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Petra Moser

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ABSTRACT

This paper introduces a new internationally comparable data set that permits an empirical investigation of the effects of patent law on innovation. The data have been constructed from the catalogues of two 19th century world fairs: the Crystal Palace Exhibition in London, 1851, and the Centennial Exhibition in Philadelphia, 1876. They include innovations that were not patented, as well as those that were, and innovations from countries both with and without patent laws. I find no evidence that patent laws increased levels of innovative activity but strong evidence that patent systems influenced the distribution of innovative activity across industries. Inventors in countries without patent laws concentrated in industries where secrecy was effective relative to patents, e.g., food processing and scientific instruments. These results suggest that introducing strong and effective patent laws in countries without patents may have stronger effects on changing the direction of innovative activity than on raising the number of innovations.

Petra Moser
MIT Sloan, E52-545
50 Memorial Drive
Cambridge, MA 02141
and NBER
moser@mit.edu

Patent laws are designed to create the optimal incentives for innovation, yet we know little about exactly how these incentives work. The need to better understand the effects of patent laws on innovation is particularly urgent today, as international agreements, such as those related to the 1993 Trade Related International Property Rights (TRIPs) agreement, are moving towards the harmonization of patent laws around the world. Industrialized countries lobby to introduce patent laws in developing countries where such laws may not exist and to increase the duration of patent grants in countries where patent rights expire quickly. While it is difficult to predict the results of such changes, historical data from the mid-nineteenth century may afford valuable lessons for patent policies today. Patent laws that existed in the mid-nineteenth century had been adopted in a relatively ad-hoc manner, dependent more on legal traditions than economic considerations; governments had just begun to experiment with patent laws and large differences in patent systems existed across countries. Patenting abroad was prohibitively expensive and almost all countries discriminated heavily against foreign patentees. As a result, domestic patent laws played a more important role in creating the incentives for innovation than at any later stage in history.

This paper introduces a new data set that reveals the effects of patent laws on innovation across a wide range of countries in 1851 and 1876. I have constructed internationally comparable data on innovation from the exhibition catalogues for two nineteenth-century world fairs on technology: the Crystal Palace Exhibition in London in 1851 and the Centennial Exhibition in Philadelphia in 1876. The Crystal Palace was the most popular event of its age, and it became the first in a long series of world fairs which allowed inventors and firms to exchange technological information internationally. More than six million visitors attended the Crystal Palace, and almost ten million visitors came to the Centennial Exhibition. For the

Crystal Palace fair I have counted and classified 13,876 exhibits in 30 industries of use. For the Centennial I have counted and classified more than 19,076 exhibits in 344 industries.

A typical entry in the exhibition catalogue begins with the exhibitor's name, address, and country of origin, followed by a brief description of the innovation, as well as some information about the exhibitor's occupation and state of patent protection. From these records, I have constructed data for 32,952 innovations, their industry of use, and country of origin. I also determine whether exhibitors held a patent or not, distinguishing foreign from domestic patents. Information on domestic patents allows me to calculate proxies for patenting rates across industries. In addition, I construct measures for the quality of innovations based on awards for inventiveness. These awards ranked all exhibits according to their novelty and usefulness, and granted prizes to the most innovative exhibits.

Exhibition data are particularly useful for studying the effects of patent laws on innovation because they measure economically useful innovation in a way that is independent of changes in patent laws. As employed here, economically useful *innovation*—the commercial introduction of new or improved products and processes—is distinct from *invention*—the conception of such products and processes. Exhibition data measure economically useful innovations, while patent data count those inventions which inventors chose to patent. This distinction matters because only a fraction of innovations are patented and not all patents develop into economically useful innovations. Historical records bear witness that national committees selected their most innovative products to be exhibited at the fairs. Participation was competitive and a uniform system of selection admitted less than one third of all applicants to exhibit at the fairs.[1] Most importantly, exhibition data measure innovation independently from

[1] *Bericht* (1852, 1853); Cole (1853); Rosenberg (1969); Curti (1950); Haltern (1971); Kroker (1975).

differences in domestic patent laws.[2] Exhibitors displayed innovations regardless of whether they could be patented at home, including many innovations which they had chosen not to patent.

Exhibition data allow me to compare innovative activity across countries with and without patents. This represents an empirical advance over the theoretical literature on patent laws which simply assumes that the existence of patent laws raises levels of innovation. Without exhibition data, empirical studies of nineteenth-century patent laws relied on patent data, but these studies cannot identify whether the existence of patents raised levels of innovation.[3] Equally important, they cannot identify whether the nature of innovation differs in countries without patent laws.[4] Nineteenth-century exhibition data allow me to analyze these questions empirically.

Previous studies of innovation have focused on the number of innovations that are created in an economy. Among the key predictions in this literature, such as Nordhaus (1969), Klemperer (1990), and Gilbert and Shapiro (1990), is that strong patent laws raise the number of innovations that are made within a country. According to this argument, countries without patent laws should display few novel technologies. In contrast, the exhibition data show that countries without patent laws brought many important innovations to the fairs. Mid-nineteenth century Switzerland, for example, had the second highest number of exhibits per capita among all countries that visited the Crystal Palace Exhibition. Moreover, exhibits from countries without patent laws received disproportionate shares of medals for outstanding innovations.

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[2] For the 19^{th} century, Coryton (1855) describes differences in what constitutes a patentable invention in Germany, Austria, Russia, and the U.S. See Coryton (1855 pp. 235-264).
[3] Lanjouw and Cockburn (2000) describe comparable difficulties in using contemporary data for predicting the results of introducing pharmaceutical product patents to developing countries.
[4] The only information about innovation in countries without patent laws comes from patents that were granted abroad. For the 19th century discrimination against foreign patentees creates bias in these data.

Countries without patent laws were exceptionally inventive in a couple of industries: food processing and the manufacture of scientific instruments.

Previous studies have ignored the effects of patent laws on the direction of innovation, although the direction of innovation appears to be a key determinant of economic growth. Kuznets (1963) observes that technological innovation concentrates in a few fields at any given time; he argues that such concentrations determine countries' potential for economic growth. 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. Rosenberg (1972) argues that the United States overtook Europe at the beginning of the twentieth century because of its concentration on labor-saving innovations.

This paper sets out to analyze the causes of such concentrations of innovative activity. More specifically, it asks the questions whether and how patent laws create or intensify a country's tendency to focus innovation in certain industries. A simple model predicts that weak patent laws encourage innovation in industries where alternative methods to protect intellectual property are particularly effective relative to patent protection. By this argument, weak patent laws may help to create differences in technological comparative advantage among industrialized countries and their followers.

Previous empirical analyses of the effects of patent laws had to rely almost exclusively on patent counts, despite some obvious limitations of these data.[5] Economic research benefits from data on mid-nineteenth-century innovations, because this period is uniquely suited to study the effects of patent laws. At the time of the Crystal Palace Exhibition in 1851, most governments had adopted patent laws but they had not yet begun to modify these laws in response to pressures from domestic interest groups. Differences in domestic patent laws were large and mattered greatly to domestic inventors, because international treaties had not yet begun to harmonize patent laws or to protect the rights of foreign patentees. However, nineteenth-century patent data are available for less than a handful of countries. Even within these countries, they omit entire industries because patent laws did not extend to all sectors of the economy. In addition, many important nineteenth-century patents, such as various improvements in the steam engine, had to be dropped from patent counts, because they could not be assigned to a specific industry. Patented inventions vary greatly in their commercial viability and quality; the quality of innovations is difficult to proxy based on patent data. Most importantly, the way in which patents measure innovation varies with changes in patent laws. The definition of what constitutes a patentable invention varies across countries. In the U.S. only first and true inventors are allowed to patent; in France first importers have equal access to exclusive patent rights. Differences in the length of patent grants, in patent costs, and in the security of patent rights create further differences in what inventors choose to patent. I analyze these issues in a separate paper.

Exhibition data offer a complement to nineteenth-century patent data which addresses many of the concerns about patent data. 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 early innovation in these countries. Exhibition data cover innovations in all industries, including those that were excluded from the patent system. Awards to the most innovative and useful exhibits provide a measure for

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[5] See Gilfillan (1930) for an early use of patent data in international comparisons. Schmookler (1962 and 1966) and

the quality of innovation. References to patents in the exhibition data allow me to distinguish patented innovations from those that are protected by alternative mechanisms.

The analysis of exhibition data suggests that patent laws may be an important factor in determining the direction of innovative activity. Exhibition data show that countries without patents share an exceptionally strong focus on innovations in two industries: 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 belong to this category. At the same time, the patentless countries have significantly smaller shares of innovation in machinery, especially in machinery for manufacturing and agricultural machinery. After the Netherlands abolished her patent system in 1869 for political reasons, the share of Dutch innovations that were devoted to food processing increased from 11 to 37 percent.

Proxies for differences in the propensity to patent across industries, which I have constructed from the Crystal Palace data, document that innovations in scientific instruments and food processing are less likely to be patented, especially compared to innovations in machinery. These proxies indicate that only 10 percent of exhibits in scientific instruments, but close to 40 percent of exhibits in manufacturing machinery are patented. Nineteenth-century sources report that secrecy was particularly effective at protecting innovations in scientific instruments and in food processing. On the other hand, patenting was essential to protect and motivate innovations in machinery, especially for large-scale manufacturing.

The remainder of this paper presents the results of using nineteenth-century exhibition data to study the effects of patent laws on innovation. Section I summarizes the predictions and

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Sokoloff (1988) employ US patents to show that invention responds to profit incentives.

findings of previous literature and outlines a model of the effects of patent laws on invention. Section II describes the exhibition data. Section III presents empirical results based on exhibition data. Section IV includes narrative evidence on the use of secrecy to protect intellectual property in the nineteenth century. Section V discusses potential sources of bias in the exhibition data and section VI concludes.

