Preliminary
Comments much appreciated
April 19, 2007

What do Inventors Patent?*

Petra Moser
Stanford and NBER

Legal disputes, such as the Blackberry case, suggest that patent rights may become vital to the economic survival of even the most successful innovations. Although it is obvious that inventors do not choose to patent all their innovations, what or why they patent is poorly understood. This paper introduces a new data set of more than 7,000 American and British innovations at three world's fairs between 1851 and 1915 to examine the patenting decisions of inventors. Exhibition data offer many benefits: they include innovations with and without patents, cover innovations across industries and across countries, and provide measures of the quality of innovations. Such data suggest that technological characteristics – whether innovations can be reverse-engineered – are the key determinant of inventors' patenting decisions. Across industries, shares of patented innovation range from 5 percent for metallurgy and 7 percent for chemicals to 30 percent for manufacturing machinery. In contrast, patenting rates are almost identical across rural and urban areas, across quality levels, and, perhaps most surprisingly, across patent systems. A comparison of chemical innovations over time reveals that patenting increased in response to improvements in scientific research tools which facilitated reverse-engineering.

* I wish to thank Ran Abramitzky, Tim Bresnahan, and Peter Temin, as well as seminar participants at Berkeley, Boulder, MIT, Pisa, Stanford, Texas Law, and UCLA for helpful comments and the Hoover Institution at Stanford for generous financial support through the National Fellows Program. Jon Casto, Alessandra Voena, Anne Yeung and Mimi Xue provided excellent research assistance.

Legal disputes, such as the Blackberry case, suggest that patent rights may become vital to the economic survival of even the most successful innovations. Although it is obvious that inventors do not choose to patent all their innovations, what or why they patent is poorly understood. This paper introduces a new data set of more than 7,000 American and British innovations at three world's fairs between 1851 and 1915 to examine the patenting decisions of inventors. Exhibition data offer many benefits; they include innovations with and without patents, cover innovations across industries and across countries, and provide measures of the quality of innovations. Such data suggest that technological characteristics – whether innovations can be reverse-engineered – are the key determinant of inventors' patenting decisions. Across industries, shares of patented innovation range from 5 percent for metallurgy and 7 percent for chemicals to 30 percent for manufacturing machinery. In contrast, patenting rates are almost identical across rural and urban areas, across quality levels, and, perhaps most surprisingly, across patent systems. A comparison of chemical innovations over time reveals that patenting increased in response to improvements in scientific research tools which facilitated reverse-engineering.

Inventors may choose not to patent if they believe that alternative mechanisms, such as secrecy, protect intellectual property more effectively. In fact, surveys of Swiss inventors in the 1880s and of U.S. manufacturing labs in 1983 and 1994 indicate that most inventors prefer secrecy to patenting (*Procès verbal*, 1883; Levin, Klevorick, Nelson, and Winter, 1987; Cohen, Nelson, and Walsh, 2000). Such surveys also reveal significant differences in attitudes towards patenting across industries. Among 19th-century inventors, chemists and dyers tended to oppose patenting, while inventors of machinery appeared to favor patents.

This paper proposes that technology-driven variation in the relative effectiveness of secrecy and patenting may be the key determinant of patenting: Patents create relatively safe property rights for a finite number of years, while secrecy offers risky protection without a finite deadline. The effectiveness of secrecy (relative to patents) varies with the nature of technologies: Secrecy carries smaller risky for innovations that are difficult to reverse-engineer, such as bright-blue dyes and sugar-laden carbonated drinks. Secrecy, however, carries high risks of discovery for technologies whose twist is copied easily, such as Cyrus MacCormick's grain reaper or the lockstitch for a sewing machine. While the effectiveness of secrecy varies with the technological characteristics of innovations, patenting is more uniformly effective across technologies. This paper argues that profit-maximizing inventors weigh the risks and benefits of patenting and secrecy, and choose to patent if the secure payoffs for the duration of the patent exceed the risky payoffs from secrecy. This implies that patenting rates should be high in industries where it is easy to reverse-engineer, but low in industries where this is difficult. If scientific progress yields new tools of analysis that facilitate reverse-engineering, patenting rates should increase.

Nineteenth-century exhibition data create a unique opportunity to examine patenting decisions across industries. As a complement to existing sources, exhibition data offer many advantages; most importantly, they include innovations with and without patents. Moreover, exhibition data cover innovations across all industries, from mining and metallurgy to chemicals, to engines, manufacturing machinery, textiles, and scientific instruments. Finally, exhibition data include measures for the quality of innovations. Jurors assigned awards to the most novel and useful inventions; these awards provide a relatively straightforward measure for quality.

Exhibition data reveal that patenting rates varied strongly across industries, and that patenting was most frequent in industries where innovations could be copied. The overall share of patented innovations was surprisingly small, with 11 percent of British exhibits in 1851.

Across industries, patenting rates varied from 5 percent in chemicals to 30 percent in manufacturing machinery. Inventors were slightly more likely to patent high-quality innovations; close to 16 percent of award-winning British innovations were protected by patent grants. But high-quality innovations followed the same patterns of patenting across industries: they were most likely to be patented in machinery, especially in manufacturing machinery, and less likely to be patented in chemicals.

Variation in the use of patents across industries turns out to be surprisingly robust to significant differences in patent laws.[1] On average, U.S. inventors were slightly more likely to patent their inventions; 15.5 percent of U.S. innovations were patented, compared with 11 percent of British innovations. Similar to British inventors, however, American inventors chose to patent innovations in machinery, especially in manufacturing machinery and engines (44 percent), but not in chemicals (3 percent). In the United States, as in Britain, urban inventors were only slightly more likely to patent innovations.

The data also suggest that scientific progress raise inventors propensity to patent. In 1851, chemicals inventions, such as alum, potash, or naphthalene, along with many dyes including indigo, madder, and Turkey red, were easy to protect by secrecy, because they were almost impossible to reverse-engineer. Exhibition data from the Crystal Palace show that chemicals innovations were rarely patented in 1851. Eighteen years later, Dimitri Mendeleyev's structuring of the elements in the periodic table changed the nature of chemical invention and set in motion a "second scientific revolution" (Haber 1958). As a new tool for chemical research, the periodic table facilitated chemical analysis and thereby reverse-engineering. Once chemical

[1] The mid-19th century offers a unique opportunity to explore the effects of patent laws on patenting. In most countries, an initial set of patent laws, which had been adopted relatively *ad hoc* was still in place. Cross-country differences in patent laws were larger than at any other time, and, prior to the Paris *Convention for the Protection of Industrial Property* in March 1883, patenting abroad was prohibitively expensive, so that inventors depended almost exclusively on domestic patents (Coryton, 1855; Godson, 1840; Penrose, 1951).

researchers had learned to use it the chemical industry transformed into the most patent-friendly industry of the 20th century.

The remainder of this paper is structured as follows. Section I presents a simple formalization of an inventor's choice between patenting and secrecy. Section II introduces the exhibition data, describes the data's main benefits and examines potential sources of bias. Section III presents evidence on differences in patenting rates across industries, across quality levels, between Britain and the United States, and across rural and urban areas, and examines these differences in logit and OLS regressions. Section IV concludes.

I. A Simple Model of Patenting Decisions

Inventors' first chose whether to invest in R&D, and then, if their research is successful, decide whether to patent or not. Inventors invest in R&D if expected profits exceed the costs of R&D

$$(1)\ \ \theta\Pi \geq C^{\mathrm{R\&D}}, \text{ where } \theta \in (0,1)$$

Π denotes expected profits, the appropriability parameter θ measures the share of profits that benefit the inventor, and $C^{R\&D}$ denotes the costs of R&D. The non-exclusive nature of information prevents inventors from appropriating 100 percent of profits (Arrow 1962); θ is therefore typically smaller than one, though it may be very close to one.[2]

This paper focuses on the second stage of the decision process, an inventor's choice between patenting and alternative ways to protect their intellectual property. In the simplest

[2] In a model where patenting is the only mechanism to protect intellectual property, the first stage of this project could be modeled as a patent race. Patent races, may, however, not be the best way to think about competition if inventors use alternative mechanisms to protect intellectual property. If secrecy is just as effective as patenting, one or all of the inventors in a patent race may decide not to patent, and, if an inventor patents, the race between two innovations may continue after a patent is issued.

case, inventors choose between patenting and secrecy, where θ^p represents appropriability through patenting and θ^s appropriability through secrecy.[3]

The key assumption for this project is that that the effectiveness of secrecy θ_i^s depends on the technological characteristics of innovations, which vary across industries *i*. Innovations that are easy to reverse-engineer, such as improvements in manufacturing machinery, may be impossible to protect by secrecy, because they are too easy to copy; in contrast, innovations that are difficult to reverse-engineer, such as dyes, can be effectively protected by secrecy. In comparison to secrecy, protection through patents is less dependent on technological characteristics and therefore more uniform across industries; to reflect this θ^p is assumed to be constant across industries. The parameter Δ_i measures the difference between legal appropriability through patents θ^p and technologically determined "natural" appropriability through secrecy θ_i^s.

Inventors choose patenting if payoffs with patent protection up to period T (when the patent expires) exceed the payoffs with secrecy and the cost of patenting $\boldsymbol{C}^p$. Patenting costs include patent fees, attorney fees, and the cost of searching prior patents. Inventors incur none of these expenditures if they chose not to patent; secrecy therefore carries no costs beyond the risk of imitation. Total profits Π_i consist of discounted per period profits $\delta^t\pi_i$, where π_i varies across industries, and, for simplicity, is assumed to be constant over time. Then, inventors choose to patent if

$$(2)\ \sum_{t=0}^{T}\theta^p\,\delta^t\pi_i - \boldsymbol{C}^p \geq \sum_{t=0}^{T}\theta_i^s\,\delta^t\pi_i \text{ or}$$

[3] If patenting and secrecy can be used as complements, the appropriability parameter θ can alternatively be presented as the sum of θ^p (appropriability through patenting) and θ^s (appropriability through alternative mechanisms, such as secrecy): $\theta^p + \theta^s = \theta$, such that $\theta \in (0,1)$.

$$\Delta_i \pi_i \sum_{t=0}^{T} \delta^t - \boldsymbol{C}^p \geq \boldsymbol{0}$$

Equation (2) illustrates the main hypotheses: Across industries, inventors are more likely to patent innovations in industries where patenting is effective relative to secrecy. Over time, scientific advances that improve tools of analysis and facilitate reverse-engineering encourage patenting as they lower the effectiveness of secrecy.[4]

A. Effects of the Quality of Innovations, Patent Laws, and Urbanization

While this paper focuses on technological determinants of patenting, previous literature has focused on non-technological explanations: the quality of innovations, the location of inventors in urban areas, and the quality of patent systems. These factors can be examined in terms of equation (2).

The first hypothesis is that inventors might be more likely to patent high-quality innovations, because such innovations promise higher revenues. Equation (2) implies that an increase in the quality of innovations, which raises revenue π_i will amplify the effects of Δ_i on patenting. This suggests that differences in patenting across industries should be more pronounced for high-quality innovations.

Second, inventors may be more likely to choose patenting, if they live in a country with strong patent laws. Strong laws have two effects: they lower the costs of patenting C^p and

[4] Although secrecy is riskier in any given period, it may outlast a patent grant by k years. Then secrecy yields additional benefits (compared to patents) for k years after the patent expires in year T of $\sum_{t=T+1}^{T+k} \theta_i^s \delta^t \pi$. This term, however, is likely to be small and have little effect on patenting decision in period 0. For example, patent renewal data reveal that few patents are renewed after their expiration data (Schankerman and Pakes 1986) which suggests that k is small. Moreover, any remaining profits after period T will be heavily discounted.

increase the effectiveness of patenting θ^p relative to secrecy, thereby increasing Δ_i. Both channel encourage patenting across industries.

