, 1855, pp. 245, 260).[11] 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 twentieth-century patent renewal data such as Ariel Pakes (1986), which chose ten 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

[11] Switzerland adopted an earlier draft of patent laws in 1888, which Schiff (1971) calls "the most incomplete and selective patent law ever enacted in modern times" (p. 93). For example, the law of 1888 offered no recourse to the courts, and therefore no means to defend patents, and it excluded all process innovations.

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

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

widely divergent patent laws, and should 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 dissimilar 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 1 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 was 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 were such instruments. At the same time, no other country, regardless of its level of industrialization, had a comparable share of innovations in this class, although instruments were among the key high-tech industries of the nineteenth century. For Britain, undoubtedly the most technologically advanced country of the mid-nineteenth century, only 8 percent of innovations occurred in instruments, a share that equals the mean and slightly exceeds the median of 6 percent across all countries. After Switzerland and Denmark, Bavaria, where patents lasted up to 15 years but were ill-enforced, had the third highest share: 14 percent of Bavaria's exhibits were in instruments.

This parallel focus of innovations is even more striking for two countries that differ so strongly in their natural endowments. Switzerland is land-locked, mountainous, and largely isolated, whereas Denmark is 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 by other characteristics of their work environment. Multinomial logit regressions, as introduced by Daniel McFadden (1974), provide the most natural approach to measure such effects.[12]

[12] Alternatively, I have fitted logit models separately for the six pairings of responses (omitting manufactures as the

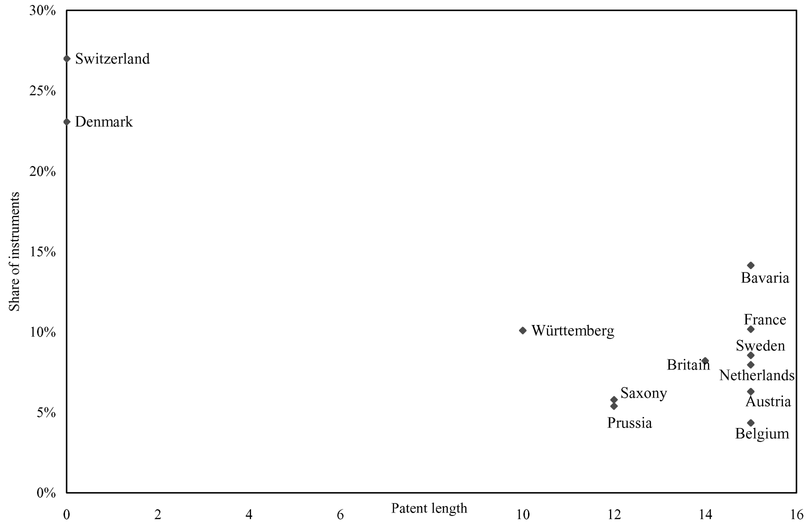

FIGURE 1. SHARES OF EXHIBITS IN SCIENTIFIC INSTRUMENTS AGAINST PATENT LENGTH IN 1851

Notes: "Share of exhibits in scientific instruments" measures the proportion of a country's exhibits that occurs in the industry class "scientific instruments." "Patent length" measures the maximum duration of a patent grant in 1851 as reported in Coryton (1855) and Lerner (2000).

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 and Figure 2 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).[13] 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.[14]

Textile 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 dependent on specialized knowledge and widely regarded as the most complex dyeing process ever invented, was most prominent among Swiss innovations in dyes.[15] 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.

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

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.

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

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

[15] 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, http://www.sdc.org.uk).

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)
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)

TABLE 5—Continued.

	(1) 1851 and 1876	(2) 1851 and 1876	(3) 1851 only	(4) 1876 only	(5) 1851 and 1876	(6) (excl. Switzerland)
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 $\pi_i(x_{ij}) = \exp(\alpha_i + \beta_i x_j)/[\exp(\alpha_{\text{mining}} + \beta_{\text{mining}} x_j) + \cdots + \exp(\alpha_{\text{manufactures}} + \beta_{\text{manufactures}} x_j)]$ from multinomial regressions that control for the logarithm of population, GDP per capita, and time (Table 7, columns 2, 3, and 4).