I. Effects of Patent Laws on Innovation

Patent laws are essential to the study of innovation because governments use them to create incentives for invention. Surveys of individual inventors and firms, from the time of the Swiss Congress on Patent Protection in 1883 and Rossman (1931), have shown that most inventions result from deliberate research efforts, which respond positively to expected profits. Previous work, such as Nordhaus (1969), Klemperer (1990) and Gilbert and Shapiro (1990), suggests that patent protection is vital to expected profits because it determines the strength of an inventor's intellectual property.[6]

This paper concentrates on the effects of two essential characteristics of patent systems: the *existence of a patent system* and *patent length*, the maximal duration of a patent grant. Among the many important features of patent systems, the length of a patent grant is especially important because it establishes how long inventors retain exclusive rights to their inventions.[7] Moreover, patent length is relatively easy to measure and compare across countries; many other features of patent laws, such as patenting costs, patent breadth, or the enforceability of patents in a court of law are difficult to quantify and impossible to compare across countries, especially for

[6] Results of the Swiss survey are reported in *Procès-Verbal du Congres Suisse*…(1883).
[7] Pakes (1986) examines the value of patent grants as options over future returns to inventions. In the nineteenth century, most countries prevented this strategic use of patents by requiring that patents be put to practical use within one or two years. See also: Coryton (1855 pp. 265, 255).

the nineteenth century.[8] This paper examines the effect of patent laws on levels of innovation, but it also introduces a richer concept of innovation: It addresses the question of how patent laws influence the direction of innovative activity.

A. *Effects on the Number of Innovations*

The prevalent view in the literature is that patent laws raise levels of innovation and that increases in the length of patent grants encourage inventive activity. Nordhaus (1969), Klemperer (1990), and Gilbert and Shapiro (1990) assume that increases in patent length raise levels of innovation.[9] Baumol (1990) argues that R&D competes for the attention of talented individuals with other high-profile activities, such as political leadership, financial dealings, or manipulation of the legal system, which are often attempts at rent-seeking. Murphy, Shleifer, and Vishny (1991) emphasize three factors that influence talented individuals' decisions whether to pursue activities that are socially productive: the size of the relevant market, the degree of diminishing returns, and the ability to keep the returns from one's activities. To the extent that patent grants increase the ability to keep the returns from innovation, they should raise levels of R&D activity in these views. The following paragraphs check whether these assumptions in the literature – excluding the possibility of adopting foreign inventions and excluding alternative methods to protect intellectual property – would be consistent with the view that increases in patent laws raise levels of innovation.

[8] The greatest costs of patenting are fees and the disclosure of patented inventions. For American and British patent data from 1790 to 1850, Khan and Sokoloff (1998) show that patenting activity increases as patent fees decrease. Disclosure of the invention, which is a requirement under most patent systems, increases the costs of patenting as it decreases competitors' costs to invent around the original invention. The risks of disclosure decrease with increases in the probability that the property rights of the original patentee will be enforced in a court of law. See Dutton (1984), Lanjouw (1994), and Khan (1995) for analyses of the effects of enforcement on innovation.

[9] In contrast, Scotchmer (1991) argues that increases in patent length may lower levels of innovation because increases in patent length reduce expected profits for future generations of inventors.

Consider a closed economy with two industries. Each country has L potential inventors, where L may be regarded as the country's labor force. Countries differ in the characteristics of their patent systems, specifically the existence of a patent system and in the maximum duration, T, of a patent grant. Within a country, inventors face identical patent fees and patent lengths in all industries. To begin, I assume that patent protection is equally suitable to protect inventions in all industries.

Inventors choose between two industries, which differ in the initial returns to invention, R, as well as in the speed at which inventions become obsolete. For simplicity, I assume that development costs, which reduce initial returns R, include patenting costs, such as patent fees and time spent in researching prior art. Suppose initial payoffs for patented inventions in the chemicals industry are R_c and initial payoffs in the machinery industry are R_m. Initial payoffs to chemical inventions exceed those of machinery inventions, but inventions in chemicals become obsolete more quickly than inventions in machinery. Let d_c and d_m represent the proportion of returns that carries over from one period to the next.[10] Then, the payoff to an innovation in chemicals at time t equals $d_c^t R_c$ and the payoff in machinery equals $d_m^t R_m$ where $0<d_c<d_m<1$. There exists $T' \in N$ such that $d_c^t R_c \geq d_m^t R_m$ for all $t \leq T'$ and $d_c^t R_c < d_m^t R_m$ for all $t > T'$. For patent lengths below T' the payoffs of innovations are higher in chemicals and for patent lengths beyond T' the payoffs are higher in machinery.

I assume that both industries experience decreasing returns to invention. Each inventor picks the most promising project and with each choice the next best available project becomes

[10] Schankerman and Pakes (1986) define $d_i = (1-\delta_i)^{-1}$ such that δ_i represents the rate of obsolescence. They discount future returns by $(1+i)^{-1}$. $0<d_i<1$ may be interpreted as including discounting by the interest rate.

less valuable.[11] For simplicity I assume that the quality of projects declines at the same rate in both industries, $g_c = g_m = g$. Then the total payoffs to the n_c-th invention in chemicals are

$$(1)\ \sum_{t=0}^{T-1} d_c^{\,t} g^{n_c - 1} R_c = (1 - d_c^{\,T})(1 - d_c)^{-1} g^{n_c - 1} R_c$$

Equation (1) models the assumption that patent protection is the only means to profit from inventions. Its right hand side expresses that the expected profits from invention are zero without patent laws.

It is plausible that competition exists among inventors for the best innovation projects; the number of potential inventors exceeds the number of potential projects: $L_j > N_j$, where N_j represents the maximum number of invention projects in country j. Potential inventors enter as long as the payoffs to invention are positive. Entry reduces the maximum returns from invention until they are only slightly greater than patenting costs, C.[12] Then,

$$(2)\ (1 - d_i^{\,T})(1 - d_i)^{-1} g^{n_i - 1} R_i = C \text{ for } i = m, c$$

This implies

$$(3)\ n_i = \ln(g)^{-1}[\ln(C) - \ln(R_i) + \ln(1 - d_i) - \ln(1 - d_i^{\,T})] + 1 .$$

Equation (3) allows me to check the comparative static effects of an increase in patent length on levels of invention. Taking first derivatives yields

$$(4)\quad \frac{\partial n_i}{\partial T} = \ln(g)^{-1} \ln(d_i) d_i^{\,T} (1 - d_i^{\,T})^{-1} > 0$$

[11] This assumption follows Machlup (1962) who argues that inventors solve problems with tools available within a given framework of general knowledge. Inventors are able to distinguish easy problems from hard problems and attack the easiest problems first. As research effort increases, inventors pick projects that are less rewarding and the returns to research decrease.

[12] With a discrete number of invention projects, returns may not be strictly zero.

Equation (4) confirms that increases in the duration of patent grants increase the number of inventions.[13] Any decrease in patent length lowers the number of innovations. By this reasoning, countries without patent laws should bring forth almost no new technologies.

The assumption that all innovation originates from patentable domestic invention neglects important alternative sources of innovation. First, it neglects the benefits of adopting foreign technologies: While the absence of patent laws lowers incentives for domestic invention, it facilitates the application of inventions that are made abroad. If domestic firms can learn about foreign technologies, they can adopt these technologies without being blocked by foreign inventors and without having to pay licensing fees. Schiff (1971) suggests that both Switzerland and the Netherlands benefited greatly from the adoption of foreign technologies when they did not have patent laws. Then, the effects of introducing patent laws depend on the tradeoff between strengthening incentives for domestic invention and increasing the obstacles to adopting foreign technologies.

B. *Effects on the Direction of Innovation*

Previous literature on innovation has neglected the effects of patent laws on the direction of innovation – the focus of innovation on a specific set of industries and instead deals almost exclusively with effects on levels of innovation.[14] I argue that a richer concept of innovation is required to understand the effects of patent laws. In addition to influencing levels of innovation, patent laws are very likely to influence the industrial composition of innovation, which in turn helps to determine a country's potential for economic growth.

[13] Similarly, increases in initial returns and decreases in patenting fees raise the number of inventions.
[14] Acemoglu (2002) examines the effects of price and market size on the bias in skill-levels of innovation.

Intuitively, the effects of patent laws vary across industries according to the relative importance of patent laws to protect inventions in these industries. In a 1994 survey of 1,478 American manufacturing firms, Cohen, Nelson, and Walsh (2000) find that firms typically rely on a range of mechanisms, including patents, secrecy, lead time, and the use of complementary assets to capture profits from their innovations. Of these mechanisms, patents are unambiguously the least important. In contrast, secrecy, whereby inventors protect their intellectual property by preventing disclosure, appears to be emphasized most heavily. The authors find patenting to be the most frequently used mechanism in two of 33 industries, while secrecy is the most used mechanism in 17 of 33 industries.[15]

Intuitively, the relative usefulness of patent grants should be inversely related to inventor's ability to keep their innovations secret. If patent laws require the disclosure of innovations, as they have done since their inception, applying for a patent grant is especially costly to innovations that are difficult to reverse-engineer, because disclosure raises the risk of imitation and even the safest patent expires at the end of the statutory term. On the other hand, innovations which are easy to reverse-engineer benefit greatly from a patent grant, because disclosure is imminent with or without patenting, while a patent helps to secure intellectual property at least for a limited period.

If the relative effectiveness of patent protection varies across industries, invention in countries without patent laws may be more likely to occur in industries where alternatives to patent protection can be used. Then, countries without patent laws may have larger proportions of innovation in industries where patents are less effective relative to secrecy. For instance, if food innovations in the nineteenth century were less suitable to patent protection than

[15] See Cohen, Nelson, and Walsh (2000 p.10). See also Levin, Klevorick, and Nelson (1987) for a survey of 650

innovations in other industries, countries without patent laws should have higher shares of their innovations in foods. At the same time, if innovations in machinery depended on patent protection, countries without patent laws would be less likely to devote significant portions of their innovative energies to machinery and may mechanize more slowly.

In countries with patent laws, the inventor's choice between patenting and secrecy represents a trade-off between certain protection for a finite period of time (through the patent) and uncertain protection to infinity (through secrecy). I define *s* to be the share of inventions that remain secret after one year and suppose that *s* equals 1 for patented inventions. Then (1-*s*) represents the risk of discovery that inventors incur if they choose not to patent their inventions. In period *t* they receive payoffs $s_i^t R_i$ without patent protection. In industries where patenting is ineffective, payoffs from secrecy exceed payoffs from patenting when

$$(5) \quad \sum_{t=0}^{T-1} d_i^t g^{n_i} R_i \leq \sum_{t=o}^{\infty} s_i^t g^{n_i} R_i \quad \text{or} \quad (1-d_i^T)(1-d_i)^{-1} \leq (1-s_i)^{-1}$$

This inequality implies that inventors are more likely to patent their inventions as patent length increases. Inventions in industries where secrecy is effective become more attractive as patent length decreases. If patent length equals zero, industries where a portion of inventions can be protected by secrecy become extremely lucrative to inventors relative to inventions in other industries. Then countries without patent laws should have larger proportions of exhibits in industries where secrecy is effective.