Finally, urban inventors may be more likely to patent than rural inventors. Inventors in cities may patent more because they are surrounded by competitors who could copy their ideas (Mokyr 1995). In terms of equation (2) this implies a lower θ_i^s for urban inventors, which increases Δ_i across industries. Case studies of British machinery inventions also suggest that urban inventors may be more likely to patent because they are more familiar with the patent system (MacLeod 1988); this would lower patenting costs C^p and increase patenting across all industries.[5]

C. Anecdotal Evidence on Secrecy and Patenting

A wealth of anecdotal evidence suggests that secrecy is more effective in some industries than others. On one end of the spectrum, secrecy does not appear to provide much protection: Biographies of 19th-century inventors of machinery include countless examples of inventions that were lost to imitators. Thomas Hancock "masticator", a machine used in the manufacture of rubber, illustrates the risks of secrecy. In 1820, Hancock invented this cylinder studded with sharp teeth to gnaw up rubber scraps from glove and suspender manufacturing. To keep his invention secret, Hancock code-named it the "pickle" and committed his workers to an oath of silence. Yet, the secret was revealed in 1832, and the masticator was copied almost immediately,

[5] Another issue that has been brought up in the literature is that process innovations may be less suitable to patent protection than product innovations (e.g, Cohen, Nelson, and Walsh 2000, p. 8). As a first test, I separate product innovations in chemicals, from methods for producing these chemicals for the American Centennial data. Specifically, I compare the innovations that inventors exhibited with the patents that protected them. Contrary to the view in the literature, these data suggest that inventors were significantly more likely to patent the processes that produced a chemical product, than the product itself. Seventy-five percent of all American chemical innovations that were patented between 1856 and 1896 (and exhibited in 1876) were protected by patents on chemical processes. This finding may be a reflection of the exceptional suitability of chemicals to secrecy and should not be interpreted to imply that products are more suitable to patenting than processes across industries. It does, however, suggest that technological characteristics at the levels of industries play an equally important role.

quickly dispersing Hancock's profits (Dragon, 1995, p. 222; Korman, 2002, pp. 26, 127-128). Once they had copied an invention and improved it, many imitators decided to seek patents. American mechanics visited English factories to study innovations in textile and paper-making machinery, and patented copies and improvements of these innovations when they returned to the United States (Wallace 1972, p.217). In 1850, Isaac Singer copied a sewing machine that Lerow and Blodgett had developed; it took Singer only eleven days to reverse-engineer the machine. Protected by patents, Singer's sewing machine became one of the 19th century most successful innovations (Scott, 1880, p. 8; Fenster, 1994, pp. 46-50; Cooper, 1968, pp. 13 and 42).

On the opposite extreme, inventors could safely rely on secrecy if their inventions were impossible to reverse-engineer. In the mid 19th century, chemicals and dyes proved particularly elusive, because their production process was obscure. Turkey red, for example, was produced by boiling yarn with alkali; steeping it in rancid oil, soda, and sheep dung; mordanting with alum and sumac; dyeing in a batch of madder, ox blood, and chalk; and finally washing to brighten the color (*Archive of the Society of Dyers and Colourists*, 2004). Indigo, which had been known the 2nd century, took more than 1,600 years to imitate. Burial offerings of indigo-colored clothing for wealthy Roman settlers were worth their weight in gold; many tried to duplicate this color, but it took until 1878 when von Bayer managed to synthesize it. Other 19th-century chemicals, such as alum, potash, naphthalene, quinine, caffeine, and tannin proved equally robust to analysis and imitation.

Such narratives suggest that secrecy offered better protection for chemicals than for machinery. The following section introduces the exhibition data, which make it possible to analyze the effects of such differences on patenting decisions.

II. The Data

An ideal data set to study patenting decisions would capture both innovations with and without patents. Patent data, however, as the traditional proxy for innovations, can only measure innovations that are patented and provide little information on other types of innovations.[6]

The data should also measure innovation across industries. This is particularly important for examining the effects of technological characteristics. By necessity, however, patent counts have to omit innovations in some industries. First, patents are classified by functional principles and many functional include innovations from a broad range of industries. For instance, the functional class "dispensing liquids" includes holy water dispensers along with water pistols, while "dispensing solids" groups tooth paste tubes with manure spreaders (Schmookler 1972, p. 88). As a result, patent data exclude important innovations such as power plant inventions and electric motors, because they cannot be assigned to a specific industry (Schmookler 1972, p. 89). Second, patent laws often restrict patenting in certain industries. In Britain, for example, the government excluded chemicals from patenting from 1919 to 1949 and restricted the patenting of military technologies throughout the 19th century (Davenport 1979, Khan 2005, p. 36-7).

Another requirement for a useful data set is that it should measure innovation independently of variations in patent laws. Without such data, the real effects of differences in patent laws are difficult to disentangle from changes in measurement. Patent data, however, are strongly dependent on the characteristics of individual patent systems. Nineteenth-century patents measures different things across industries: In the United States only "first and true" inventors were allowed, while other countries, including Britain, granted patents to the first importer (Coryton, 1855, pp. 235-264).

[6] In addition to missing innovations that are not patented, patents also appear to include many inventions that never became commercially useful (Dutton, 1984, pp. 6-7; Griliches, 1990, p. 1669). Firm-level surveys suggest that 5 to 20 percent of patents become economically viable (Meinhardt 1946, p. 256).

Finally, the data should measure the quality of innovations. This is crucial for patented inventions which vary greatly in their quality (Griliches 1990, p. 1669, Dutton, 1984, pp. 6-7). For example, patent counts assign equal weight to U.S. Patent No. 8,294, Singer's "Improvement of the Sewing Machine" (U.S. patent No. 8,294 and No. 8,295, Francis Wilbar's improvement in roof construction. By 1880, Singer's "Sewing Machine modestly hides itself away beneath the three million of the nine million roofs of America" (Scott 1880, p. 6), but Wilbur's roof was rarely used. The quality of a patent can be measured by the number and the diversity of later patents that cite this patent (Trajtenberg 1990). If, however, only a portion of inventions are patented, citation data may underestimate the quality of innovations. Moreover, to the extent that patenting rates vary across industries, citations may underestimate the quality of innovations in industries that rely on alternative mechanisms to protect intellectual property.

Exhibition data can address many of these issues, and, as a complement to patent data, help to construct a more complete data set on innovation.

A. Benefits of the Exhibition Data

Most importantly, exhibition data measure innovations with and without patents. Exhibition data measure *innovations*—commercially viable new or improved products and processes—rather than *inventions*—conceptions of such products and processes. Exhibition data are comparable across countries; they capture innovations across all industries, and they include awards that distinguish high-quality exhibits.

Exhibition data are drawn from the records of two 19th-century world's fairs, the Crystal Palace Exhibition in London in 1851, the American Centennial Exhibition in Philadelphia in 1876, and the Panama-Pacific International Exposition in San Francisco in 1915. The Crystal

Palace Fair was named after a 1,848-feet long glass house, whose architecture of cast iron and steel revolutionized building design (Frampton 1983, p. 11). In 1851, the Crystal Palace was the largest enclosed space on earth; its exhibition halls covered 772,784 square feet, an area six times that of St. Paul's Cathedral in London, and housed a total of 17,062 exhibitors from 25 countries and 15 colonies (*Bericht* III 1853, p. 674; Kretschmer, 1999 p. 101). In 1876, exhibitors would walk 22 miles to see the six largest halls of the U.S. Centennial Exhibition; 30,864 exhibitors from 35 countries displayed their innovations there (Kroker, 1975, p. 146). In 1915, the entire Marina and Presidio area of San Francisco was converted to a fair ground, which welcomed 30,000 exhibits from 32 countries. In 1851, London had less than two million inhabitants; at the same time, the Crystal Palace fair attracted more than six million visitors (Evelyn Kroker, 1975 p. 146). In 1876, almost ten million people attended the Centennial Exhibition; 19 million visitors attended the Panama-Pacific Exposition.

From the catalogues that guided visitors through these fair, and the reports of national commissions, I have collected detailed data for more than 7,000 exhibits including brief descriptions of each innovation, its geographic location, its industry of use, the exhibitors' name, patent status, and whether the exhibit received an award for exceptional inventiveness.

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

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

This exhibit is classified in the Crystal Palace industry class number 9, "Agricultural and Horticultural Machines and Implements". There are a total of 30 industry categories; they span the entire spectrum of production, from mining and chemicals to engines, manufacturing machinery, and scientific instruments. I have classified all 6,377 British and 544 American entries in the *Official Catalogue* into the 30 classes.[7]

A few examples of British and American exhibits may help to illustrate the data. Among the British exhibits of manufacturing machinery, visitors to the Crystal Palace found a new "machine for setting the teeth of saws" (exhibit 242, G. Vaughn, Marylebone) and a "curvilinear sawing machine for ships' timbers…" (exhibit 417, C.M. Barker, London). Among chemicals exhibits, they saw "Colours produced by the combination of fatty acids with metallic oxides and peroxides" (exhibit 78, C. Humfrey, Southwark), "samples of ultramarine", "refined Indian blue", and a "newly invented black dye, particularly recommended for silk" (exhibits 69, C. Lee, London). Exhibits in food processing were akin to recipes, including the first version of the meat biscuit (a vile predecessor of the *PowerBar*), but also more palatable attempts at producing milk chocolate, bouillons, and infant formula. Exhibits included "preserved provisions" for military and scientific expeditions (exhibit 12, J.H. Gamble, London) and methods of food preservations for household use, such as "meats, preserved without the use of salt" (exhibit 23, G.H. Underwood, Pendleton, Manchester) and "tart fruits, jams, jellies, &c. hermetically sealed, which retain for years their flavour and quality" (exhibit 11, Copland, Barnes, & Co., Eastcheap). Improvements in crops, such as J. Sutton's "purple-topped yellow hybrid turnip, valuable for late sowing…" (exhibit 112, Reading) and T. Fordham's "samples of improved white wheat, weigh 66 lbs per bushel and prolific beans" (exhibit 94, Snelsmore Hill East), were also covered in this class. British innovations in scientific instruments included optical and medical devices (such as false teeth and a metal corset for curing scoliosis), marine clocks, improvements in the accuracy of pocket watches, barometers, and theodolites. Exhibits in manufactures ranged from hats and

[7] American inventors contributed 549 exhibits to the Crystal Palace fair. I exclude five exhibits because they were American expatriates in London. I also exclude all exhibits in the Crystal Palace class "art", which includes drawings, paintings, sculptures, and the many water fountains that served to cool the exhibition buildings.

buttons, which had just begun to be mass produced, to finished metal products, such as A. Horton's "Locks on a new principle, applicable for all doors and gates" (exhibit 674, Ashburton) or E. Cotterill's "patent climax detector locks" (exhibit 307, Ashted, near Birmingham) and R.A. Savage's "alarm bedstead and bedsteads for invalids" (exhibit 56, 15 St. James' Sq., London).

American exhibits at the Crystal Palace included S.C. Blodgett's sewing machines (exhibit 551, New York) in the section for manufacturing machinery, as well as power-loom lathes from the machine shops at Lowell, Massachusetts (447, Lowell Machine Shop, Lowell). The class agricultural machinery, displayed Cyrus McCormick's "Virginia grain reaper", as one of the highlights of the Crystal Palace exhibition (U.S. exhibit 73). Among the military innovations visitors could admire Samuel Colt's revolving cylinder handgun, the "revolver" (exhibit 321, Hartford, Connecticut). All of these innovations in machinery were protected by patents.

Uniform rules of selection ensured that exhibits were comparable across countries and across rural and urban regions. All exhibits were chosen according to "novelty and usefulness". National commissions nominated local representatives to choose exhibits, and double-checked their choices (*Bericht*, 1853 pp. 40, 64). Britain, for example, nominated 65 local commissions to identify exhibits for the Crystal Palace. Each of these commissions established several collection points. To avoid biases through transportation costs, exhibitors were only required to cover transportation costs to the nearest local collection point. Inventors submitted a written application to their local commission, which specified "what is novel and important about the product, how its production shows special skillfulness and proves an original approach" (*Bericht,* 1853 pp. 50, 117). At both the national and the local level, a comprehensive system of evaluation helped to enforce these selection criteria.

B. Identifying Patented Innovations

Patented innovations are identified by matching exhibits at the world's fairs with their patent records. For the Crystal Palace fair in 1851, I have matched all 549 U.S. exhibits with U.S. patents granted between 1841 and 1851 (*Annual Report of the United States Patent Office,* 1841 - 1851). For two later fairs, the American Centennial Exhibition in Philadelphia in 1876, and the Panama-Pacific International Exhibition in San Francisco in 1915, I focus on two industries: one where narrative evidence suggests that secrecy is highly effective – chemicals – and another where narrative evidence suggests that secrecy is ineffective – manufacturing machinery. For these two industries, I have matched all exhibits to their patent records. This process yields 139 innovations chemical and 74 in manufacturing machinery for 1876, and 90 innovations in chemicals and more than 90 innovations in manufacturing machinery for 1915.