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 dependent 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

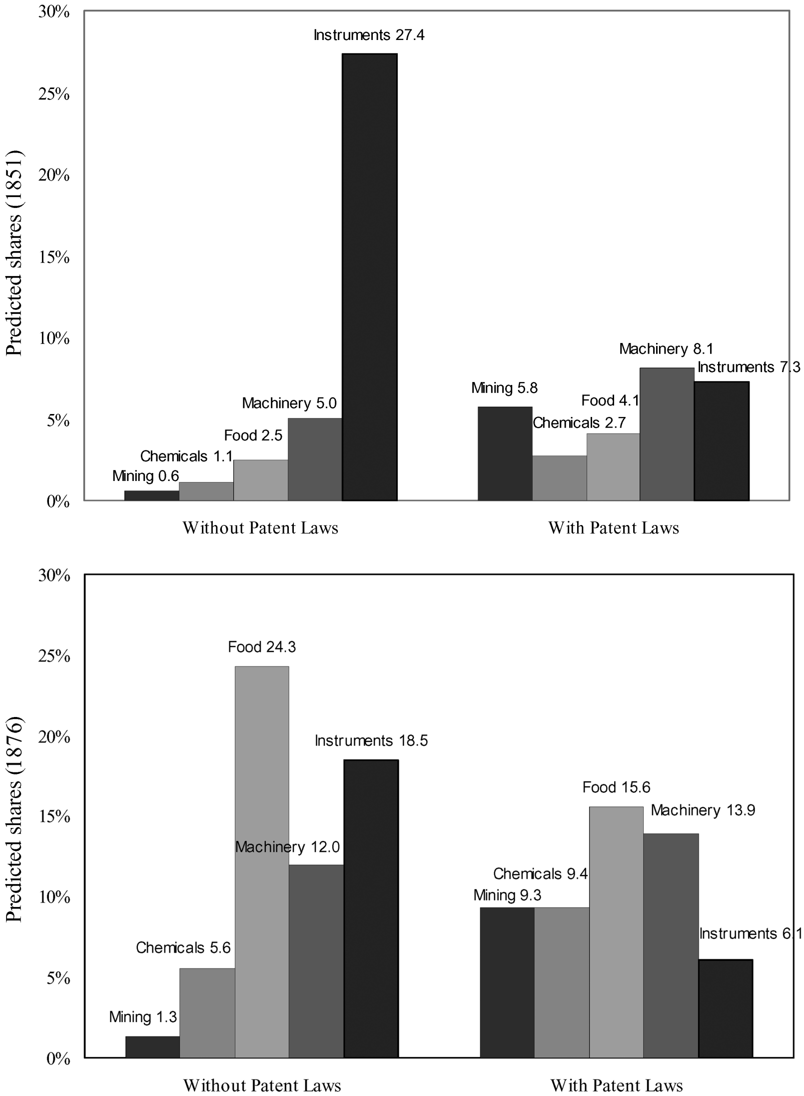

FIGURE 2. PREDICTED INDUSTRY SHARES, 1851 AND 1876

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).

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).

Resource 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 nineteenth century. Instead, I verify 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 nineteenth-century high-tech industries, chemicals, and scientific instruments, which were at the vanguard of technological progress in the nineteenth 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; Michael Kremer, 1993).

Table 6 and Figure 2 also suggest 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 had shares of about 2 percent in countries without patent laws and 4 percent in other countries (columns 3 and 4). By 1876, the share of foodstuffs had risen to about one-quarter for countries without patent laws and to nearly 16 percent for countries with patent laws (columns 5 and 6). Many important innovations in food processing originated in late-nineteenth-century Switzerland, such as milk chocolate, liquid soup seasoning, bouillon, and baby food (see Schiff, 1971, pp. 54–58, 111–12).

At the same time, the focus on scientific instruments weakens between the exhibitions: in 1851, 27 percent of all exhibited innovations from patentless countries were in scientific instruments compared to 7 percent for other countries. In 1876 these shares 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, which had adopted a strong patent system.