Similarly, the effects of increases in patent length should vary with the natural lifetime of innovations in each industry. In industries where inventions remain valuable for many years after the end of the patent grants, increases in patent length would significantly raise expected profits from invention. In contrast, if inventions are most lucrative in the first few years but

U.S. firms in 1983, and Harabi (1991) for a survey of 358 Swiss R&D labs.

become obsolete very quickly, expected payoffs should be insensitive to changes in the duration of patent grants. Then, changes in patent length are likely to influence the distribution of innovation across industries, if patent grants are sufficiently short.

With two industries, inventors choose industry c if the total returns in industry *c* exceed the total returns in industry *m*:

$$(6)\quad \sum_{t=0}^{T-1} d_c{}^t g^{n_c-1} R_c > \sum_{t=0}^{T-1} d_m{}^t g^{n_m-1} R_m$$

Because the number of potential inventors *L* exceeds the number of potential invention projects *N*, inventors enter both industries until expected returns in both industries are nearly equal. Then, approximately

$$n_c - n_m = [\ln(1-d_m{}^T) - \ln(1-d_m) - \ln(1-d_c{}^T) + \ln(1-d_c) + \ln R_m - \ln R_c]\ln(g)^{-1} \text{ and}$$

$$(7)\quad \frac{\partial(n_c - n_m)}{\partial T} = [-(1-d_m{}^T)^{-1} d_m{}^T \ln(d_m) + (1-d_c{}^T)^{-1} d_c{}^T \ln(d_c)]\ln(g)^{-1} < 0$$

for $0<d_c<d_m<1$ and $g<1$. Equation (7) implies that invention shifts from industries with early payoffs to industries with later payoffs as patent length increases. If patent life is short, industries with high initial payoffs are more attractive. As patent life increases, the advantages of early payoffs decrease relative to payoffs that are long-lived. Then, countries with long patent grants should have greater shares of their innovations in industries where the natural lifetime of inventions is long, and smaller shares in industries where inventions become obsolete more quickly.

If the length of patent grants exceeds the natural life time of innovations, the effects of further increases in the length of patent grants may become quite small. For European inventions in the second half of the nineteenth century, Schankerman and Pakes (1986) find that only ten percent of all patents survive for the whole statutory term. In pre-1920 Germany, only four percent survived for the statutory term of 15 years. This suggests that, for countries with long patent grants, small changes in patent length may have only small effects on the economy-wide levels of innovation. They may however have significant effects on the relative profitability of innovations across industries.

In addition to the features of patent laws, other country characteristics, such as levels of development and the size of domestic markets, are likely to influence levels and the direction of innovation. Kremer (1993) and Sokoloff (1988) show that access to large markets for new goods increases expected profits from innovation and thus encourages innovation. Alternatively, large markets for innovations may create opportunities for specialization and knowledge spillovers among competing firms. Deardorff (1992) and Helpman (1993) argue that the effects of patent laws vary between developing and industrialized countries and that patent laws, which work well in industrialized countries, may prove detrimental to developing economies. In contrast, Diwan and Rodrik (1991) demonstrate that strong patent laws can be beneficial for developing countries if they encourage technologies that differ from those invented in developed countries. My paper uses world's fair data from 1851 and 1876 to examine whether nineteenth-century patent laws influenced the direction of technological change for countries in the early stages of their industrialization.

II. The Data

From the catalogues of the Crystal Palace Exhibition in London in 1851 and the American Centennial Exhibition in Philadelphia in 1876 I have constructed a new, internationally comparable data set on nineteenth-century innovation.[16] More than six million people visited the Crystal Palace and almost ten million attended the Centennial Exhibition (see Kroker, 1975 p. 146). A total of 17,062 exhibitors from 25 countries and 15 colonies displayed their innovations at the Crystal Palace; 30,864 exhibitors from 35 countries participated in the U.S. Centennial (see *Bericht III*, 1853 p. 674; Kretschmer, 1999 p. 101). In 1851, the Crystal Palace was the largest enclosed space on earth; its exhibition halls covered 772,784 square feet, an area four times that of St. Peter's in Rome, or six times that of St. Paul's Cathedral in London. In 1876, a visitor at the Centennial Exhibition had to walk 22 miles to see the exhibits in all six principal Exhibition buildings.

A typical entry in the exhibition catalogues includes a brief description of the exhibited innovation as well as the name and the home location of its presenter. For example, consider Britain's exhibit number 32 in class 9 of J. Bendall from Woodbridge, England:

> 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 industry classes. For the Centennial data, I have counted 19,076 exhibits in 344 industry classes. I have been able to match all Centennial classes

[16] These fairs have the highest quality of data. Participation in the two most promising alternatives, the 1873 *Weltausstellung* in Vienna and the 1889 International Exposition in Paris suffered from political turmoil that had arisen among participating countries.

to Crystal Palace classes except for categories of innovations that were new to the later exhibition.[17]

Among the major benefits of the exhibition data is that the exhibits cover innovations from all industries. Industry classes span the entire spectrum of production: they range from mining and minerals, chemicals, and food processing, to engines, manufacturing machinery, scientific instruments, and art. Such coverage has been difficult to attain with historical patent data; patented inventions are classified by functional principles, and often cannot be assigned to a specific industry of use.[18] For example, studies of historical patent counts have been unable to classify important innovations such as power plant inventions, electric motors, or bearings (Schmookler, 1972 p. 89). Moreover, economy-wide patent data are not available for countries that exclude specific industries from patent protection. In the nineteenth century, Austria, Belgium, France, and Saxony exclude certain industries from patent protection, namely chemicals, foods, and medicines (Coryton, 1855 pp. 241, 244, 249, 266).

Based on the original classification scheme of the 1851 catalogue, I combine the exhibition data from thirty into seven industry classes: “mineral products”, “chemicals”, “food”, “machinery”, “scientific instruments, “textiles”, and “manufactures”. This classification avoids the problem of treating equally a choice between “woolens” and “flax” (closely related industries in the textiles sector), and a choice between “woolens” and “scientific instruments” (textiles and machinery). It 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.

[17] New Centennial classes were systems of education, other institutions and organizations, marine mammals (live, stuffed, and salted), and ornamental trees.

A uniform system of selecting exhibits ensured that all participating countries chose exhibits according to the same criteria of novelty and usefulness. National governments valued the exhibitions to showcase their technologies, and often competed to demonstrate their technical supremacy in a certain industry (*The Times*, October 20, 1849). A comprehensive system of reviews by local and national commissions was created to ensure that a country's cutting-edge technologies were presented at the fairs. This combination of national and local commissions guaranteed that innovations from both urban and rural areas were exhibited. National commissions delegated the authority to select exhibits to local branch commissions. For example, Britain's national commission for the Crystal Palace nominated 65 local commissions to select exhibits. Local commissions typically consisted of two to 10 academics and business people, representing the area's main industries (*Bericht*, 1852 pp. 37 and 90). In their applications to the local commissions, 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). Exhibitors had to cover transportation costs only to these local collection points. After local commissions had selected their exhibits, national commissions checked that no local commission contributed two identical products (*Bericht*, 1853 pp. 40 and 64). Awards to the most innovative exhibits served to enforce the selection of exhibits at the fairs. No participant could excuse himself from the juror's evaluation. Signs such as "Not entered in the competition" were explicitly prohibited. A general ban on price tags was intended to prevent competition through price rather than novelty (*Bericht*, 1853 pp. 29, 50, 98 and 111).

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[18] To recall a famous example, the functional class "dispensing liquids" includes holy water dispensers along with water pistols, while "dispensing solid" groups tooth paste tubes with manure spreaders. See Schmookler (1972 p. 88).

Exhibition data are an invaluable complement to patent data because they measure innovations – economically useful applications of new technologies – rather than inventions, as do patent data. Exhibits satisfy a stronger test of practicality than other measures of innovation, because exhibits were selected for usefulness along with inventiveness and because exhibitors typically hoped to sell their innovations at the fairs.[19] For the twentieth century, firm-level surveys have found that only between 5 to 20 percent of patents become economically useful innovations (Meinhardt, 1950 p. 256). In the nineteenth century, utility often was often not even required for a patent grant.[20]

Another benefit of exhibition data is that they include awards as a proxy for the quality of innovation. Griliches (1990 p. 1669) observes that patented inventions differ greatly in quality and in the magnitude of inventive output associated with them. 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, citation measures are difficult to collect and not as yet available to measure the quality of nineteenth-century inventions.[21] In contrast, reliable proxies for quality can be created with relative ease from the records of the world fairs. At both exhibitions, international panels of industry experts evaluated all exhibits according to criteria of novelty and usefulness and awarded medals to the exhibits that they considered most inventive and useful. Panels were between 6 and 12 people strong and membership was divided equally among university professors, representatives of professional organizations, and businessmen. At the Crystal Palace, 5,438 exhibits received awards (*Bericht III*, 1853 p. 707;

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[19] For a comprehensive review of the costs of exhibiting see Haltern (1971).

[20] For example, Coryton (1855 pp. 235 and 239). Brown and Jeffcott (1932) compile amusing if slightly unexpected "mad inventions" from the records of the United States Patent Office. Among them are "a novel device for automatically effecting polite salutations by the elevation and rotation of the hat" and an air-cooled rocking chair (No. 562,908, patented March 10, 1896, and No. 92,379, patented July 6, 1869).

[21] Currently the 1920s are the earliest period when citation data are available (Nicholas, forthcoming).

Haltern, 1971 p.155). Juries awarded Council Medals, the highest honor, to the most innovative exhibits, Prize Medals to the second-most innovative exhibits, and Honorable Mentions to exhibits that they deemed impressive but not outstanding. One percent of all exhibits received Council Medals, the highest honor for inventiveness, 18 percent received Prize Medals, the second-highest honor, and 12 percent received Honorable Mentions.