Exhibitors are matched by first name, last name, address, and the descriptions of their innovations. For example, the following entries are counted as a match:

U.S. exhibit 23; Otis, B.H.; Cincinnati, Ohio; Boring and mortising machine

and

U.S. patent No. 4387; Otis, Benjamin H.; Dedham, Mass; Mortising machine; granted Feb. 20, 1846

This procedure may overestimate the true share of patented innovations: To be defined as a match, an exhibitor and a patentee must have the same last name, and the patent must be related to the exhibit, though it need not be the same invention. For example, U.S. exhibit 524, G. Borden's meat biscuit is matched with Gail Borden's patent for the "preparation of portable soup-bread," a process to preserve the nutrients of meat and vegetables in a bread-like substance (*United States Patent No. 7,066*, granted on February 5, 1850).[8] If exhibits and patents are not identical, this matching procedure may overestimate patenting.

For British exhibits at the Crystal Palace, patented innovations can be identified from the short descriptions in the exhibition catalogues. For example, J. Bendall's "universal self-adjusting cultivator … pat." denotes a patent. Patenting rates are constructed by dividing the number of exhibits that report a patent by the total number of exhibits. Exhibitors had strong incentives to report their patents truthfully: On the one hand, patents may have served as a signal of high-quality (MacLeod 1988, p. 85), which encouraged exhibitors to report all patents that they owned. On the other hand, jurors carefully checked all exhibits; this implied that exhibitors who claimed false patents faced a real risk of discovery.

C. High-quality Innovations

Awards to the most innovative exhibits provide a measure for the quality of innovations. International panels of six to twelve industry experts, professors, business people, and other practitioners (including famous contemporaries like Hector Berlioz) ranked all exhibits according to their "novelty and usefulness" (*Bericht* 1853, pp. 37, 90). At the Crystal Palace Exhibition, juries awarded Council Medals, equivalent to gold medals, to 1 percent of all exhibits, Prize (or silver) Medals to 18 percent, and Honorable Mentions to 12 percent of all exhibits (*Bericht* 1853 p. 707; Haltern 1971 p. 155). I have recorded detailed information on 745 British and 112 American award-winners from the reports of the German Commission to the

---

[8] Google's new patent engine facilitates this process for 1876 and 1915 (www.google.com/patents). This is particularly helpful because the increase in the volume of U.S. patents after 1851 makes it almost impossible to manually match exhibits with patent records. Despite technological progress, I decide to match patents manually for the Crystal Palace: Google's search engine does currently not appear reliable for this early data, as some patents that we know to exist for the 1840s do not currently show up in a patent search. This is not a problem for the later years.

Crystal Palace (*Bericht*, 1853). Translated from the German original, a typical entry looks like this:

> Britain, industry class 18, exhibit 78, Mercer, John: Process of modifying cotton fibers through exposure to acidic alkali, which sets off remarkable changes in the physical and chemical characteristics of cotton fibers. Council Medal[9]

I have matched these records with entries in the British catalogues, based on each exhibit's number, its exhibitor's name, and the description of its innovation.

D. Urban Innovations

To test whether urbanization encourages patenting, I locate all exhibits on contemporary maps. In this process, historical maps such as the *Times Handy Atlas* are complemented with information in contemporary gazetteers like *Bartholomew's Gazetteer of the British Isles* (1887) and dictionaries of geographic place names, such as the *Getty Thesaurus of Geographic Place Names*. For example, the town of Woodbridge in the example above can be identified as a market town and parish in the county of Suffolk according to the *National Gazetteer of Great Britain and Ireland (1868)*.

By this process, I have identified registration counties for 4,688 innovations, 93 percent of all English exhibits in 1851 (Table 1 and Figure 1). Within the city of London, I have matched street addresses to registration districts for 2,297 innovations in London, 91 percent of the total innovations.[10] To enable geographic comparisons over time, I have also assigned 1,121

[9] The original reads "Prozess der Modifikation der Baumwollfaser durch ätzendes Alkali, wodurch die physischen und chemischen Eigenschaften derselben aus eine merkwürdige Weise verändert und verbessert werden."
[10] Exhibits whose location cannot be identified tend to originate from very small towns. For London, nearly all exhibits with a street address can be matched to districts using both http://mapquest.co.uk/ and 19th-century maps.

English exhibits at the American Centennial Exhibition in Philadelphia in 1876 to their registration counties.

E. Potential Sources of Bias

There are two potential sources of bias in the exhibition data. Most importantly, exhibition data may under-represent innovations that were protected by secrecy rather than patents, because exhibiting might increase the risk of discovery. Exhibitors, however, found ways to advertise their innovations without disclosing industrial secrets: they showed samples of output, rather than displaying the innovation itself. For example, Drewsen & Sons of Silkeborg, Jutland, exhibited "Specimens of paper, glazed by a machine constructed by the exhibitor", instead of the machine itself (see *Official Catalogue, First Edition*, 1851 p. 210). If, however, the exhibition data under-represent innovations that were protected by secrecy, they will overestimate the share of innovations that are patented and underestimate differences in patenting across industries.

Second, the data may underestimate large and heavy innovations that were too costly to transport to the fairs. Exhibition records suggest, however, that inventors avoided this problem by exhibiting models or blueprints of their innovations. For example, the suspension bridge that was being constructed across the Dnieper in Kiev was shown as a model at the Crystal Palace (Rolt 1970, p. 157). Forty-five percent of Britain's 194 British exhibits in the class Number 7, "Civil Engineering, Architecture, and Building Contrivances," were represented by models. To check for bias due to transportation costs, I compare the location of exhibits at the Crystal Palace with the locations of all 1,121 English exhibits at the Centennial Exhibition in Philadelphia in 1876. If transportation costs bias the data towards London, the City's share of innovations should be lower at the American fair when differences in transportation costs across England were negligible relative to total transportation costs. Yet, the Centennial data show that London's share of exhibits was almost identical at the American fair, with 49 percent in 1876 compared to 50 percent in 1851. The share of innovations from other large cities (defined as cities with more than 50,000 inhabitants) is similar as well, with 30 percent in 1851 and 32.0 percent in 1876. Rural innovations accounted for 19.9 percent in 1851 and 19.2 in 1876.

The data may also underestimate increases in shifts towards patenting over time, particularly in chemicals. Between 1851 and 1915, the share of companies increased from 15% percent of U.S. chemical exhibits in 1851, to 44% in 1876, and 85% in 1915. Companies are more difficult to match with specific patents, because patents are recorded by the name of individuals. Consider, for example, General Electric's exhibit at the Panama-Pacific Exhibition.

> "Vacuum and Gas-filled Lamps, Vacuum Furnace, Miscellaneous Laboratory Apparatus, Production and Purification of Argon and Nitrogen."

I can match this exhibit with several patents by General Electric on vacuum and gas-filled lamps, but not with an individual inventor.

The rising importance of large companies is also reflected in a trend towards assignments. Under the U.S. law, inventors have the option of assigning their patent to other individuals or firms. Patent data for a representative state suggest that this bias is negligible for the Crystal Palace exhibition. Only 1 in 454 patents in Connecticut had been assigned until 1851, less than 0.2 percent of all Connecticut patents (Figure 1).[11] Assignments did, however, become more common over time: By 1876, more than one third of all patents were assigned. I match exhibits with assignments as well as regular patents, but assignments may be harder to

[11] Connecticut is well suited as a representative state to collect the data because of its high economic and inventive activity in the 19th century. The data start in 1836 because a fire at the Patent Office destroyed all earlier patents.

identify if they are made to firms. If this process underestimate increases in patenting over time, the effects of scientific breakthroughs on patenting will be more difficult to detect.

III. Empirical Tests of Patenting across Industries

This section uses the exhibition data to test competing hypotheses about inventors' patenting decisions. Equation (2) implies that inventors are more likely to patent innovations, if patents are effective relative to secrecy (high Δ_i), and if innovations are highly profitable (high π_i). In terms of the industry examples above, this implies that machinery innovations should be more likely to be patented than chemicals and that award-winning innovations should be more likely to be patented than average exhibits. Equation (2) also suggests that technological characteristics which favor patenting over secrecy should have larger effects for innovations that are more profitable. In other words, differences in patenting rates across industries should be more pronounced for award-winning innovations. Finally, increases in the cost of patenting C^p should lower the probability of patenting regardless of relative appropriability Δ_i.

These predictions can be presented as a function of the variables π_i, Δ_i and C^p, where $I(.)$ is an indicator function and $y = 1$ if an inventor patents and 0 otherwise

$$(3)\ y = I\, f(\Delta_i, \pi_i, C^p) \geq 0, \textit{ where}$$

$$\frac{\delta f(\Delta,\pi)}{\delta\Delta} \geq 0, \frac{\delta f(\Delta,\pi)}{\delta\pi} \geq 0, and\ \frac{\partial^2 f(\Delta,\pi)}{\partial\pi\partial\Delta} \geq 0$$

To test these predictions, I examine patenting across industries, countries, quality levels, and locations. I compare crosstabs and analyze the data in linear probability and logit regressions for the entire data set and separately by industry. A linear approximation of equation (2) with a positive interaction term between profitability π_i and relative appropriability Δ_i yields the regression equation

$$(4)\ y = \alpha + \beta_1 \Delta_i + \beta_2 \pi_i + \beta_3 \Delta_i \pi_i - \beta_4 C^p$$

In regressions that include a complete set of industry dummies, manufactures serves as the omitted industry control. Regressions with the full data include dummies for one industry with extremely high and another with extremely low relative appropriability through patents Δ_i. Following the narrative evidence, I chose *chemicals* as an industry with low Δ_i (low effectiveness of patents relative to secrecy) and *manufacturing machinery* as an industry with high Δ_i (high effectiveness of patents relative to secrecy). Interaction terms between *high-quality* and industry dummies for *chemicals* and *manufacturing machinery* test whether increases in the quality of innovations amplify the effects of technological characteristics.

One problem with these regressions is that both appropriability and profitability vary across industries. To identify the effects of differences in profitability (while holding appropriability constant) I compare *high-quality* and average-quality innovations within the same industry. Consider two steam engines, for example, which would be roughly comparable in their technological suitability to patenting Δ_i. One of the engines is of average quality among the exhibits at the fair and does not win an award, while the other engine wins an award for exceptional "novelty and usefulness". The *high-quality* variable allows me to check which of these two inventions is (on average) more likely to be patented.[12]

[12] To measure the effects of variation in appropriability (at equal profitability), I would like to compare two types of innovations with different technological characteristics within the same industry. To perform this test, I will divide 1,679 British innovations in textiles at the Crystal Palace into three categories: dyeing, machinery, and other

A. Only Few Innovations are Patented

The first surprising result is that only a small share of innovations appears to have been patented. In 1851, only 11.1 percent of British innovations were patented (Table 2). The share of patented innovations is only slightly higher in the American data at 15.5 percent. This suggests that inventors relied much more heavily on alternative mechanisms than has been previously thought. The following paragraphs explore alternative hypotheses to identify what caused such low propensities to patent.

B. Patenting Rates Vary Significantly Across Industries

Exhibition data suggest that inventors' propensity to patent varies strongly across industries. Compared to an average of 11 percent, and a mean of 10 percent, patenting rates ranged from 5 percents in mining and metallurgy and in chemicals to almost 30 percent in manufacturing machinery (Table 3). Other industries with low patenting rates were textiles, (heavily focused on dye stuffs) with 7 percent, and food processing (including many exhibits that were akin to recipes) with 8 percent.

Production processes in all four of the industries with low patenting rates would have been easy to keep secret. Innovations in mining and metallurgy were heavily dependent on resource endowments, but they also included processes to make new and better-quality metals, that were difficult to reverse engineer. For example, it took English inventors many years to uncover the process of making steel that was fine and malleable enough to produce parts for watches that were as small as Swiss watches at the time.

---

innovations. Textiles are more suitable to this comparison than chemicals, because, prior to mass production, there are innovations in machinery innovations in the 19^{th} century chemical industry.