C. *The Netherlands' Abolition of Patent Laws in 1869*

Changes in patent laws 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 patents 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 toward 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 3). 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.

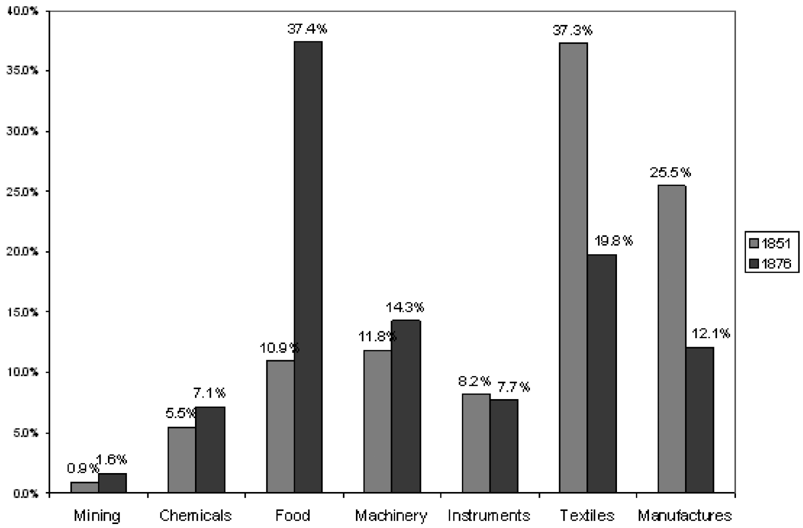

FIGURE 3. DUTCH INNOVATIONS ACROSS INDUSTRIES BEFORE AND AFTER THE ABOLITION OF PATENT LAWS IN 1869

Note: Calculated from entries in *Official Catalogue* (1851) and United States Centennial Commission (1876).

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.[16] 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 nonnegative weights $(w_1, w, \ldots w_J)'$ 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 3, and let X_0 be a $(K \times J)$ matrix of the values for these same variables in the set of possible control countries. Let the $(K \times K)$ 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 $(X_1 - WX_0)'V(X_1 - WX_0)$. Each country is

[16] Abadie and Gardeazabal (2003) construct a weighing matrix to mimic the growth path of GDP in the Basque country. Similarly, Yi Qian (2004) uses the Mahalanobis estimator to examine the effects of a country's 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 (2002) for a comprehensive discussion of the Mahalanobis estimator.

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	−0.0366	−0.0662	0.0647	0.0911	−0.0422
	(0.0336)	(0.0509)	(0.0302)	(0.0110)	(0.0195)	(0.0107)
Chemicals	−0.0173	−0.0707	−0.0612	−0.0910	−0.1883	−0.0457
	(0.0216)	(0.0341)	(0.0210)	(0.0220)	(0.0287)	(0.0171)
Food processing	0.0310	0.0515	−0.0867	−0.0889	0.0197	0.0455
	(0.0484)	(0.0254)	(0.1668)	(0.0598)	(0.0272)	(0.1178)
Machinery	0.0590	−0.0506	−0.0449	0.0014	−0.0424	−0.0202
	(0.0615)	(0.0131)	(0.0241)	(0.0599)	(0.0158)	(0.0038)
Instruments	0.1696	0.2535	0.2524	0.1387	0.1329	0.1559
	(0.0200)	(0.0528)	(0.1092)	(0.0075)	(0.0421)	(0.0639)
Textiles	−0.0922	0.0340	0.1867	0.1887	0.4916	0.0237
	(0.1455)	(0.1762)	(0.1266)	(0.1901)	(0.2274)	(0.0888)
Manufactures	−0.1121	−0.1811	−0.1801	−0.2136	−0.5046	−0.1160
	(0.0640)	(0.1103)	(0.0427)	(0.0812)	(0.1295)	(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 (2002).

allowed to be used as a match twice, equivalent to allowing one replacement.[17]

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 subset 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). In addition to reducing the share of machinery innovations, the absence of patent laws strongly reduced the proportion of manufacturing innovations, especially of high quality, as this manufacturing became increasingly dependent on innovations in machinery and mechanization. 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, columns 4 and 5), lending further support to the hypothesis that patent laws exert a noticeable influence on the direction of innovation.