In this paper I include data on exhibits from Austria, Bavaria, Belgium, Britain, Denmark, France, the Netherlands, Norway and Sweden, Prussia, Saxony, Switzerland, and Württenberg. Data from these Northern European countries add to 11,610 exhibits in 1851 and close to 6,482 in 1876. Although my data include more than 18,000 exhibits from Northern Europe, country characteristics are the only source of variation. From this point of view, the relevant number of observations equals the number of countries times the number of industry categories. I have exhibition data for 22 counties in 1851 and 1876 combined. These data are divided into seven industry categories. Then, the number of observations in my data set is 154. I restrict the analysis to Northern Europe because I can check the selection process for these countries most carefully and because they are similar in characteristics that I cannot control for, such as climate, culture, and religious beliefs. At the same time, these countries vary considerably in the characteristics of their patent systems.

A. *Information on Nineteenth-century Patent Laws*

Detailed data on nineteenth-century patent laws allow me to study the effects of patent laws on exhibited innovations. For states whose borders are comparable between 1850 and today I use Lerner's (2000, 2002) data on patent laws. His data, constructed from inventors' manuals on patenting in foreign countries, proceed in twenty-five year intervals that include

1850 and 1875.[22] For states with border changes, such as pre-unification Germany, I obtain information from inventors' guides to international patent laws by Godson (1840), Kingsley and Pirsson (1848), and Coryton (1855). I make this distinction because countries that are unified today often had widely divergent patent laws in the mid-nineteenth century. 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 demanded 20 times as much as their Prussian counterparts to be compensated for processing a grant.

The variable "patent length" is defined as the maximal duration of the patent, which inventors can be granted at the time of application.[23] 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 they abolished 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 twentieth-century patent renewal data such as Pakes (1986), who 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.

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[22] Lerner's sample includes the sixty countries with the highest gross domestic product in 1997 as they were listed in the International Monetary Fund's *International Financial Statistics*.

B. *Data on Other Country Characteristics*

To account for the influence of a country's size and other characteristics, I include data on population, GDP, education, and the share of labor in agriculture. I use data from the *Annuaire Statistique* (1916) and from Maddison (1995, 2002) on gross domestic product (GDP) and population in 1850 and 1875. Nineteenth-century data on country characteristics are relatively sparse, especially for 1850. For this year, I do not have separate GDP data for Bavaria, Prussia, Saxony, and Württenberg. I proxy such data by multiplying population figures from the *Annuaire Statistique* with German GDP per capita as reported in Maddison (1995, 2002).

There are no Swiss GDP data for 1851 or 1876; data on Swiss GDP is available only for 1870 and 1899 (Maddison, 1995 p. 182). I use Swiss GDP in 1870 to proxy GDP in 1875 and extrapolate a value for 1850 based on Swiss GDP in 1870 and 1899.[24] These estimates are crude and, for this reason, I repeat all tests excluding them. From Mitchell (1998) I draw data on shares of GDP and of male labor employed in agriculture, fisheries, and forestry.[25] Mitchell has observations on GDP shares for 10, and observations on labor shares for 18 of the 24 countries in my data set. Data for shares of agriculture are missing for Switzerland and Russia in both years and for Germany in 1851. I extrapolate these data and repeat all regressions including shares of agriculture. I also include data on total numbers of students enrolled in primary education and primary-school students per 1,000 children ages 5 to 14 from Lindert (2001). Such data are available for 16 of my 22 country observations.

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[23] I assume that awards occur very shortly after the application. This assumption is consistent with the way in which data on patent fees in Lerner (2000) are constructed but it ignores differences in the fee structure for patent lengths below the maximal duration of the grant.

[24] Swiss GDP in 1850 is approximated linearly from values for 1870 and 1899.

III. Using Exhibition Data to Examine the Effects of Patent Laws

This section uses the exhibition data to test the predictions presented in section II. The first part examines the effects of patent laws on levels of innovations; the second checks for effects of patent laws on the direction of innovative activity.

A. *Effects on the Number of Innovations*

Previous literature on patent laws has assumed that increases in patent length at any level motivate increases in the quantity of innovations. However, innovating firms in countries without patent laws may be able to rely on alternative means to protect their intellectual property, and they may benefit from the freedom of adopting foreign inventions that the absence of patent laws affords. If patentable domestic inventions are the only means to achieve innovation, countries without patent laws should bring few innovations to the fairs. On the other hand, if foreign inventions and domestic inventions without patent grants also lead to innovation, then countries without patent laws should display many innovations at the fairs.

Plots of exhibition data, such as Figure 1, suggest that exhibits per capita are independent of patent lengths. Switzerland, a country that did not adopt patent laws until 1907, exhibited the second largest number of innovations per capita (110 exhibits), after Belgium (117 exhibits).[26] Denmark, the other country without patent laws, contributed 37 exhibits per capita, the median number of exhibits. The coefficients of linear correlation between patent length and exhibits per capita are negative 0.0531 for data from both exhibitions and positive 0.1556 for the Crystal Palace only. Comparisons of medal recipients across countries yield similar results. With 0.8

[25] I use "male" rather than total labor because the counting of female labor varies across countries.
[26] Exhibits per capita measure total exhibits at the Crystal Palace per million inhabitants in 1851.

Council Medals per million people, Switzerland has the third highest share of awards per capita among all participating countries.

Regressions of exhibits on country characteristics yield some evidence against the hypothesis that patent laws raise the levels of innovation. Table 4 reports the results of negative binomial regressions of the total number of exhibits on country characteristics. I use negative binomial regressions instead of ordinary least squares because data for the dependent variable "numbers of exhibits" are counts and the distribution of these counts is skewed to the left. Negative binomial are preferable to Poisson regressions because the data are overdispersed: Log-likelihood ratio tests in the second to last row in Table 4 confirm that the variance of the dependent variable exceeds its mean.[27] The coefficients in column (1) suggest that countries without patent laws or with short patent grants exhibit fewer innovations than countries with long patent lives. However results in columns (2) to (4) indicate that other country characteristics, such as population and the status as a host country, are better predictors for the number of exhibited innovations. Similar results hold when the dependent variable includes award-winners only; the positive effects of patent laws disappear as I control for population.[28] All results are robust to the inclusion of variables for education, geographical distance to the exhibitions, and labor shares in agriculture.

Both data plots and regression results suggest that countries without patent laws were able to bring forth a considerable number of innovations, despite possibly weaker incentives for domestic invention. For Denmark, Switzerland, and the Netherlands, the benefits of not having

[27] In the Poisson regression model the dependent variable y_i has mean *and* variance $\mu_i = \exp(x_i'\beta)$. The negative binomial model generalizes the variance function to $V[y_i|x_i] = \mu_i + \alpha\mu_i$, where the parameter α measures dispersion around the mean. For descriptions of the Poisson and negative binomial models see Cameron and Trivedi (1998 pp. 70-85) or Hausmann, Hall and Griliches (1984).

[28] I have repeated all tests with an alternative measure of patent length: patent length with extensions, which takes account of differences in the ability to renew a patent. All results are similar.

patent laws (particularly the ability to legally copy foreign inventions) appear to have neutralized the negative effects on the incentives for domestic invention. Two caveats apply. First, exhibition data may be an imperfect measure of innovation, because the number of exhibits may be biased by other country characteristics such as country size or economic strength. My regressions include controls such as population, GDP, levels of education, and shares of employment in agriculture, but some omitted variable bias might remain. All countries without patent laws are small and this may be why including population reduces the statistical significance of patent laws. Second, although the theoretical and empirical literature on innovation has emphasized the effects of patent lengths, other features of patent systems, such as the breadth of patent grants and inventors' expectations about the enforcement of patent grants may be equally important. Nonetheless, even the most cautious interpretation of the data confirms that mechanisms other than patent protection must have existed to protect intellectual property and that the absence of patent laws did not unambiguously hinder innovation in countries without patent laws. Innovators in countries without patent laws found ways to mitigate the disadvantages of their position, possibly by focusing on industries that relied less on patent laws.

B. *Effects on the Direction of Innovative Activity*

A major benefit of exhibition data is that they enable us to study the effects of patent laws on the direction of innovation. Exhibition data are the first source of comprehensive data on innovation in all of a country's industries. To the best of my knowledge, there are no alternative sources of economy-wide data on innovation which are comparable across countries.

I use the exhibition data to investigate how country characteristics, and specifically patent laws, influence inventors' choice of industry and thus the direction of innovative activity.

If patent laws influence the direction of innovative activity in the way that I outlined in section II, the distribution of innovations across industries should differ strongly across countries with widely divergent patent laws. In contrast, the distributions of innovations across industries should be similar across countries with identical patent lengths. Chi-square tests of homogeneity suggest that differences in the direction of innovation increase with patent length. Distributions of exhibits from countries with long-lived patents are more different from each other than are distributions from countries with short-lived patent grants. One plausible explanation for this fact is that changes in patent length have little effect if patents are long-lived because innovations become obsolete prior to the expiration of the patent grant. Schankerman and Pakes' (1986) finding that only 10 percent of European inventions in the second half of the nineteenth century survive for the whole statutory term lends support to this hypothesis. If the lifetime of patent grants exceeds the natural lifetime of innovations, other determinants of innovation may outweigh the influence of patent laws and create differences in the direction of innovations across countries.

In contrast, countries with short patent grants and those without patent laws patent laws are more similar to each other than countries with long patent grants. In Figures 2 and 3, histograms of exhibits at the Crystal Palace reveal that distributions of exhibits across industries are remarkably similar for the two patentless countries in 1851: Switzerland and Denmark. Chi-square tests of homogeneity fail to reject the hypothesis that the distribution of exhibits across industries is identical for Switzerland and Denmark. For eight categories, the chi-square statistic is 6.37 including art and 5.01 excluding art, both of which are significant at the five percent level. Differences in the natural endowments between landlocked, mountainous Switzerland and sea-swept Denmark make these similarities in the direction of innovation even more remarkable.

Within machinery, the countries without patent laws reveal a striking resemblance in their focus on scientific instruments. Figure 3 shows that both countries allocate about one fourth of their total exhibits to this category, which includes optical instruments and watches along with instruments for scientific measurement, thermometers, theodolites, and barometers. At customary significance levels, the chi-square statistic of 7.82 fails to reject the hypothesis that the distributions of Swiss and Danish exhibits across machinery are identical. Twenty-seven percent of Switzerland's exhibits and 23 percent of Denmark's exhibits at the Crystal Palace are of scientific instruments.