Regression results in Table 7 confirm pronounced inter-industry differences in patenting.[13] Marginal effects of logit regressions imply that the probability of being patented was between 12 and 13 percent higher for manufacturing machinery (Table 7 column IV, V, and VI). OLS regressions, as a crosscheck for the logit regressions, show an even larger effect, of 20 to 21 percent (Table 7, column I to III). Inventors of other types of machinery were also more likely to patent their inventions; the marginal effect on patenting measures 10 to 17 percent for engines, 8 to 14 percent for agricultural machinery, and 4 to 7 percent for innovations of civil, military and naval engineering (Table 7, columns I-VI).

In contrast, innovations in textiles and chemicals were significantly less likely to be patented. Marginal effects in Table 7 reveal that inventors were between 6 and 8 percent less likely to patent chemical innovations (compared to manufactures), and between 4 and 5 percent less likely to patent textiles. Coefficients for food processing and scientific instruments are negative but not statistically significant for the British data.

D. High-quality Innovations are More Likely to be Patented

Another prediction of the model is that more profitable innovations should be more likely to be patented. If this is true, award-winning innovations should be more likely to be patented than average exhibits: because they are more "novel and useful" than average exhibits, they will also, on average be more profitable.

Exhibition data confirm that award-winning innovations were more likely to be patented than innovations of average quality. In 1851, 15.8 percent of award-winning exhibits were patented, compared to 11.1 percent across exhibits (Table 4, bottom row). Coefficients on the *high-quality* variable in OLS and logit regressions confirm that inventors were more likely to

[13] Probit regressions yield similar results to logits in all specifications.

patent innovations of high-quality: The probability that a British exhibit in 1851 was patented was 7 to 9 percent higher for exhibits that won awards (Table 7, columns I to VI).

The data also show that inter-industry differences in patenting are robust to differences in quality: Inventors did and did not patent high-quality innovations in the same industries as average innovations. Innovations in mining and metallurgy have the lowest patenting rates for innovations of high- as well as average-quality, followed by chemicals and textiles. Manufacturing machinery is again the industry with the highest proportion of both high-quality and average-quality patented inventions, followed by agricultural machinery and engines.

Separating awards into gold, silver, and bronze yields further evidence that high-quality innovations were patented more frequently. Twenty-seven percent of exhibits that received gold medals were protected by patents (Table 4, bottom row), compared with 18 percent of exhibits that won silver and 10 percent of exhibits that won bronze.

C. Quality Amplifies the Effects of Technological Characteristics

The data make it possible to test another prediction of equation (2), that differences in profitability should amplify the effects of technological differences. If this is true, differences in patenting rates across industries should be more pronounced for award-winning innovations.

In patent-averse industries, high-quality innovations are more likely to be patented, but differences are fairly small. Among innovations in mining and metallurgy, 6 percent of high-quality innovations are patented, compared with 5 percent of average quality (Table 4). Among chemicals, 8 percent of award-winning exhibits are patented, compared to 5 percent of average quality. For textiles, patenting increases from 7 to 9 percent for high-quality innovations, and for food processing, patenting increases from 8 to 10 percent. The biggest difference among the more patent-averse industries occurs for scientific instruments, from 10 to 16 percent. These comparisons suggest that the effect of quality on patenting may be larger for innovations that already have some tendency to be patented, possibly based on their technological characteristics.

In industries that use patents more frequently, quality has a significant effect on patenting. In other words, increases in the quality of innovations appear to amplify inventors' propensity to patent, if technological differences favor patenting already. Almost 50 percent of award-winning innovations in manufacturing machinery were patented (compared with 30 percent of average quality), 40 percent of engines (compared with 25 percent), and 41 percent of agricultural machinery (compared with 20 percent).

Logit and OLS regressions confirm that cross-industry differences in patenting increase with the quality of innovations. Marginal coefficients in Table 8 suggest that award-winning innovations in manufacturing machinery were between 18 and 35 percent more likely to be patented (18 percent for logit regressions in columns IV to VI, and 35 percent for OLS regressions in column I to III, compared to 12 and 20 percent for innovations of average quality). Similarly, award-winning innovations in engines and agricultural machinery were more likely to be patented with marginal effects of 15 to 26 percent for engines, and 15 to 30 percent for agricultural machinery (compared with 10 to 12 percent for engines, and 8 to 11 percent for agricultural machinery of average quality). In textiles, the propensity to patent decreased by 10 to 12 percent for textiles (Table 8, columns I to VI) and by approximately 8 percent for chemicals (Table 8, columns II and III, OLS regressions only).

D. Large Differences in Patent Laws have Limited Effects

Finally, increases in the cost of patenting C^p should lower the probability of patenting regardless of relative appropriability Δ_i. The comparison between British and American innovations yields an approximate test for the effects of patent laws on patenting. In 1851, both countries had the same patent length T (14 years), but the costs of patenting C^p varied a great deal. In Britain, inventors paid up to $37,000 in patent fees, compared with only $618 in the United States (in 2000 US$, from Lerner, 2000). American inventors could mail their applications to the patent office, while British inventors faced a drawn-out and costly process. Jeremy Bentham (1843) describes a British patent application:

> "A new idea presents itself to some workman or artist…. He goes, with a joyful heart, to the public office to ask for his patent. But what does he encounter? Clerks, lawyers, and officers of state, who reap beforehand the fruits of his industry. This privilege is not given, but is, in fact sold for from £100 to £200–sums greater than he ever possessed in his life. He finds himself caught in a snare which the law, or rather extortion which has obtained the force of the law."[14]

Because differences in the costs of patenting were so large Britain and the United States, a comparison between the two countries might yield a reasonable test of the effects of patent laws: Many other factors could explain differences in patenting decisions between the two countries but if they look similar, it is unlikely that patent costs had much of an effect.

The small difference between overall patenting rates in Britain and the United States, already suggest that patent laws had a much smaller effect than would have been expected (15.5 percent in the United States versus 11.1 percent in Britain, Table 2). Although the U.S. patent system was significantly cheaper and more effective, American inventors in the mid 19th century do not appear to have taken advantage of it much more than British inventors.

[14] From the *Collected Works* of Jeremy Bentham (1843), cited in Coulter (1991, p.76). Charles Dickens' gives another vivid description in a "Poor Man's Tale of a Patent".

Moreover, American innovations appear to have been patented--and not patented--in the same industries. In industries that tended to avoid patents, the proportion of patented innovations was roughly equal in the United States and Britain: 3 percent of U.S. chemical innovations were patented (compared to 5 percent of British innovations, Table 5), 6 percent of textiles (compared to 7 percent), and 7 percent of innovations of food processing (compared to 8 percent).

Similar to quality differences, lower patent costs may, however, have amplified differences in patenting rates that resulted from technological differences. Exhibition data show that U.S. inventors were even more likely to patent machinery innovations than were British inventors. Exhibits of machinery, especially of manufacturing machinery and engines, were significantly more likely to be patented. Forty-four percent of American exhibits in manufacturing machinery were patented (compared to 30 percent of British exhibits), 43 percent of U.S. engines (compared to 25 of British engines), 37 percent of agricultural machinery (compared to 20 percent), and 36 percent of exhibits in military and naval engineering (compared to 12 percent).

Regressions for American innovations show that inter-industry differences are robust to controls for quality and urbanization. Innovations in manufacturing machinery were between 17 and 31 percent more likely to be patented (31 percent for OLS regressions in column I, 17 to 18 percent in columns V to VI of Table 9). Similarly, innovations in engines were between 18 and 30 percent more likely to be patented (30 percent in column I and 18 percent in columns V to VI, Table 9). Innovations in agricultural machinery had between 14 and 24 percent higher patenting rates. In contrast, exhibits in textiles and chemicals were less likely to be patented (between 10 and 12 percent for textiles, and approximately 10 percent for chemicals, Table 9, column I) although, due to the small number of observations, the effect is not statistically significant for chemicals.

Similar to British innovations, American innovations appear to be more likely if they are of high quality; innovations of high-quality have between 10 and 15 percent higher patenting rates than innovations of average-quality (15 percent for OLS and 10 to 12 percent for logit regressions).[15]

Exhibition data shed light on another hypothesis about the effects of patent laws: High costs of patenting are commonly assumed to favor patenting (and thereby R&D investments) in capital-intensive goods, such as manufacturing machinery or engines (e.g., Khan 2005, p.31). A comparison between exhibition data for the United States and Britain, however, suggests that U.S. inventors were even *more* likely to use patents than were British inventors, although patenting costs were much lower in the United States. This suggests that the effects of technological characteristics, and more specifically, a relatively strong need for patents in manufacturing machinery and engines, outweighed the potential effects of capital intensity.

E. (Some) Urban Inventors Patent More

Exhibition data also confirm the hypothesis that urban inventors patent more, though this effect is relatively small. In the British data, 13 percent of London's innovations were patented compared to 11 percent of innovations in the rest of England.[16] In the United States, 17 percent of innovations in Philadelphia and New York were patented, compared to 15 percent of innovations from towns with less than 1,000 people (Figure 2).

[15] With 113 award-winning innovations from the United States, the number of observation is too small to calculate logit regressions, and industry dummies for chemicals and engines are dropped. The strong positive effect on manufacturing machinery, however, remains robust in logit regressions of American innovations of high-quality.

[16] In other words, the odds that an innovation was patented in London were 1.3 times the odds in the rest of England. In the odds-ratio test, the p-value for the difference is 0.006, thus suggesting a significant difference.

There is, however, no evidence that patenting increased with city size. In the U.S. small cities ranging from 5,000 to 50,000 people and medium-sized cities from 100,000 to 400,000 people had lower patenting rates than rural areas (Figure 2). OLS and logit regressions of the British data, yield only weak evidence that urbanization encourages patenting. In the British data, a coefficient of 0.008 for the size of the originating city (measured as the logarithm of population, Table 7, columns I and IV) indicates that the propensity to patent increased by 6 percent for an inventor in a town of 5,000 people compared to a single rural inventor, and by 11 percent for an inventor in London (equivalent to an increase in population of approximately 2.4 million). Dividing the data into categories of urbanization, coefficients for cities from 5,000 to 100,000 people, 100,000 to 400,000, above 400,000, and for the city of London, are not significant (Table 7, columns II, III, V, and VI).[17] In the U.S. data, there are no distinguishable patterns in patenting across levels of urbanization or across cities.

Dividing the data by industries again suggests that machinery innovations are particularly sensitive to factors that increase patent use. Twenty-two percent London's machinery innovations are patented compared to 17 percent elsewhere; the p-value for this difference is 0.018. This increase in patenting for machinery mirrors the amplified propensity to patent high-quality and U.S. innovations in machinery. The difference is even stronger for mining and metallurgy, where, 18 percent of London's innovations are patented, compared to 3 percent elsewhere. An odds-ratio test shows that this difference is statistically significant at a p-value of 0.002. A closer look at the data shows that the nature of mining innovations varies strongly between London and the provinces; London develops (and patents) machinery and mining equipment, whereas innovations from the provinces are strongly connected to resources. In three of the remaining industries (instruments, textiles, and other manufactures), patenting rates are

[17] Alternative cut-off points for "rural innovations" and urban categories yield similar results.

almost identical for London and the rest of England. For innovations in chemicals and food processing, patenting rates are lower in London than they are in the rest of England, although these differences are not statistically significant.[18]

In sum, comparisons of patenting rates across industries, suggest that technology-driven differences across industries had the strongest effects on patenting. Moreover, industries where inventors had a high propensity to patent experienced a further increase in patenting for innovations of high quality. Inventors in the United States patented (and did not patent) in the same industries as in Britain, and the tendency to patent was amplified in industries with high propensities to patent. Urban inventors may have been more likely to patent, but rural-urban differences are small compared to cross-industry variation. The following section contrasts these results on 19th century patenting rates with the available data on contemporary patents to evaluate the effects of scientific progress.

IV. Changes over Time: Do Scientific Breakthroughs Encourage the Use of Patents?

If the effectiveness of secrecy and patenting depends on the technological characteristics of innovations, the propensity to patent is likely to respond to scientific progress. The chemicals industry offers an opportunity to examine this idea: with the introduction of the periodic table in the late 1860s, this industry experienced a shock to scientific progress, which made it easier not only to reverse-engineer chemical inventions, but also to describe them in a patent.

In 1851, chemical inventions, such as alum, potash, naphthalene, along with many dyes including indigo, madder, and turkey red, were difficult to reverse-engineer. Crystal Palace data in the previous section has shown that they were also rarely patented. Eighteen years later,

[18] There are too few observations to run logit regressions of patenting behavior with the data from London only. OLS regressions, however, confirm the cross-industry patterns in patenting in the data for all of Britain: Chemicals and textiles are less likely to be patented, and machinery is more likely to be patented.