[17] Allowing one replacement produces higher quality matches by increasing the number of possible matches.

VI. Conclusions

This paper has introduced a new dataset on innovations at two nineteenth-century world's fairs, which allows 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 Exhibition in Philadelphia in 1876. Exhibition data indicate that patent laws influence the direction of innovative activity. In the nineteenth century, the absence of patent laws appears to have guided innovation toward industries where mechanisms other than patent laws protected intellectual property. Innovators 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

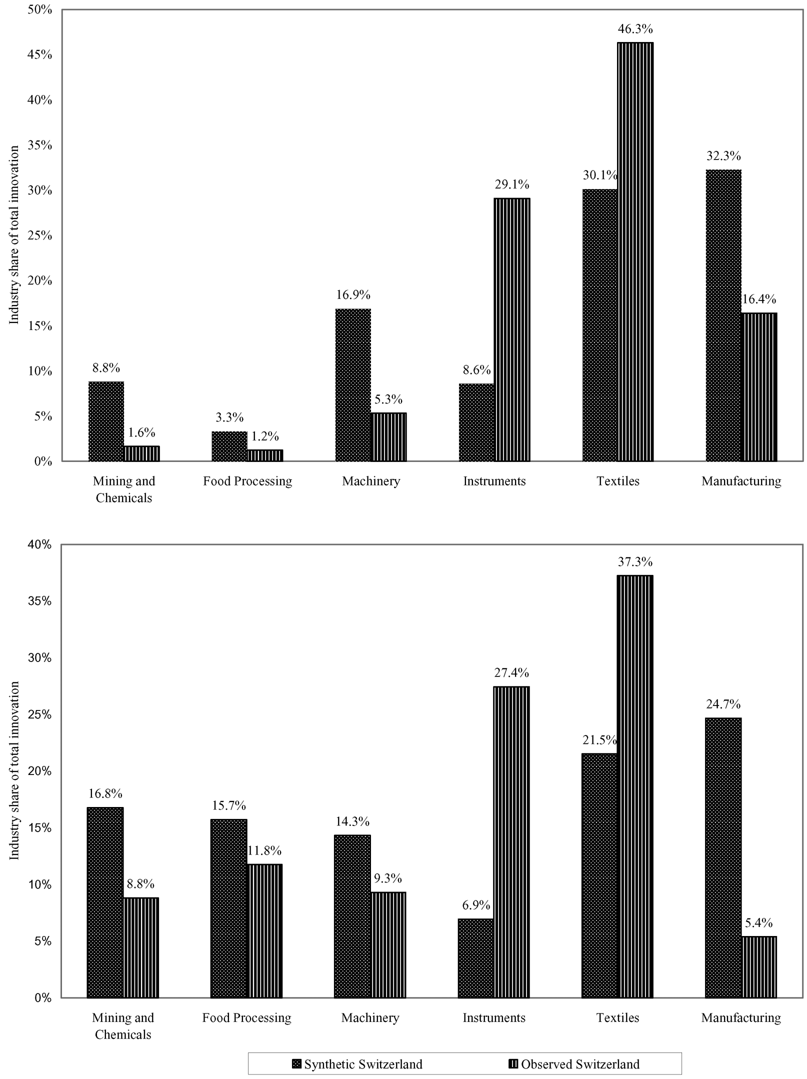

FIGURE 4. SYNTHETIC VERSUS OBSERVED SWITZERLAND, 1851 AND 1856

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, 2002).

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 longstanding 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 of 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 availability 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 suggest that patent laws help to shape 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 nineteenth century, a focus on manufacturing machinery allowed the United States 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 nineteenth century may have played an important role in encouraging the American focus on manufacturing machinery that spurred economic growth toward the end of the century.

Unlike the case of the nineteenth-century United States, the introduction of patent laws in 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 that 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 the developing and developed world.

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