No other country has comparable shares of innovations in scientific instruments. Figure 4 shows that only eight percent of Britain's exhibits are in instruments. Britain, as the most developed country in 1851, devotes a significantly smaller portion of her innovations to this nineteenth-century, cutting-edge industry. Britain's share equals the mean across all countries, and slightly exceeds the median of six percent. Bavaria, where patents last up to 15 years, has the third highest share: 14 percent of her exhibits are in instruments. France, where patents last 15 years, and Württenberg, where patents last ten years, each devote 10 percent of their innovations to scientific instruments. In comparison, American patents last 14 years, and only 13 percent of American exhibits are in scientific instruments.

In the following paragraphs I use data from both exhibitions in multinomial regressions to check more rigorously how patent laws influence the direction of innovation. Experiment *j* is to draw a count from the exhibition records for country *j* and determine the industry it belongs to. For example, I draw an exhibit from the exhibition data for Germany and determine whether it belongs to "mining and metals", "chemicals", "food", "machinery", "scientific instruments", "textiles", or "manufactures". Clearly the outcomes of these experiments are mutually exclusive, and therefore the probabilities that counts fall within a specific subclass add to one. I make the strong (but not implausible) assumption that draws for the 22 country observations in 1851 and 1876 constitute experiments that are independent of each other. Under these conditions, the data represent independent draws from a multinomial distribution. Let $\pi_i (x_{ij})$ denote the probability that an exhibit in country *j* occurs in industry *i* (where *i* = "mining", "chemicals"…"manufactures") at values of *k* explanatory variables $x_j = (1, x_{j\text{“no patent laws”}}, x_{j\text{“short patent grants”}}, x_{j\text{log (population)}}, x_{j\text{gdp per capita}}, \ldots)$. Then,

$$\pi_i (x_{ij}) = \exp (\alpha_i + \beta_i x_j) / [\exp (\alpha_{mining} + \beta_{mining} x_j) + \ldots + \exp (\alpha_{manufactures} + \beta_{manufactures} x_j)].$$

One pair of coefficients is redundant. I set $\alpha_{manufactures} = \beta_{manufactures} = 0$ for the largest industry class, which is manufacturing. I use multinomial logit regressions to estimate values for these coefficients and to calculate predictions (according to the equation above) for industry shares under different types of patent systems. This method fits the multinomial logit model by maximizing the likelihood subject to *simultaneously* satisfying the six equations that satisfy the model (seven industry categories minus one). Alternatively, I have fitted logit models *separately* for the six pairings of responses. 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. I omit "manufactured goods", because it is the largest class.

I divide the data into two separate samples and run regressions with different sets of country characteristics. To assess changes over time, I analyze data from the Crystal Palace and the Centennial separately as well as jointly. This division avoids the problem that the distribution of exhibits for a given country in 1876 is not independent from the distribution of exhibits for the same country in 1851. Regressions control for country size through logarithms of population and for levels of development through GDP per capita. I have repeated all regressions excluding GDP and population and found all results robust to those changes. I have also replicated all tests with information on all countries for which I have data, including Russia, Spain, Portugal, Italy, Canada, and the United States.

Multinomial regressions of exhibition data indicate that patent laws help to determine the direction of innovative activity. Coefficient values in Table 5 and predicted values in Table 6 confirm that countries without patent laws have significantly larger shares of innovation in scientific instruments than do other countries. Countries without patent laws also have significantly smaller shares in manufactures and somewhat smaller shares in machinery and manufactures. In the period between the two exhibitions, the focus of innovation shifted away from textiles, scientific instruments, and manufacture. For countries without patent systems, the share of textiles did not fall as rapidly. In contrast, the decline in manufactures was pronounced. Innovation in countries without patent systems became more concentrated on food processing. At the same time, innovation became distributed more evenly in countries that had patent systems. Strong patterns of concentration within economies disappeared and patterns of innovation became more similar to each other across countries.

For countries without patent laws, predicted shares of innovations in scientific instruments are significantly higher than for other countries. Patentless countries have almost one fourth of their exhibits in scientific instruments, while other countries have less than one fifteenth of their exhibits in instruments. This difference is larger at the earlier exhibition: In

1851, 28 percent of all exhibited innovations from patentless countries are in scientific instruments compared to eight percent for other countries. Figure 5 illustrates predicted shares for the smallest industry classes in 1851 and 1876. It shows that the share of scientific instruments declines between 1851 and 1876 but continues to be greater for countries without patent laws. In Figure 5b shares for 1876 are 19 and 6 percent, respectively.[29]

Countries without patent laws also have larger proportions of their innovations in food processing. In 1851, most innovations in food processing are new methods of preservation; in 1876, instant meals, such as beef extracts, and mass-produced foodstuffs, such as margarine, have become more prominent. In regressions with data from both exhibitions, the predicted shares for foods are 13.5 percent for countries without patent laws and 9 percent for countries with patent laws. Similarly, predicted values for countries with short and long patent grants indicate that countries with short patent grants have significantly higher proportions in food than those with long patent grants. 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.

The Netherlands, which for political reasons abandoned her patent system in 1869, experienced a strong shift towards food processing after this change in patent laws (see Penrose, 1951). The proportion of Dutch innovations that were devoted to food processing increased from 11 to 36 percent between 1851 and 1876, replacing textiles as the most prominent industry for Dutch innovations.

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[29] These results are robust to changes in the definition of "short patents". They do not change if patent length is included as a continuous or squared variable. I have also repeated all tests controlling for shares of agriculture and various measures of education, though such data are sparse until the 1870s.

Countries without patent laws also have significantly lower proportions of their exhibits in the class "mining and mineral products." This difference may be a result of resource endowments rather than differences in patent laws. In the nineteenth century, patenting played a crucial role in protecting innovations in machinery for resource extraction. For example, Beatty (1996) finds that mining and metallurgy were the most frequent industry categories among nineteenth-century patents in Mexico (p. 155). However, Switzerland, Denmark, and the Netherlands lack good deposits of iron and coal along with the protection of a patent system.[30] Their inadequate resource endowments offer a compelling alternative explanation for the paucity of innovations in these industries. To account for this possibility, I omit mining and metallurgy from the regressions. This does not change the coefficient values for other categories.[31]

Predicted industry shares, which are represented in Figure 5 suggest that the existence of domestic patent laws mattered more in 1851 than it did in 1876. In 1851, the emphasis on scientific instruments in countries without patent laws is striking. By 1876, differences in distribution are still significant, but both types of countries have shifted innovations towards similar industries, albeit to varying degrees. A likelihood ratio test statistic of 122.4 rejects the null hypothesis that the coefficients on patent laws and other country characteristics are identical between 1851 and 1876.[32] This is consistent with the results of studies of the history of patent laws such as Lamoreaux and Sokoloff (1999) who suggest a strengthening of international markets for patent protection towards the turn of the nineteenth century. Data in these studies, as well as Lerner (2000) indicate that the level of discrimination against foreign patentees

[30] For an example of a country study that treats resource endowments see Schiff (1971). The Netherlands, for instance had no ore, and only limited coal deposits. (Schiff, 1971 p. 35)
[31] The Hausmann-McFadden test statistic for IIA is 6.65.
[32] The likelihood ratio test statistic is $-2(\ln L_{pooled} - (\ln L_{1851} + \ln L_{1876}) = 122.24$. Degrees of freedom are equal to the sum of the parameters in the separate regressions for 1851 and 1876 minus the number of parameters in the pooled

decreased over the course of the nineteenth century. Although further evidence is necessary, I would cautiously argue that the importance of domestic patent laws decreased with improvements in international markets for patent protection.

Population and GDP per capita are other important influences on the distribution of innovative activity across industries. The logarithm of population is significant in all specifications. Likelihood ratio tests reject the hypothesis that country size has no effect on the distribution of innovation across industries. These results confirm the arguments of Sokoloff (1988) and Kremer (1993) that population and the size of the domestic market influence innovation. In contrast to previous work, which has focused on levels of innovation, I find that country size also influences the direction of innovation. Size may allow large economies to develop innovative capacity in sectors where innovations depend on large scale to be profitable.

In industries where alternative mechanisms are effective relative to patent protection, smaller shares of exhibits should refer to patents. Moser (2003) uses British exhibition data to construct a proxy for the proportion of innovations that are patented across industries and geographic locations. This proxy is calculated as the number of exhibits that refer to a patent divided by the total number of exhibits. It would be a perfect measure of patenting rates if exhibitors listed patents if and only if they held patent grants. As an approximation, this assumption seems plausible: exhibitors with patents advertise their patents to raise the value of their innovations; exhibitors without patents are unlikely to claim patents, because they would be discovered easily.

Patenting rates for British exhibits vary between 5 and 38 percent across industries. Less than five percent of innovations in mining and metallurgy refer to patent grants, compared to

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regression. Degrees of freedom are 3 (4 plus 5 minus 6) and the critical value of the chi-square distribution at 5 almost 39 percent of innovations in manufacturing machinery. In scientific instruments, less than nine percent of innovations appear to be patented. This share is astonishingly small given the prominent position of scientific instruments at this time. In food, less than 10 percent of innovations are patented. At the same time, almost every fourth innovation in machinery refers to a patent. The proportion of patented innovation is highest in manufacturing machinery, with more than 38 percent, and in engines (29 percent) and agricultural machinery (23 percent).

Comparisons of patenting rates across industries confirm that patent protection is relatively less important in scientific instruments and food processing, key industries on which inventors in countries without patent laws focus innovation. In the next section, I summarize narrative evidence from nineteenth-century sources which confirms that secrecy was important in scientific instruments and food processing

IV. The Use of Secrecy in Scientific Instruments and Food Processing

Narrative evidence confirms that secrecy was widely used to protect innovations in scientific instruments and food processing. For example, the report of the German Crystal Palace Commission describes how 12 industry experts unsuccessfully attempted to reconstruct the watch springs invented by F. Lutz of Switzerland. Similarly, the Commission reports relate 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).

Jaquet and Chapuis (1945) relate many instances when Swiss watchmakers went through great troubles to keep new production processes secret. For example:

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percent significance is 7.81.