Dimitri Mendeleyev's structuring of the elements changed the nature of chemical invention.[19] The periodic table, as a tool of analysis, set in motion a "second scientific revolution" that made it much easier to analyze and thereby reverse-engineer inventions (Haber, 1958).

The full benefits of the periodic may have taken some time to materialize, as chemists learned to use it and built the necessary stock of knowledge. Until the late 19th century, prominent chemists deplored the slow pace of progress. For example, Henry Bowers (1895, p.431) wrote about the manufacture of soda salts

> Theory has marked out a number of paths, but practice has not yet succeeded in following any of these to a satisfactory result. (Henry Bower, 1895, p.431)

Exhibition data map out this slow progress until 1876, but then show a strong surge in patenting rates in 1915 (Figure 3). For 1876, only 7 years after the periodic table was introduced, data on innovations at the American Centennial Exhibition suggest that patenting behavior in chemicals had barely changed. Of 70 British exhibits in chemicals in 1876, only 2 (less than 3 percent) appear to have been patented. In contrast, among 104 British exhibits in machinery in 1876, 34 exhibits (33 percent) were patented. U.S. data showed similarly low levels of patenting for chemical innovations; only 4 percent of American innovations in chemicals were patented, compared with 25 percent in manufacturing machinery. By the time of the Panama-Pacific Exhibition, however, patenting rates in chemicals had increased to more than 25 percent (Figure 3).[20]

---

[19] Mendelyev's discovery was one of several attempts to structure the elements. In 1864, John Newlands classified the elements into 11 groups and observed that any given element would exhibit analogous behavior to the eighth element following it (the law of octaves). In the same year, Lothar Meyer published an abbreviated version of a periodic table which listed more than 20 elements listed in order of their atomic weights. Meyer constructed an extended table in 1868, which was published in 1870.

[20] Unfortunately, there is no British data at the fair of 1915. Britain and Germany had agreed that neither country should participate in the Panama Pacific Exposition (Kretschmer 1999, p.172). Belgium, which Germany had just invaded to gain a better angle for attacking France, participated jointly with that country.

Patent data for inventions in textile dyes corroborate these trends. In the 1840s and 1850s, less than a handful of American inventors patented dyes each year (Figure 3, based on data in Schmookler 1972). After 1869, however, the number of chemical patents increased to about 40 per year, close to ten times its previous levels. Figure 3 also shows that patenting spiked in the 1920s and 1930s, and returned to its normal path of growth in the 1940s and 1950s. By that time, the U.S. Patent Office granted about 80 chemicals patents each year.[21]

Comparisons of patent data across industries also confirm the increased importance of patenting in chemicals. By the 1920s, 15 percent, or 277 of 1,867 U.S. patents that were assigned to publicly traded companies, occurred in chemicals (Moser and Nicholas, 2004, p. 390). By the late 20th century surveys suggest that chemicals had become *the* most patent-friendly industry. Edwin Mansfield's (1986) survey of 100 U.S. manufacturing firms in 12 industries finds that firms in chemicals and pharmaceuticals considered themselves to be heavily dependent on patent protection. Firms in those industries responded that patents were essential to developing and bringing to market more than 30 percent of their inventions. Levin, Klevorik, Nelson, and Winter's (1987) survey of 650 manufacturing firms reveals that U.S. R&D labs in chemicals and pharmaceuticals find patents to be the most reliable mechanism to protect intellectual property. By 1994, chemicals and pharmaceuticals are the only industries (among a total of 33 industries) where inventors cite patenting as the most effective mechanism to protect intellectual property (Cohen, Nelson, and Walsh, 2000, p. 10). The emphasis on patent protection in chemicals and pharmaceuticals stands in stark contrast with the low propensities to patent chemicals in the mid 19th century, prior to the introduction of the periodic table.

---

[21] Schmookler's patent data are not exhaustive; he had to assign patents that were classified by function to industries, and was unable to classify patents that could be used in more than one industry (Schmookler (1972, p.79)

IV. Conclusions

This paper has introduced a new data set on more than 7,000 British and American innovations between 1851 and 1876 to examine the determinants of patenting decisions. As a first surprising result, the data reveal that only a small proportion of innovations are patented; 11 percent of British innovations, and less than 16 percent of U.S. innovations in 1851. The fact that patenting rates are low in the United States is particularly noteworthy, because patenting was much cheaper and more effective in the U.S. than in any other country at this time.

Exhibition data also show that patenting varies strongly across industries. In 1851, only 5 percent of chemical innovations were patented, compared to 30 percent of innovations in machinery. Inter-industry differences in patenting are robust to comparisons across rural and urban inventors and across countries. Remarkably, American inventors patented (and did not patent) in the same industries.

Cross-industry differences in patenting are equally robust to adjustments for the quality of innovations. Innovations of high quality are slightly more likely to be patented overall, but they are patented (and not patented) in the same industries as other innovations. In fact, quality appears to amplify existing variation across sectors. These results suggest that variation in technological characteristics across industries may be the key determinant of patenting.

Exhibition data also indicate that scientific progress may encourage patenting. In the mid 19th century, very few chemicals were protected by patents, probably because they could be easily kept secret. The periodic table, however, drastically reduced the effectiveness of secrecy. As a new tool of analysis the periodic table made it easier to analyze and reverse-engineer chemical inventions. Once chemists learned to use it, inventors switched to patents: Between 1851 and 1915, patenting rates for chemicals increased from 5 to more than 25 percent.

REFERENCES

Annual Report of the United States Commissioner of Patents, Washington, DC: Government Printing Office, 1841-1851.

Arrow, Kenneth. “The Economic Implications of Learning by Doing,” *Review of Economic Studies*, XXIX (1962), 155-73.

Ben-Atar, Doron S. *Trade Secrets: Intellectual Piracy and the Origins of American Industrial Power*, New Haven, CT: Yale University Press, 2004.

Bentham, Jeremy. *Collected Works*, London, UK: 1843.

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

Booth, Charles. *Descriptive Map of London Poverty 1889*, London UK: Macmillan, 1891.

Bowers, Henry, “The Chemical Industry”, Chapter LXIII in Chauncey M. Depew, LL.D., editor, *1795-1895, One Hundred Years of American Commerce*, D.O. Haynes Co., Philadelphia, 1895, II volumes, pp.429-432.

Cohen, Wesley, Richard R. Nelson, and John P. Walsh. “Protecting Their Intellectual Assets: Appropriability Conditions and Why U.S. Manufacturing Firms Patent (or Not).” *NBER Working Paper No. 7552*, 2000.

Cooper, Carolyn, C. *Shaping Invention*: *Thomas Blanchard’s Machinery and Patent Management in Nineteenth-Century America*, New York, NY: Columbia University Press, 1991.

Cooper, Grace Rogers. *The Invention of the Sewing Machine*, Washington, DC: Smithsonian Institution, 1968.

Coryton, John. *A Treatise on the Law of Letters-patent, for the sole use of inventions in the United Kingdome of Great Britain and Ireland; including the practice connected with the grant; to which is added a summary of the patent laws in force in the principal foreign states; with an appendix of statutes, rules, practical forms, etc.*, Philadelphia, PA: T. & J.W. Johnson, 1855.

Coulter, Maureen. *Property in Ideas: The Patent Question in Mid-Victorian Britain*, Kirksville, MO: Thomas Jefferson University Press, 1991.

Davenport, Neil. *The United Kingdom Patent System*, London, UK: Kenneth Mason, 1979.

Dragon, Andrea. “Wild Men. The First Twenty-five Years of the Rubber Industry,” *Essays in Economic and Business History*, XIII (1995), 217-229.

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

Fenster, Julie M. “Seam Stresses,” *American Heritage of Invention & Technology*, IX, 3 (1994), 40-52.

Frampton, Kenneth, *Modern Architecture, 1851-1945*, New York NY: Rizzoli International Publications, 1983.

Gallini, Nancy. "Patent Policy and Costly Imitation," *RAND Journal of Economics*, XXIII (1992), 52-63.

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

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

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

Haber, L.F. *The Chemical Industry during the Nineteenth Century: A Study of the Economic Aspect of Applied Chemistry in Europe and North America*, Oxford, UK: Oxford University Press, 1958.

Habbakuk, H. *American and British Technology in the 19th Century*, Cambridge, UK: Cambridge University Press, 1962.

Hägerstrand, Torsten. *The Propagation of Innovation Waves*, Lund Studies in Geography, Series B, No. 4, Lund: C.W.K. Gleerup, 1952.

Hall, Bronwyn H, Adam B. Jaffe, and Manuel Trajtenberg. "The NBER Patent Citation Data File: Lessons, Insights and Methodological Tools," *NBER Working Paper No. 8498*, 2001.

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

Haven, Charles Tower and Frank A. Belden. *A History of the Colt Revolver*, New York, NY: Morrow, 1940.

Henderson, Rebecca, Adam Jaffe and Manuel Trajtenberg. "Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations," *Quarterly Journal of Economics*, (1993).

Higgs, Robert. "American Inventiveness, 1870 – 1920," *Journal of Political Economy*, LXXVIX (1971), 661-67.

Hewish, John. *Rooms near Chancery Lane: the Patent Office under the Commissioners, 1852-1883*, London, UK: British Library, 2000.

Jacobs, Jane, *The Economy of Cities,* New York, NY: Vintage, 1969.

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

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

Korman, Richard. *The Goodyear Story. An Inventor's Obsession and the Struggle for a Rubber Monopoly*, San Francisco, CA: Encounter Books, 2002.

Kortum, Samuel and Josh Lerner. "What is Behind the Recent Surge in Patenting?" *Research Policy*, XXVIII (1999), 1-22.

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

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

Lamoreaux, Naomi L. and Kenneth L. Sokoloff. "The Geography of Invention in the American Glass Industry, 1870-1925," *Journal of Economic History, VOL #(* 2000), PP#

Lamoreaux, Naomi L., and Kenneth L. Sokoloff. *1996 Proceedings of the National Academy of Sciences of the United States of America*, XCIII, 23 (1996), 12686-12692.

Lanjouw, Jenny O. and Mark Schankerman. "Stylized Facts of Patent Litigation: Value, Scope, and Ownership," *NBER Working Paper No. 6297*, 1997.

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

Lerner, Josh. "150 Years of Patent Protection," *NBER Working Paper No. 7478*, 2000.

Lindert, Peter. *Growing Public: Volume 2, Further Evidence: Social Spending and Economic Growth Since the Eighteenth Century,* Cambridge, UK: Cambridge University Press, 2004.

MacLeod, Christine*.* *Inventing the Industrial Revolution: the English Patent System, 1660-1800* Cambridge, UK: Cambridge University Press, 1988.

Machlup, Fritz. *An Economic Review of the Patent System*, Washington, DC: Government Printing Office, 1958.

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

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

Mokyr, Joel. "Urbanization, Technological Progress, and Economic History," in Giersch, Herbert, ed., *Urban Agglomeration and Economic Growth*, New York, NY: Springer, 1995.

Moser, Petra. "Do Patent Systems Increase Innovation?" Working Paper, 2006a.

Moser, Petra. "Do Patents Encourage Knowledge Spillovers?" Working Paper, 2006b.

Moser, Petra. "How Do Patent Laws Influence Innovation? Evidence from 19th-Century World's Fairs," *American Economic Review,* XCV, 4 (2005), 1215-1236.

Moser, Petra and Tom Nicholas. "Was Electricity a General Purpose Technology? Evidence from Historical Patent Citations," *American Economic Review*, XCIV, 2 (2004), 388-394.

The National Gazetteer of Great Britain and Ireland", London, UK: Virtue & Co., 1868.

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

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

Pred, Allan R. *The Spatial Dynamics of US Urban-Industrial Growth, 1800–1914: Interpretive and Theoretical Essays.* Cambridge: MIT Press. 1966.

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

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

Rose, E. "Innovation in American Culture," *Social Forces,* XXVI, 3 (1948), 255-272.

Rosenberg, Nathan. *The American System of Manufactures*, Edinburgh, UK: Edinburgh University Press, 1969.