> 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.[33]

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 inventions from imitation. They succeeded in honoring this agreement from 1823 to 1840 (see Jaquet and Chapuis, 1945 p. 165).

In food processing, the history of margarine illustrates the relative effectiveness of secrecy. Margarine first 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, willingly described how margarine could be made, considering himself protected by his 1869 French 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 efforts to obtain information from his rival's workers. Many other important innovations in food processing originated in late nineteenth-century Switzerland: milk chocolate, liquid soup seasoning, bouillon, and baby food (see Schiff, 1971 pp. 54-58, 111-112).

V. Potential Sources of Bias and Endogeneity

One common problem with analyzing the effects of patent laws is that patent laws may be endogenous to innovation. Anecdotal evidence for the late nineteenth and for the twentieth

[33] Jaquet and Chapuis (1945 p.170), my translation. See Landes (1983) for further examples.

century suggests that a country's choice of patent laws was often influenced by the nature of her technologies. In the 1880s, for example, two of Switzerland's most important industries – chemicals and textiles – were strongly opposed to the introduction of a patent system, as it would restrict their use of processes developed abroad. When Switzerland adopted her first patent laws, the Swiss laws excluded inventions which could not be represented by a model or physical replica, effectively excluding all inventions in dyeing and chemical processes (see Penrose, 1951 p. 16; Schiff, 1971 pp. 86, 92).

However, endogeneity appears to be a much smaller problem in the mid-nineteenth century than in any other period. Historical records suggest that early patent laws were determined by cultural and political factors rather than by the nature of technologies. Table 2 shows that most European countries adopted their patent systems well before 1851 (for data, see Machlup and Penrose, 1950; Penrose, 1951; Machlup, 1958). Early patent laws appear to have evolved with little planning or concern for existing clusters of innovation: "The patent system as it stands today has to a considerable extent 'just grow(n)' without much reference to fundamental principles, escaping the social planning of men into unexpected byways …" (Penrose, 1951 p. 19). Lerner (2000) argues that key characteristics of patent laws across 60 countries from 1850 to 1990 are best explained by political systems and legal tradition: Countries with democratic institutions are more likely to have patent protection and they grant longer-lived awards.

A related concern is that Switzerland's focus on scientific instruments was a result of historical accidents or, as has been proposed, Switzerland's mountainous terrain, and had nothing to do with patent laws. This is unlikely because, although the beginnings of the Swiss watch-making industry can be traced back to the revocation of the Edict of Nantes in 1685, Switzerland became a prominent seat of watch-making only in the second quarter of the nineteenth century. In earlier years, Paris and London had been the centers of European watch-making and prominent Swiss watchmakers were active in both of these foreign cities, rather than in their home country (Jaquet and Chapuis, 1945 p. 123). As late as the first quarter of the nineteenth century, unemployment among Swiss watchmakers in the Jura was so high that local authorities attempted to retrain watchmakers for other professions. It was only towards the mid-nineteenth century that Switzerland came into her own as a center of watch-making. At that time, most of the growth occurred outside of Geneva, in towns where watch-making was a relatively new trade, such as Bern, Neufchatel, and Fribourg (see Landes, 1983 pp. 275-289).

In addition to endogeneity and heterogeneity that is unrelated to patent laws, one needs to consider potential sources of bias in the way in which exhibition data measure innovation. In general, bias appears to be a lesser problem for measuring the distribution rather than the absolute number of innovations. One potential source of bias for the number of innovations is that Britain's Central Commission allocated space to individual countries according to their own perception of a country's relative importance as an innovator. But these restrictions on space do not appear too stringent. Visiting countries could request larger allocations or construct additional buildings to house their exhibits.[34] When the United States Commission to the Crystal Palace thought that U.S. exhibitors would be short on 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 spaces on the Centennial grounds: Australia, Brazil, Canada, Egypt, Germany, Great Britain, Japan, Morocco, Spain, Sweden, and

[34] Local commissions asked potential exhibitors to include space requirements in their applications (*Bericht*, 1852 p.35). If it was harder for large exhibits to be accepted, large exhibits may be more innovative. To check this, I have calculated the floor space per exhibitor for each of the 30 industry classes at the Crystal Palace. By this measure, exhibits of agricultural machinery and machines for direct use would be most innovative because they took 91 and 95 square feet of floor space compared to an average of 28.5. On the other hand, judging inventiveness

Turkey constructed cheap and temporary structures to house additional exhibits.[35] To address potential distortions that remain, I control for country size and analyze distributions of exhibits, by dividing exhibits in each industry by the total number of exhibits.

Exhibition data may underreport technological innovations that are easy to imitate or reverse-engineer, if such innovations were not exhibited for fear of imitation. Contemporary records indicate that this fear of copying 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 the Crystal Palace, a system of registration, which was available to all exhibitors, acted as a cheap and fast patent system; only 500 of 13,750 exhibitors took advantage of it (see *Bericht III*, 1853 pp. 697-701).

At both fairs, exhibitors found ways to advertise their innovations without disclosing the secrets of their inventions. Rather than exhibiting a new piece of machinery, or describing a new process, many exhibitors displayed 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 his papermaking machine, which he kept secret (see *Official Catalogue,*

by floor space implies that china, porcelain and earthenware are significantly more innovative than chemical exhibits, which seems unreasonable.

[35] *Visitor's Guide* (1875 p. 18). The average number of acres per exhibitor was approximately equal at the two exhibitions. It was 0.00118 in 1851 and 0.00125 in 1876.

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."[36]

Heavy and fragile exhibits, which would otherwise have been under-represented due to transportation costs, were exhibited as models or 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."[37] Among the engineering exhibits there was a model of the suspension bridge that was being constructed across the Dnieper at Kiev. Robert and Alan Stevenson (respectively the grandfather and the uncle of Robert Louis Stevenson) showed models of lighthouses they had designed for the Bell Rock and for Skerryvore (see Rolt, 1970 p. 157). In sum, the records indicate that exhibition data are a useful measure of innovation. Bias and problems of endogeneity, to the extent that they exist, are unlikely to be severe enough to invalidate analyses of the effects of patent laws.

VI. Conclusions

This paper has introduced a new data set that permits an empirical investigation of the effects of patent laws across countries. The data have been constructed from the catalogues of two nineteenth-century world fairs: the Crystal Palace Exhibition in London in 1851 and the Centennial Exhibition in Philadelphia in 1876. Exhibition data have revealed no evidence that patent laws increased levels of innovative activity, but they indicate that patent laws influenced

[36] *Official Catalogue* (1851 p.28). Some inventors even considered it safe enough to disclose production processes at the world fairs. For example, a British inventor exhibited "Patent railway carriage and other axles, with illustrations of the processes of manufacture…" (Exhibit 543, Official catalogue, 1851 p. 33).

the direction of innovative activity. The absence of patent laws appears to have guided innovative activity towards industries where mechanisms other than patent laws protected intellectual property; in the nineteenth-century, inventors in countries without patent laws concentrated innovation in industries where secrecy was an effective alternative to patent grants. Secrecy was especially effective in scientific instruments, and every fourth exhibit from countries without patent laws came from that industry while no more than one seventh of other countries' innovations were in scientific instruments. Between 1851 and 1876, the manufacture of scientific instruments became mechanized. Further progress in this industry required innovations in manufacturing machinery, which depended crucially on patent protection. During this time, inventors in countries without patent laws began to specialize in food processing, another industry where secrecy was effective. The Netherlands, where the free trade party succeeded to abolish patent laws in 1869, increased her share in food processing from 11 to 33 percent after the abolition of her patent laws. These finding suggest an important consideration for international patent policies: The introduction of strong and effective patent laws in countries without patents may have stronger effects on changing the direction of innovative activity than on raising the number of innovations.

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[37] *Official Catalogue* (1851, pp. 18-19). The German Commission also reports on the wide-spread use of models. For example, see *Bericht* (1853 pp. 196, 201, 210, 215, 230).

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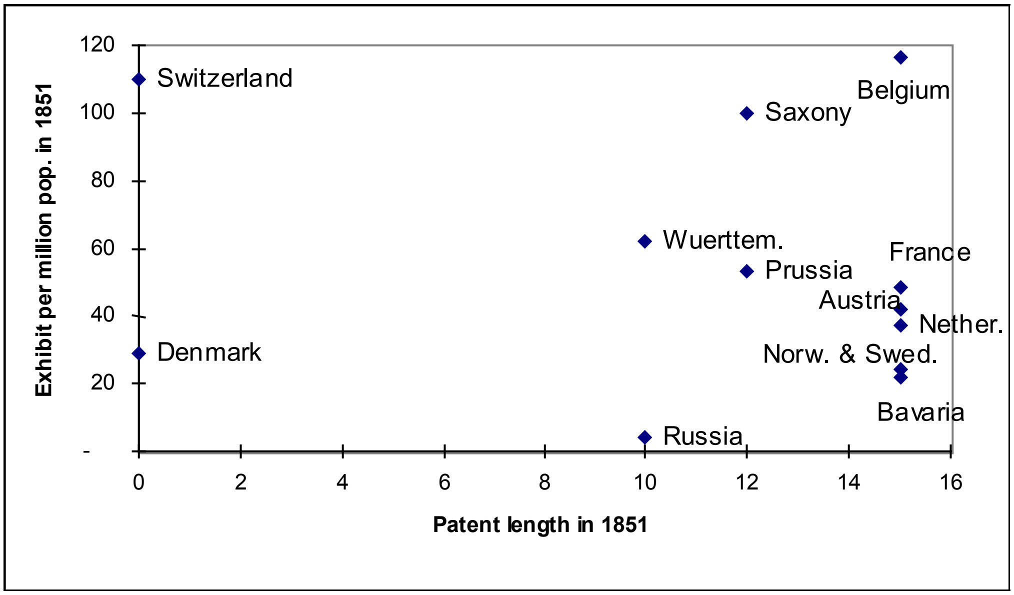
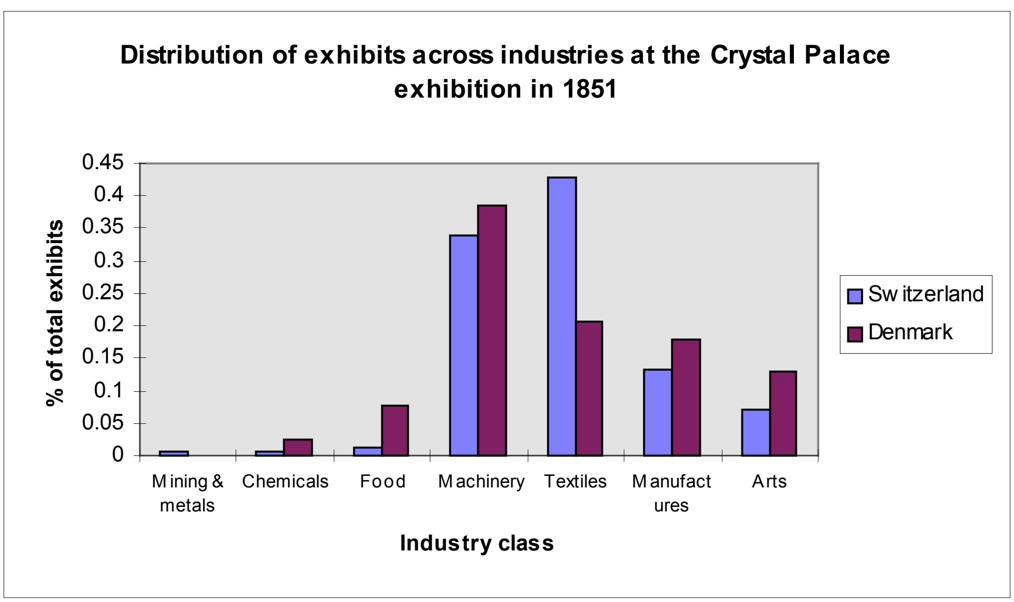
FIGURE 1 – PATENT LENGTHS AND EXHIBITS
PER MILLION PERSONS IN 1851



Notes: Exhibits per million population in 1851 measures the total number of a country's exhibits at the Crystal Palace divided by that country's population in millions in 1851 or the closest of two preceding years if there are no data for 1851. I have excluded Britain to get a clearer picture of the remaining countries. Britain's has 383 exhibits per one million population. Data on population are drawn from Annuaire Statistique (1916) and Maddison (1995); data on patent length from Coryton (1855) and Lerner (2001).

FIGURE 2 – DISTRIBUTION OF EXHIBITS
ACROSS INDUSTRIES IN 1851



Notes: This classification follows the original classification of exhibits in 1851 as reported in Bericht (1853). The class machinery includes scientific instruments along with engines, carriages, and railway equipment, manufacturing machinery, machinery for construction, as well as guns and other military equipment.

FIGURE 3 – SWISS AND DANISH EXHIBITS OF DIFFERENT TYPES OF MACHINERY IN 1851

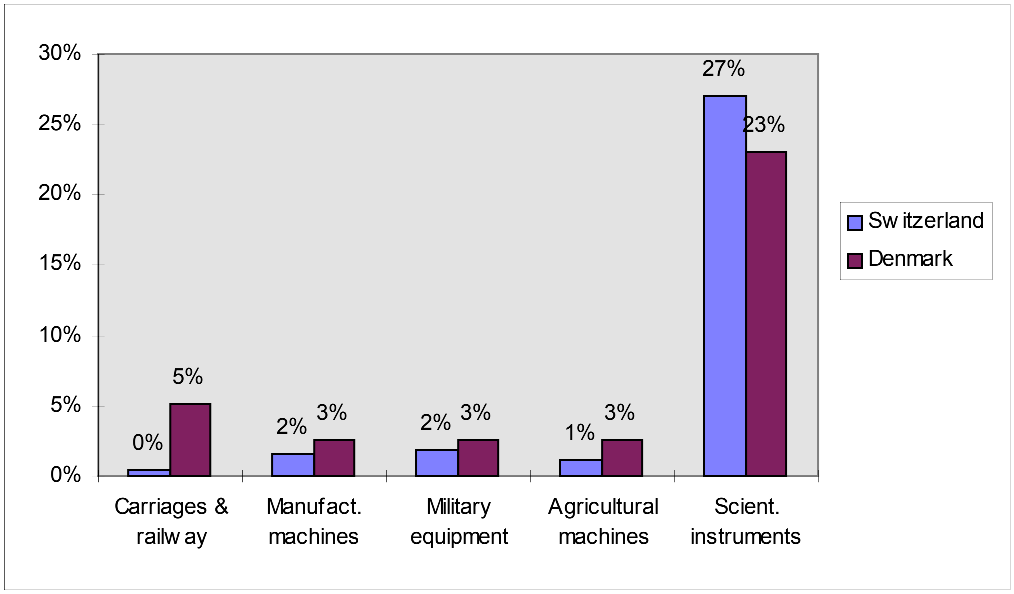
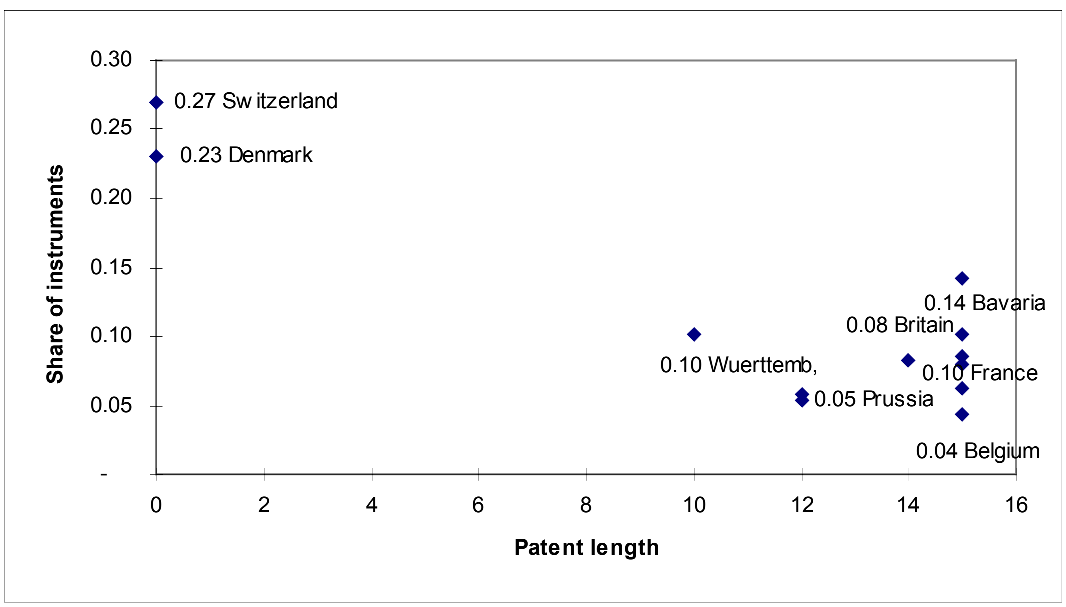


FIGURE 4 – SHARES OF EXHIBITS IN SCIENTIFIC INSTRUMENTS AGAINST PATENT LENGTH IN 1851



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 5a – PREDICTED INDUSTRY SHARES IN 1851

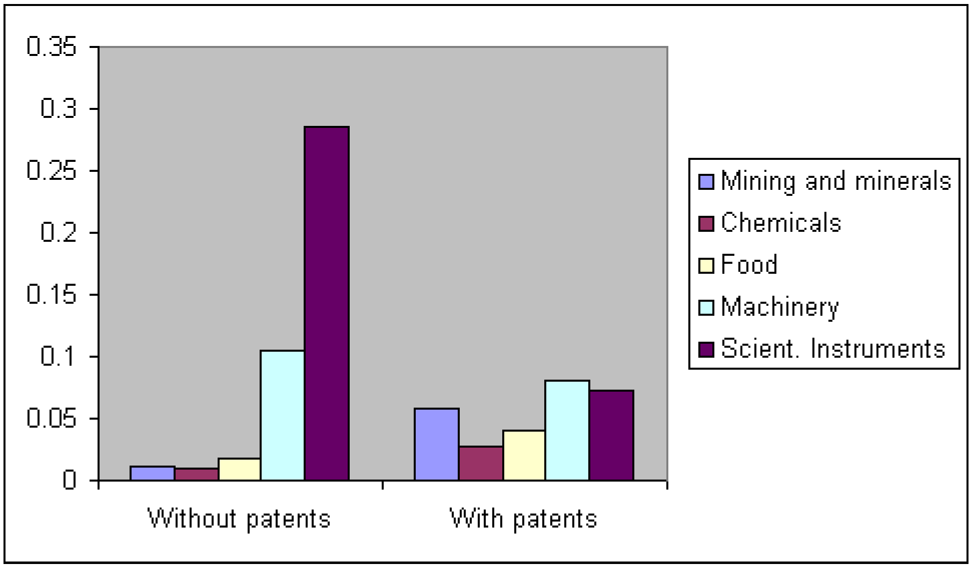
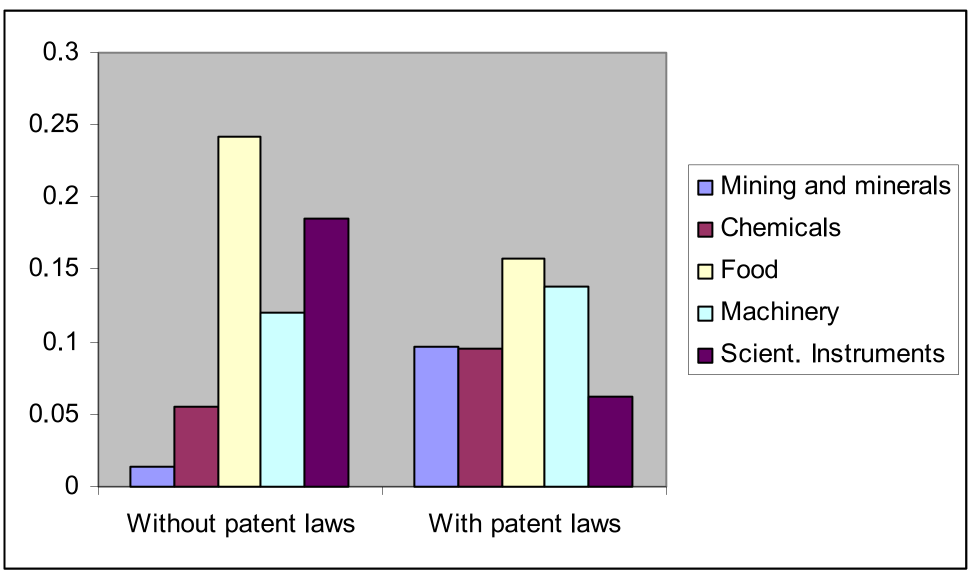


FIGURE 5b – PREDICTED INDUSTRY SHARES IN 1876



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 A2 reports the values for multinomial coefficients $\alpha_{i,}$ and β_i. The Newton-Raphson iterative maximum likelihood method is used to calculate multinomial coefficients

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

Source: Data are drawn from *Bericht III* (1853) and Kretschmer (1999). Among forty participating countries in 1851 fifteen were British colonies. For this paper, I have restricted the data set to Northern European countries because these are fairly homogenous in their climates, culture, and other characteristics. Northern European countries include only those for which data on patent laws were available. Luxembourg and some smaller German states are excluded because their data are very spotty.