Panama-Pacific International Exposition Company. *Directory Of Exhibits: Palace Of Fine Arts, Panama Pacific International Exhibition*. San Francisco: Wahlgreen Co., 1915.

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

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

Scotchmer, Suzanne. "Standing on the Shoulders of Giants: Cumulative Research and the Patent Law," *Journal of Economic Perspectives*, V, 1 (1991), 9-41.

Scott, John. *Genius Rewarded, or the Story of the Sewing Machine.* New York, NY: J. J. Caulon, 1880.

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

Schmookler, Jacob. *Invention and Economic Growth*, Cambridge, UK: University Press, 1966.

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

Snow, John. *Snow on Cholera: being a reprint of two papers by John Snow, M.D., together with a Biographical Memoir by B.W. Richardson, M.D. and an Introduction by Wade Hampton Frost, M.D.*, London, UK: Oxford University Press, 1936

Sokoloff, Kenneth. "Inventive Activity in Early Industrial America," *Journal of Economic History*, 1986.

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

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

Weber, Max, *Wirtschaft und Gesellschaft*, Tübingen, Germany: Mohr, first edition 1921, 5th revised edition 1976.

TABLE 1 – STATISTICS ON THE WORLD FAIRS OF 1851, 1876, AND 1915

	EXHIBITION		
	Crystal Palace	Centennial	Panama- Pacific
Location	London	Philadelphia	San Francisco
Year	1851	1876	1915
Countries	40	35	32
Exhibitors	17,062	30,864	30,000
Visitors	6,039,195	9,892,625	19,000,000
Area (in acres)	25.7	71.4	635
Prominent Exhibits	MacCormick's grain reaper, Colt's revolver, steam engines, manufacturing machinery, typewriter	Corliss steam engine, telephone, Westinghouse's pressure break, Edison's quadruplex telegraph	Eastman Kodak's two color-photography, Ford's conveyer belt, a phone line from San Francisco to New York

Notes: Data from *Bericht* (1853) and Kretschmer (1999).

TABLE 2 – BRITISH AND U.S. EXHIBITS AND PATENTS IN 1851

	Exhibits	Patented Exhibits	Share Patented
Britain	6,377	708	11.1%
Britain	549	85	15.5%

Notes: Data from the *Official Catalogue* (1851) and *Bericht* (1853). Exhibits in the *Official Catalogue* are matched with awards in *Bericht* based on exhibitors' names, exhibit numbers, and the description of exhibits and awards. For Britain, patented exhibits are identified from references to patents in the *Official Catalogue*; for the United States, by matching exhibits with patents in the *Annual Report of the United States Patent Office, volumes 1841-1851.*

TABLE 3 –PATENTING RATES ACROSS INDUSTRIES, BRITISH EXHIBITS IN 1851

	Exhibits		Awards	
Industry	**Total**	**% Patented**	**Total**	**% Patented**
Mining	418	5.0%	72	5.6%
Chemicals	136	5.1%	75	8.0%
Food processing	140	7.9%	72	9.7%
Engines and Carriages	406	24.6%	77	40.3%
Manufacturing Machinery	242	29.8%	70	47.1%
Civil Engineering	203	15.8%	29	20.7%
Military and Naval Engineering	356	12.1%	59	13.6%
Agricultural Machinery	261	19.9%	37	40.5%
Scientific Instruments	581	9.6%	139	15.8%
Manufactures	1,955	10.2%	595	16.5%
Textiles	1,679	6.8%	520	8.7%
All industries	6,377	11.1%	1,745	15.8%

Notes: For Britain, innovations with patents are identified as innovations whose descriptions in the exhibition catalogue refer to a patent. Awards are exhibits that received a prize for exceptional "quality and usefulness". I have matched exhibitors with lists of award-winners in the report of the German Commission to the Crystal Palace (*Bericht* 1853).

TABLE 4 – AWARD-WINNING BRITISH INNOVATIONS IN 1851

	All levels		Gold		Silver		Bronze	
Industry	**Total**	**% Patented**	**Total**	**% Patented**	**Total**	**% Patented**	**Total**	**% Patented**
Mining	72	5.6%	3	33.3%	31	3.2%	38	5.3%
Chemicals	75	8.0%	0	0.0%	41	9.8%	34	5.9%
Food processing	72	9.7%	2	0.0%	39	12.8%	31	6.5%
Engines and Carriages	77	40.3%	7	57.1%	69	39.1%	1	0.0%
Manufacturing Machinery	70	47.1%	15	40.0%	55	49.1%	0	0.0%
Civil Engineering	29	20.7%	3	0.0%	19	15.8%	7	42.9%
Military and Naval Engineering	59	13.6%	6	0.0%	45	17.8%	8	0.0%
Agricultural Machinery	37	40.5%	4	50.0%	31	41.9%	2	0.0%
Scientific Instruments	139	15.8%	16	18.8%	88	17.0%	35	11.4%
Manufactures	595	16.5%	19	15.8%	329	12.2%	247	12.1%
Textiles	520	8.7%	2	100.0%	330	8.2%	188	8.5%
All industries	1,745	15.8%	77	27%	1,077	18%	591	10%

Notes: For Britain, innovations with patents are identified as innovations whose descriptions in the exhibition catalogue refer to a patent. Awards are exhibits that received a prize for exceptional "quality and usefulness". I have matched exhibitors with lists of award-winners in the report of the German Commission to the Crystal Palace (*Bericht* 1853)

TABLE 5 – PATENTING RATES FOR BRITISH AND AMERICAN EXHIBITS IN 1851

	Britain		United States	
Industry	**Total**	**% Patented**	**Total**	**% Patented**
Mining	418	5.0%	51	7.8%
Chemicals	136	5.1%	32	3.1%
Food processing	140	7.9%	70	7.1%
Engines and Carriages	406	24.6%	30	43.3%
Manufacturing Machinery	242	29.8%	32	43.8%
Civil Engineering	203	15.8%	6	0.0%
Military and Naval Engineering	356	12.1%	11	36.4%
Agricultural Machinery	261	19.9%	27	37.0%
Scientific Instruments	581	9.6%	73	16.4%
Manufactures	1,955	10.2%	96	16.7%
Textiles	1,679	6.8%	116	6.0%
All industries	6,377	11.1%	544	15.5%

Notes: For Britain, innovations with patents are identified as innovations whose descriptions in the exhibition catalogue refer to a patent. For the U.S., American exhibitors at the Crystal Palace are matched with patentees and their inventions in the *Annual Reports of the Commissioner of Patents*, 1841 to 1851.

TABLE 6 – PATENTING RATES IN LONDON VERSUS THE REST OF BRITAIN, WITH ODDS RATIO TESTS

Industry	**Patenting Rates**		**Odds Ratio**	**Standard Error**
	London	**Other**		
Mining	17.6%	2.7%	7.857	1.739
Machinery	22.2%	17.2%	1.372	1.159
Other Manufacturing	13.1%	11.2%	1.195	1.189
Scientific Instruments	9.4%	8.2%	1.149	1.398
Textiles	7.3%	6.9%	1.063	1.241
Food Processing	9.1%	17.1%	0.483	3.129
Chemicals	5.7%	12.5%	0.424	2.300
All industries	13.1%	10.7%	1.262	1.095

Notes: The odds ratio measures odds of patenting in London divided by odds of patenting in the rest of Britain Patenting rates are calculated as the proportion of innovations that are patented. The tabulation includes 4,728 English innovations that were listed in the *Official Catalogue* (1851). Innovations with patents are identified in the descriptions of exhibits in the *Catalogue*. Locations are drawn from these descriptions also and matched to London and other counties using 19th-century maps and gazetteers.

TABLE 7 – BRITISH EXHIBITS IN 1851, LINEAR PROBABILITY AND LOGIT REGRESSIONS (MARGINAL EFFECTS), DEPENDENT VARIABLE IS 1 FOR PATENTED EXHIBITS

	OLS			Logit		
	I	**II**	**III**	**IV**	**V**	**VI**
Quality	**0.087**	**0.076**	**0.076**	**0.076**	**0.066**	**0.066**
	[0.011]**	**[0.010]****	**[0.010]****	**[0.008]****	**[0.007]****	**[0.007]****
City Size						
Population in logs	**0.008**	-	-	**0.008**	-	-
	[0.003]**	-	-	**[0.003]****	-	-
Rural [between 5,000 and 100,000]	-	0.028	-	-	0.03	-
	-	[0.066]	-	-	[0.068]	-
City above 100,000	-	0.022	-	-	0.025	-
	-	[0.066]	-	-	[0.068]	-
City above 400,000	-	0.03	-	-	0.032	-
	-	[0.066]	-	-	[0.068]	-
London	0.006	0.056	-	0.005	0.056	-
	[0.013]	[0.066]	-	[0.011]	[0.068]	-
Industry Classes						
Mining and metallurgy	-0.02	**-0.036**	**-0.041**	-0.03	**-0.051**	**-0.056**
	[0.017]	**[0.013]****	**[0.012]****	[0.024]	**[0.021]***	**[0.020]****
Chemicals	**-0.057**	**-0.065**	**-0.068**	-0.063	**-0.077**	**-0.08**
	[0.025]*	**[0.020]****	**[0.020]****	[0.036]	**[0.034]***	**[0.034]***
Food processing	-0.023	-0.034	-0.038	-0.021	-0.034	-0.038
	[0.031]	[0.024]	[0.024]	[0.032]	[0.028]	[0.028]
Engines	**0.17**	**0.153**	**0.154**	**0.114**	**0.102**	**0.103**
	[0.024]**	**[0.022]****	**[0.022]****	**[0.013]****	**[0.012]****	**[0.012]****
Manufacturing machinery	**0.212**	**0.204**	**0.198**	**0.131**	**0.125**	**0.119**
	[0.033]**	**[0.030]****	**[0.030]****	**[0.016]****	**[0.014]****	**[0.014]****
Civil, military, and naval engineering	**0.065**	**0.049**	**0.044**	**0.057**	**0.044**	**0.04**
	[0.018]**	**[0.016]****	**[0.016]****	**[0.014]****	**[0.013]****	**[0.013]****
Agricultural machinery	**0.139**	**0.116**	**0.111**	**0.106**	**0.088**	**0.082**
	[0.029]**	**[0.025]****	**[0.025]****	**[0.017]****	**[0.015]****	**[0.015]****
Scientific instruments	-0.002	-0.003	0	-0.003	-0.004	0
	[0.015]	[0.014]	[0.014]	[0.015]	[0.014]	[0.014]
Textiles	**-0.041**	**-0.036**	**-0.037**	**-0.05**	**-0.042**	**-0.044**
	[0.010]**	**[0.009]****	**[0.009]****	**[0.012]****	**[0.011]****	**[0.011]****
Constant	-0.03	0.044	**0.078**	**-0.332**	**-0.249**	**-0.215**
	[0.036]	[0.066]	**[0.007]****	**[0.035]****	**[0.067]****	**[0.007]****
Observations	5,439	6,377	6,377	5,439	6,377	6,377
R-square	0.06	0.05	0.05	0.0725	0.0648	0.0629
Log Likelihood				-1834.97	-2079.27	-2083.41

Notes: Marginal effects are calculated at the sample means. Data on exhibits were collected from the *Official Catalogue* (1851) and assigned to industry classes according to the original classification scheme of the Crystal Palace fair. Patented exhibits are identified in the *Official Catalogue*. I construct a measure of high-quality by matching exhibits in the *Official Catalogue* with a list of award-winning exhibits in the reports of the German commission to the Crystal Palace fair (*Bericht* 1853). Manufactures are the omitted industry class.