TABLE 2– DEVELOPMENT OF PATENT LAWS 1500 TO 1876

1474	Venice grants monopolies of ten years to inventors of new machines
1623	English Statute of Monopolies repeals the practice of royal monopoly grants to all except inventors.
1790	U.S. Patent Act
1791	The French Constitutional Assembly passes a patent law.
1793	U.S. establishes a registration system for patent applications.
1810	Austria enacts patent laws.
1812	Russia enacts patent laws.
1815	Prussia enacts patent laws.
1817	Belgium and the Netherlands enact patent laws.
1820	Spain enacts patent laws.
1825	Bavaria enacts patent laws.
1826	Sardinia enacts patent laws.
1829	In Britain, Select Parliamentary Committees explore proposals for reforms of the patent system.
1834	Sweden enacts patent laws.
1836	Württenberg enacts patent laws.
	U.S. adopts the system of patent examination that is still in use today.
1843	Saxony enacts patent laws.
1851	Crystal Palace Exhibition in London, England
1852	The British Parliament approves the Patent Law Amendment Act.
	The Amendment establishes a renewal system, and lowers patenting costs.
1855-1873	Patent Controversy
1869	Netherlands abolish all patent laws
1871	Harmonization of German patent laws
1876	U.S. Centennial Exhibition in Philadelphia

TABLE 3 – COUNTRY CHARACTERISTICS

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

Sources: *Annuaire Statistique* (1916), Coryton (1855), Lerner (2000), and Maddison (1995). Patent length measures the maximal duration of a patent grant. Population and GDP data are from Maddison (1995), except for Switzerland and the German states in 1851. Maddison's GDP data are expressed in million 1990 Geary-Khamis dollars. Population data for Bavaria, Prussia, Saxony, and Württenberg are drawn from the Annuaire Statistique (1916). GDP data for the German states in 1851 are calculated by multiplying population by the value of Germany's GDP per capita as reported in Maddison (1995). Swiss GDP in 1850 is calculated as Swiss GDP in 1870 minus 20/29 times the increase in GDP between 1870 and 1899. 1870 and 1899 are the earliest years for which Maddison (1995) has Swiss GDP data.

TABLE 4 – NEGATIVE BINOMIAL REGRESSIONS OF EXHIBITS ON COUNTRY CHARACTERISTICS

	Total Exhibits				"Award" Exhibits	
	[1]	[2]	[3]	[4]	[5]	[6]
No Patent Laws	-1.78*** (0.56)	-0.23 (0.41)	-1.28 (0.44)	-0.43 (0.34)	-1.86*** (0.99)	0.20 (0.86)
Short Patent Grants	-1.34*** (0.63)	0.16 (0.45)	-0.84 (0.50)	-0.28 (0.48)		
Population (in log form)		0.98*** (0.16)		0.73*** (0.14)		1.06*** (0.25)
GDP Per Capita				-0.36 (0.32)		0.01 (1.03)
Host Country			2.36*** (0.80)	2.04*** (0.61)		1.09 (1.12)
Crystal Palace				-0.48 (0.41)		
Constant	6.97*** (0.26)	-2.33*** (1.45)	6.47*** (0.21)	0.75 (1.47)	6.03*** (0.41)	-4.17 (2.72)
α	0.98	0.41	0.60	0.25	1.65	0.45
LR test	8.36***	30.92***	21.36***	42.83***	2.15	21.33***
Log-Likelihood	-164.20	-152.92	-157.70	-146.96	-79.56	-69.98

Notes: "No patent laws", "short patent grants", "host country", and "Crystal Palace" are dummy variables. Short patents are defined as patent lengths below 10 years. In the regressions of the total number of exhibits on country characteristics I use negative binomial regressions instead of ordinary least squares because the data for the dependent variable "numbers of exhibits" are counts and these counts are skewed to the left. I use negative binomial instead of Poisson regressions because the data are overdispersed: log-likelihood ratio tests in the second to last row attest that variances are greater than means. (In the Poisson regression model the dependent variable y_i has mean *and* variance $\mu_i = \exp(x_i'\beta)$. The negative binomial model generalizes the variance function to $V[y_i|x_i] = \mu_i + \alpha\mu_i$, where the parameter α measures dispersion around the mean.)

TABLE 5 – MULTINOMIAL LOGIT REGRESSIONS

	With GDP per capita		Without GDP per capita	
	Coefficient	Standard Error	Coefficient	Standard Error
Mining and Minerals				
No patent laws	-0.7718	0.4104	-0.7587	0.4087
Short patent grants	1.6885	0.1874	1.3475	0.1809
Population in log form	-0.0923	0.0552	0.0919	0.0487
GDP per capita	0.8013	0.0976	-	-
Crystal Palace	0.1665	0.1066	-0.2274	0.0907
Constant	-2.5735	0.5005	-2.3110	0.4919
Chemicals				
No patent laws	0.3839	0.2666	0.4224	0.2662
Short patent grants	0.4665	0.2063	0.4342	0.2024
Population in log form	0.0612	0.0618	0.0769	0.0591
GDP per capita	0.0837	0.1002	-	-
Crystal Palace	-1.5504	0.1034	-1.5854	0.0938
Constant	-1.8051	0.5947	-1.7533	0.5924
Food Preparations				
No patent laws	1.3500	0.1859	1.3236	0.1864
Short patent grants	0.3808	0.1717	0.5251	0.1687
Population in log form	0.1155	0.0515	0.0556	0.0498
GDP per capita	-0.3603	0.0870	-	-
Crystal Palace	-2.0171	0.0887	-1.8623	0.0806
Constant	-0.7475	0.4990	-1.0358	0.4995
Machinery				
No patent laws	1.4138	0.1976	1.3793	0.1936
Short patent grants	1.6671	0.1753	1.2102	0.1697
Population in log form	0.3308	0.0461	0.5096	0.0419
GDP per capita	0.8978	0.0675	-	-
Crystal Palace	0.3704	0.0758	-0.0963	0.0647
Constant	-6.2159	0.4477	-5.6199	0.4278
Scientific Instruments				
No patent laws	2.2937	0.1733	2.3246	0.1733
Short patent grants	0.2200	0.2294	0.2895	0.2275
Population in log form	0.2494	0.0486	0.2198	0.0464
GDP per capita	-0.1581	0.0793	-	-
Crystal Palace	-0.1272	0.0882	-0.0500	0.0793
Constant	-3.3149	0.4689	-3.4223	0.4719
Textiles				
No patent laws	0.9218	0.1426	0.9640	0.1422
Short patent grants	-0.4523	0.1549	-0.3633	0.1536
Population in log form	-0.0362	0.0295	-0.0889	0.0271
GDP per capita	-0.2458	0.0575	-	-
Crystal Palace	-0.0457	0.0616	0.0672	0.0564
Constant	0.8520	0.2723	0.7675	0.2729
Exhibits	14,935		14,935	
Countries	22		22	
Countries*Industries	154		154	
Log-likelihood	-24,560.13		-24,772.18	

TABLE 6 – PREDICTED VALUES

	Patent Laws 1851 and 1876		Patent Laws 1851 only		Patent Laws 1876 only	
	No	Yes	No	Yes	No	Yes
Mining and Minerals	1.2% (0.0045)	7.6% (0.0469)	1.1% (0.0057)	5.8% (0.0168)	1.3% (0.0038)	9.7% (0.0546)
Chemicals	3.4% (0.0210)	5.5% (0.0359)	1.0% (0.0017)	2.7% (0.0032)	5.6% (0.0059)	9.5% (0.0075)
Food Processing	13.5% (0.0837)	9.1% (0.0687)	1.8% (0.0051)	4.0% (0.0073)	24.3% (0.0216)	15.8% (0.0351)
Machinery	10.0% (0.0492)	11.1% (0.0647)	10.5% (0.0554)	8.0% (0.0527)	12.0% (0.0343)	13.9% (0.0510)
Scientific Instruments	22.7% (0.0254)	6.9% (0.0169)	28.6% (0.0027)	7.3% (0.0131)	18.5% (0.0122)	6.2% (0.0184)
Textiles	36.4% (0.0983)	30.0% (0.1037)	39.6% (0.0540)	38.0% (0.0474)	29.6% (0.0124)	20.6% (0.0591)
Other Manufactures	12.9% (0.0186)	29.7% (0.0605)	17.4% (0.0024)	34.1% (0.0129)	8.7% (0.0022)	24.3% (0.0367)

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 A2 reports the values for multinomial coefficients α_i, and β_i.

TABLE 7 – SHARES OF ENGLISH EXHIBITS THAT REFER TO PATENTS IN 1851

Industry Class	Patenting Rates
Mining	4.81%
Chemicals	11.84%
Food Processing	9.68%
Scientific Instruments	8.63%
Machinery	22.48%
Engines, railways and marine mechanism	28.57%
Manufacturing machines and tools	38.67%
Civil engineering and architecture	14.57%
Naval architecture and military engineering	15.54%
Machines and processes in agriculture	23.44%
Manufactures	12.02%
Textiles	8.23%
Total	12.61%

Notes: Patenting rates are calculated by dividing references to patents by the total number of exhibits in an industry. To ensure comparability, this information is based on data from England only.