TABLE 8 – BRITISH AWARD WINNERS IN 1851, LINEAR PROBABILITY AND LOGIT REGRESSIONS (MARGINAL EFFECTS), DEPENDENT VARIABLE IS 1 FOR PATENTED EXHIBITS

	OLS			**Logit**		
	I	**II**	**III**	**IV**	**V**	**VI**
City Size						
Population in logs	-0.002	-	-	-0.002	-	-
	[0.007]	-	-	[0.007]	-	-
Rural [between 5,000 and 100,000]	-	-0.177	-	-	-0.094	-
	-	[0.282]	-	-	[0.166]	-
City above 100,000	-	-0.235	-	-	-0.146	-
	-	[0.282]	-	-	[0.166]	-
City above 400,000	-	-0.243	-	-	-0.155	-
	-	[0.282]	-	-	[0.166]	-
London	-0.008	-0.225	-	-0.009	-0.137	-
	[0.028]	[0.283]	-	[0.029]	[0.167]	-
Industry Classes						
Mining and metallurgy	**-0.089**	**-0.112**	**-0.107**	-0.104	**-0.147**	**-0.143**
	[0.044]*	**[0.032]****	**[0.031]****	[0.068]	**[0.063]***	**[0.062]***
Chemicals	-0.063	**-0.079**	**-0.082**	-0.067	-0.092	-0.096
	[0.045]	**[0.035]***	**[0.035]***	[0.057]	[0.052]	[0.052]
Food processing	-0.067	-0.068	-0.065	-0.072	-0.073	-0.07
	[0.045]	[0.037]	[0.038]	[0.057]	[0.048]	[0.049]
Engines	**0.262**	**0.238**	**0.240**	**0.167**	**0.146**	**0.149**
	[0.063]**	**[0.058]****	**[0.058]****	**[0.035]****	**[0.031]****	**[0.031]****
Manufacturing machinery	**0.352**	**0.306**	**0.309**	**0.211**	**0.181**	**0.183**
	[0.067]**	**[0.061]****	**[0.062]****	**[0.037]****	**[0.032]****	**[0.032]****
Civil, military, and naval engineering	0.041	0.002	-0.003	0.033	0.002	-0.003
	[0.058]	[0.043]	[0.042]	[0.044]	[0.038]	[0.037]
Agricultural machinery	**0.306**	**0.215**	**0.243**	**0.187**	**0.126**	**0.151**
	[0.095]**	**[0.080]****	**[0.082]****	**[0.051]****	**[0.041]****	**[0.042]****
Scientific instruments	-0.002	0	-0.004	-0.002	0	-0.003
	[0.038]	[0.035]	[0.034]	[0.035]	[0.031]	[0.031]
Textiles	**-0.097**	**-0.087**	**-0.084**	**-0.12**	**-0.102**	**-0.099**
	[0.020]**	**[0.019]****	**[0.019]****	**[0.027]****	**[0.024]****	**[0.024]****
Constant	**0.193**	0.387	**0.162**	**-0.178**	-0.059	**-0.197**
	[0.090]*	[0.282]	**[0.014]****	**[0.089]***	[0.165]	**[0.011]****
Observations	1,470	1,745	1,745	1,470	1,745	1,745
R-square	0.09	0.08	0.08	0.0876	0.0825	0.0766
Log Likelihood				-613.01	-697.48	-701.98

Notes: I have collected data on exhibits in the *Official Catalogue* (1851) and assigned each exhibit to an industry class according to the original classification scheme in 1851. Patented exhibits are identified in the descriptions of innovations in the *Official Catalogue*. I construct a measure of high quality by matching exhibits in the Official Catalogue with a list of award-winning exhibits in the reports of the German commission to the Crystal Palace fair (*Bericht* 1853). Manufactures are the omitted industry class.

TABLE 9 – U.S. EXHIBITS, LINEAR PROBABILITY AND LOGIT REGRESSIONS (MARGINAL EFFECTS), DEPENDENT VARIABLE IS 1 FOR PATENTED EXHIBITS

		OLS			**Logit**	
	I	**II**	**III**	**IV**	**V**	**VI**
High quality	**0.146**	-0.06	-0.085	**0.124**	**0.101**	**0.103**
	[0.045]**	[0.191]	[0.214]	**[0.033]****	**[0.031]****	**[0.032]****
<u>City Size</u>						
Population in logs	0.003	-	-	0.001	-	-
	[0.009]	-	-	[0.008]	-	-
Town between 5,000 and 100,000	-	-0.052	-	-	-0.038	-
	-	[0.078]	-	-	[0.052]	-
City above 100,000	-	0.013	-	-	0.003	-
	-	[0.078]	-	-	[0.051]	-
City above 400,000	-	0.34	-	-	-0.003	-
	-	[0.347]	-	-	[0.046]	-
<u>Industry Classes</u>						
Mining and metallurgy	-0.049	-0.78	-0.829	-0.057	-0.051	-0.058
	[0.053]	[0.749]	[0.790]	[0.068]	[0.062]	[0.062]
Chemicals	**-0.105**	-0.9	-0.868	-0.158	-0.178	-0.175
	[0.050]*	[0.800]	[0.770]	[0.107]	[0.108]	[0.109]
Food processing	-0.091	-0.756	-0.813	-0.106	-0.099	-0.104
	[0.047]	[0.682]	[0.734]	[0.061]	[0.057]	[0.057]
Engines	**0.297**	-0.471	-0.477	**0.179**	**0.178**	**0.18**
	[0.099]**	[0.793]	[0.800]	**[0.052]****	**[0.051]****	**[0.051]****
Manufacturing machinery	**0.309**	-0.469	-0.462	**0.177**	**0.169**	**0.169**
	[0.101]**	[0.782]	[0.775]	**[0.052]****	**[0.049]****	**[0.048]****
Civil, military, and naval engineering	0.14	-0.737	-0.652	0.093	0.05	0.052
	[0.121]	[0.831]	[0.748]	[0.066]	[0.068]	[0.068]
Agricultural machinery	**0.238**	-0.468	-0.527	**0.144**	**0.142**	**0.136**
	[0.105]*	[0.720]	[0.769]	**[0.056]****	**[0.055]****	**[0.054]***
Scientific instruments	**0.033**	-0.791	-0.732	**0.028**	**0.011**	**0.015**
	[0.057]	[0.818]	[0.763]	[0.044]	[0.044]	[0.044]
Textiles	**-0.099**	-0.789	-0.829	**-0.123**	**-0.111**	**-0.114**
	[0.042]*	[0.709]	[0.747]	**[0.054]***	**[0.051]***	**[0.052]***
Constant	0.084	0.755	0.913	**-0.227**	**-0.203**	**-0.212**
	[0.102]	[0.643]	[0.802]	**[0.089]***	**[0.046]****	**[0.030]****
Observations	485	545	545	485	545	545
R-square	0.14	0.01	0.01	0.155	0.1427	0.1399
Log Likelihood				-179.35	-203.72	-204.37

Notes: Marginal effects are evaluated at sample means. I have collected data on exhibits in the *Official Catalogue* (1851) and assigned each exhibit to an industry class according to the original classification scheme in 1851. Patented exhibits are identified by matching names of exhibitors and descriptions of inventions with patents in the *Annual Reports of the United States Patent Office*. Manufactures are the omitted industry class.

TABLE 10.A – U.S. AND BRITAIN, LINEAR PROBABILITY REGRESSION
INDEPENDENT VARIABLE IS 1 FOR A PATENTED EXHIBIT AND 0 OTHERWISE

	Mining and Metallurgy				Chemicals			
	I	II	III	IV	I	II	III	IV
High-quality	0.005	0.005	0.017	0.017	0.071	0.066	0.058	0.058
	[0.029]	[0.029]	[0.028]	[0.028]	[0.036]*	[0.034]+	[0.032]+	[0.032]+
U.S.	0.014	0.014	0.031	0.028	-0.017	-0.02	-0.033	-0.033
	[0.034]	[0.034]	[0.033]	[0.033]	[0.047]	[0.046]	[0.041]	[0.041]
London	-0.028	-0.029	-0.031	-0.053	-0.029	-0.074	-0.073	-0.061
	[0.159]	[0.130]	[0.131]	[0.131]	[0.107]	[0.069]	[0.069]	[0.063]
Other city (>100k)	0.036	0.036	0.037	-	-0.016	-0.015	-0.015	-
	[0.021]+	[0.021]+	[0.021]+	-	[0.038]	[0.038]	[0.038]	-
High-quality * U.S.	0.262	0.262	-	-	-0.071	-0.065	-	-
	[0.136]+	[0.136]+	-	-	[0.104]	[0.103]	-	-
High-quality * London	-0.005	-	-	-	-0.071	-	-	-
	[0.276]	-	-	-	[0.130]	-	-	-
Constant	0.028	0.028	0.025	0.048	0.029	0.032	0.036	0.024
	[0.018]	[0.018]	[0.018]	[0.012]**	[0.039]	[0.039]	[0.038]	[0.025]
Observations	470	470	470	470	168	168	168	168
R-squared	0.02	0.02	0.01	0	0.04	0.04	0.03	0.03

Notes: Data on exhibits from the *Official Catalogue* (1851) Patented exhibits with patents in the *Annual Reports of the United States Patent Office*, 1841-1851. Standard errors are in brackets; + denotes significant at 10 percent; * significant 5%; and ** significant at 1 percent.

TABLE 10.B – U.S. AND BRITAIN, LINEAR PROBABILITY REGRESSION
INDEPENDENT VARIABLE IS 1 FOR A PATENTED EXHIBIT AND 0 OTHERWISE

	Food processing				Engines and Carriages			
	I	II	III	IV	I	II	III	IV
High-quality	0.033	0.032	0.025	0.031	0.238	0.175	0.165	0.165
	[0.046]	[0.045]	[0.038]	[0.038]	[0.062]**	[0.054]**	[0.054]**	[0.054]**
U.S.	-0.009	-0.009	-0.019	-0.003	0.249	0.236	0.215	0.215
	[0.052]	[0.051]	[0.041]	[0.040]	[0.083]**	[0.083]**	[0.082]**	[0.082]**
London	-0.113	-0.121	-0.123	-0.072	0.116	0.065	0.063	0.058
	[0.160]	[0.139]	[0.138]	[0.136]	[0.064]+	[0.059]	[0.059]	[0.050]
Other city (>100k)	-0.07	-0.07	-0.069	-	0.011	0.011	0.008	-
	[0.040]+	[0.040]+	[0.039]+	-	[0.049]	[0.049]	[0.049]	-
High-quality * U.S.	-0.026	-0.025	-	-	-0.676	-0.613	-	-
	[0.082]	[0.082]	-	-	[0.443]	[0.443]	-	-
High-quality * London	-0.033	-	-	-	-0.247	-	-	-
	[0.312]	-	-	-	[0.123]*	-	-	-
Constant	0.113	0.113	0.117	0.065	0.178	0.191	0.195	0.199
	[0.044]*	[0.044]*	[0.042]**	[0.030]*	[0.042]**	[0.041]**	[0.041]**	[0.027]**
Observations	210	210	210	210	437	437	437	437
R-squared	0.02	0.02	0.02	0.01	0.05	0.04	0.04	0.03

Notes: Data on exhibits from the *Official Catalogue* (1851) Patented exhibits with patents in the *Annual Reports of the United States Patent Office*, 1841-1851. Standard errors are in brackets; + denotes significant at 10 percent; * significant 5%; and ** significant at 1 percent.

TABLE 10.C – U.S. AND BRITAIN, LINEAR PROBABILITY REGRESSION

INDEPENDENT VARIABLE IS 1 FOR A PATENTED EXHIBIT AND 0 OTHERWISE

	Manufactury Machinery				**Civil, Military and Naval Eng.**			
	I	II	III	IV	I	II	III	IV
High-quality	0.243	0.243	0.258	0.258	0.016	0.026	0.036	0.038
	[0.064]**	[0.064]**	[0.061]**	[0.061]**	[0.040]	[0.040]	[0.039]	[0.039]
U.S.	0.14	0.14	0.172	0.173	0.032	0.034	0.094	0.097
	[0.093]	[0.093]	[0.085]*	[0.085]*	[0.100]	[0.101]	[0.085]	[0.085]
London	-0.26	-0.26	-0.254	-0.224	-0.095	0.15	0.148	0.113
	[0.455]	[0.455]	[0.455]	[0.452]	[0.200]	[0.175]	[0.175]	[0.173]
Other city (>100k)	-0.042	-0.042	-0.041	-	0.048	0.047	0.047	-
	[0.063]	[0.063]	[0.063]	-	[0.033]	[0.033]	[0.033]	
High-quality * U.S.	0.191	0.191	-	-	0.219	0.209	-	-
	[0.229]	[0.229]	-	-	[0.187]	[0.187]		
High-quality * London	0	-	-	-	0.984	-	-	-
	[0.000]	-	-	-	[0.397]*		-	-
Constant	0.26	0.26	0.254	0.224	0.095	0.094	0.093	0.127
	[0.059]**	[0.059]**	[0.058]**	[0.034]**	[0.029]**	[0.029]**	[0.029]**	[0.016]**
Observations	274	274	274	274	576	576	576	576
R-squared	0.08	0.08	0.07	0.07	0.02	0.01	0.01	0

Notes: Data on exhibits from the *Official Catalogue* (1851) Patented exhibits with patents in the *Annual Reports of the United States Patent Office*, 1841-1851. Standard errors are in brackets; + denotes significant at 10 percent; * significant 5%; and ** significant at 1 percent.

TABLE 10.D – U.S. AND BRITAIN, LINEAR PROBABILITY REGRESSION
INDEPENDENT VARIABLE IS 1 FOR A PATENTED EXHIBIT AND 0 OTHERWISE

	Agricultural Machinery				**Scientific Instruments**			
	I	II	III	IV	I	II	III	IV
High-quality	0.249	0.249	0.223	0.222	0.093	0.076	0.092	0.093
	[0.072]**	[0.072]**	[0.068]**	[0.067]**	[0.040]*	[0.030]*	[0.029]**	[0.029]**
U.S.	0.206	0.206	0.166	0.166	0.056	0.053	0.084	0.085
	[0.090]*	[0.090]*	[0.082]*	[0.081]*	[0.043]	[0.043]	[0.039]*	[0.038]*
London	0.25	0.25	0.243	0.237	0.067	0.056	0.053	0.049
	[0.185]	[0.185]	[0.184]	[0.182]	[0.038]+	[0.035]	[0.035]	[0.027]+
Other city (>100k)	0.017	0.017	0.011	-	0.005	0.006	0.005	-
	[0.049]	[0.049]	[0.049]	-	[0.031]	[0.031]	[0.031]	-
High-quality * U.S.	-0.219	-0.219	-	-	0.148	0.165	-	-
	[0.214]	[0.214]	-	-	[0.098]	[0.095]+	-	-
High-quality * London	0	-	-	-	-0.041	-	-	-
	[0.000]	-	-	-	[0.061]	-	-	-
Constant	0.15	0.15	0.157	0.163	0.056	0.058	0.056	0.059
	[0.040]**	[0.040]**	[0.039]**	[0.027]**	[0.027]*	[0.027]*	[0.027]*	[0.016]**
Observations	288	288	288	288	651	651	651	651
R-squared	0.06	0.06	0.06	0.06	0.03	0.03	0.03	0.03

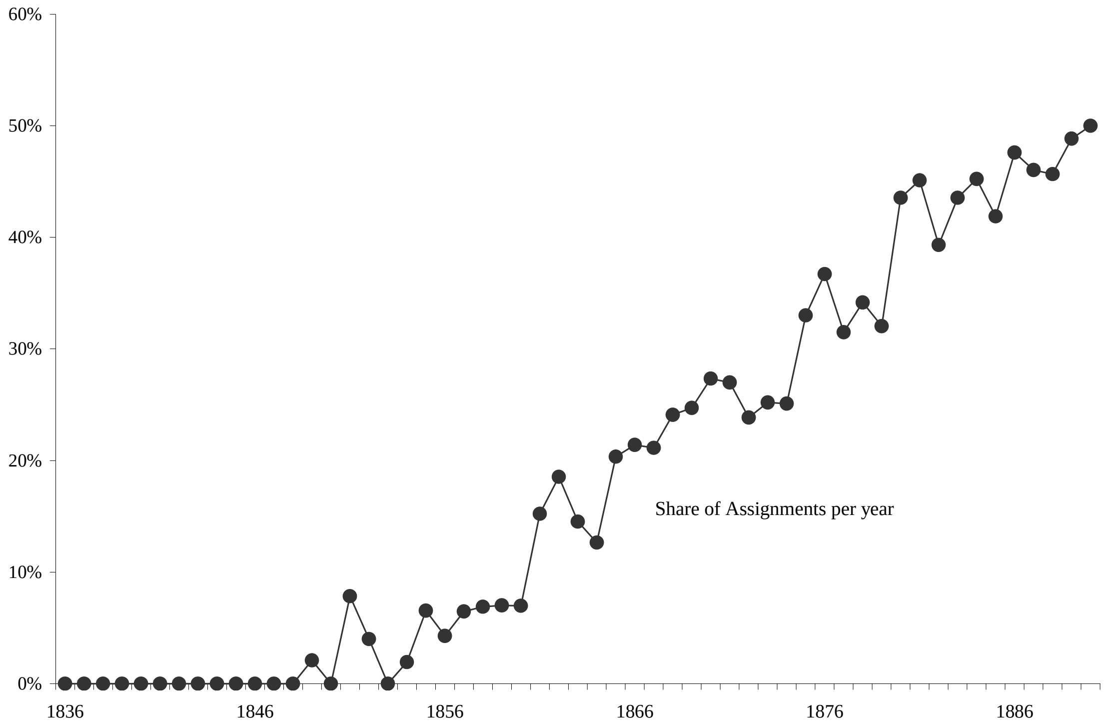
Notes: Data on exhibits from the *Official Catalogue* (1851) Patented exhibits with patents in the *Annual Reports of the United States Patent Office*, 1841-1851. Standard errors are in brackets; + denotes significant at 10 percent; * significant 5%; and ** significant at 1 percent.

TABLE 10.E – U.S. AND BRITAIN, LINEAR PROBABILITY REGRESSION
INDEPENDENT VARIABLE IS 1 FOR A PATENTED EXHIBIT AND 0 OTHERWISE

	Manufactures				**Textiles**			
	I	II	III	IV	I	II	III	IV
High-quality	0.086	0.088	0.092	0.092	0.035	0.026	0.028	0.028
	[0.017]**	[0.015]**	[0.015]**	[0.015]**	[0.015]*	[0.013]+	[0.013]*	[0.013]*
U.S.	0.054	0.055	0.075	0.074	-0.015	-0.018	-0.01	-0.01
	[0.036]	[0.036]	[0.032]*	[0.032]*	[0.028]	[0.028]	[0.024]	[0.024]
London	0.056	0.059	0.06	0.057	-0.003	-0.016	-0.016	-0.014
	[0.023]*	[0.020]**	[0.020]**	[0.017]**	[0.020]	[0.017]	[0.017]	[0.015]
Other city (>100k)	0.004	0.003	0.004	-	-0.004	-0.004	-0.004	-
	[0.017]	[0.017]	[0.017]	-	[0.014]	[0.014]	[0.014]	-
High-quality * U.S.	0.096	0.094	-	-	0.022	0.032	-	-
	[0.078]	[0.077]	-	-	[0.056]	[0.056]	-	-
High-quality * London	0.012	-	-	-	-0.042	-	-	-
	[0.036]	-	-	-	[0.032]	-	-	-
Constant	0.061	0.06	0.059	0.061	0.063	0.066	0.066	0.063
	[0.014]**	[0.014]**	[0.014]**	[0.009]**	[0.012]**	[0.012]**	[0.012]**	[0.008]**
Observations	2052	2052	2052	2052	1796	1796	1796	1796
R-squared	0.03	0.03	0.03	0.03	0	0	0	0

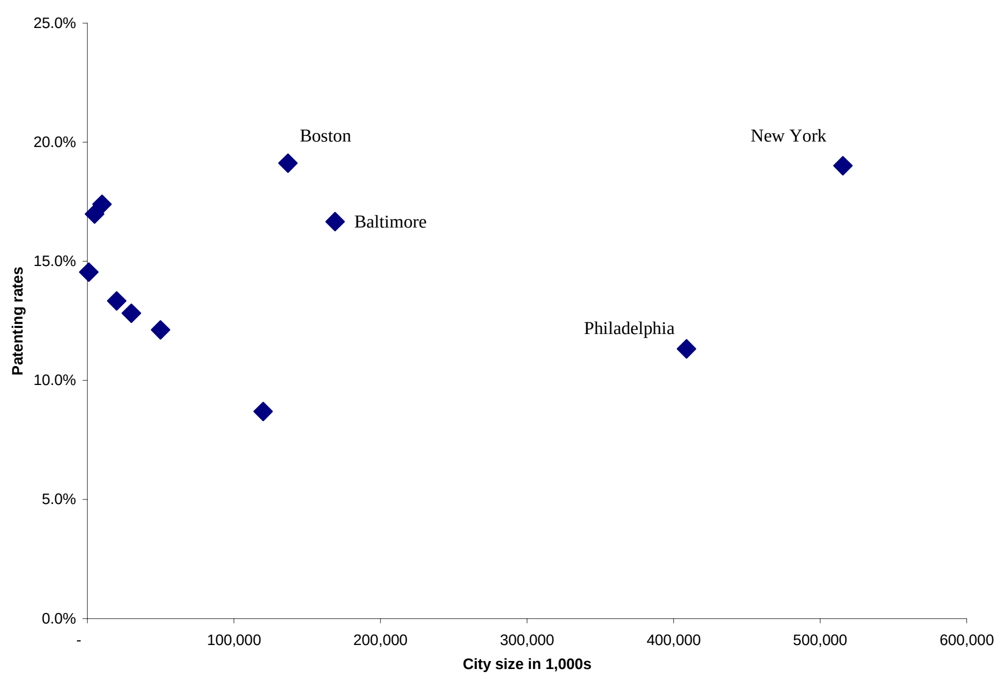
Notes: Data on exhibits from the *Official Catalogue* (1851) Patented exhibits with patents in the *Annual Reports of the United States Patent Office*, 1841-1851. Standard errors are in brackets; + denotes significant at 10 percent; * significant 5%; and ** significant at 1 percent.

FIGURE 1 – ASSIGNMENTS OF PATENTS IN THE STATE OF CONNECTICUT



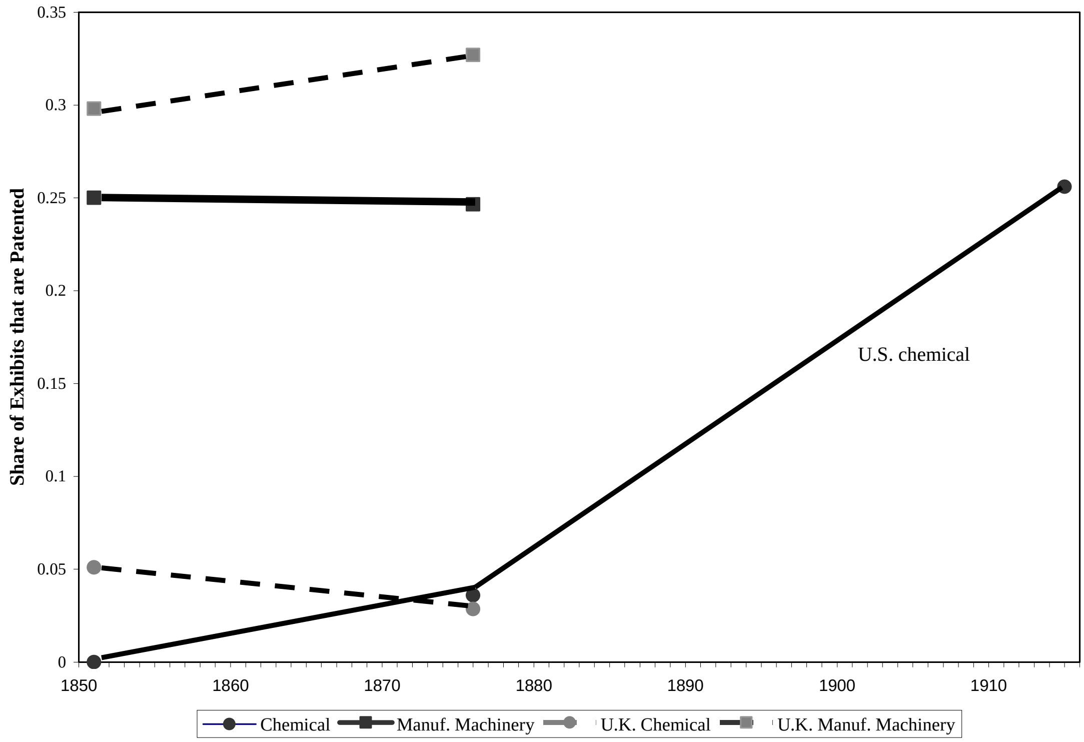
Notes: Data include all patents issued or assigned to residents of the State of Connecticut, including patents issued or assigned to companies. Annual Reports of the United States Patent Office, 1836 to 1890.

FIGURE 2 – CITY SIZE AND PATENTING RATES IN THE UNITED STATES IN 1851



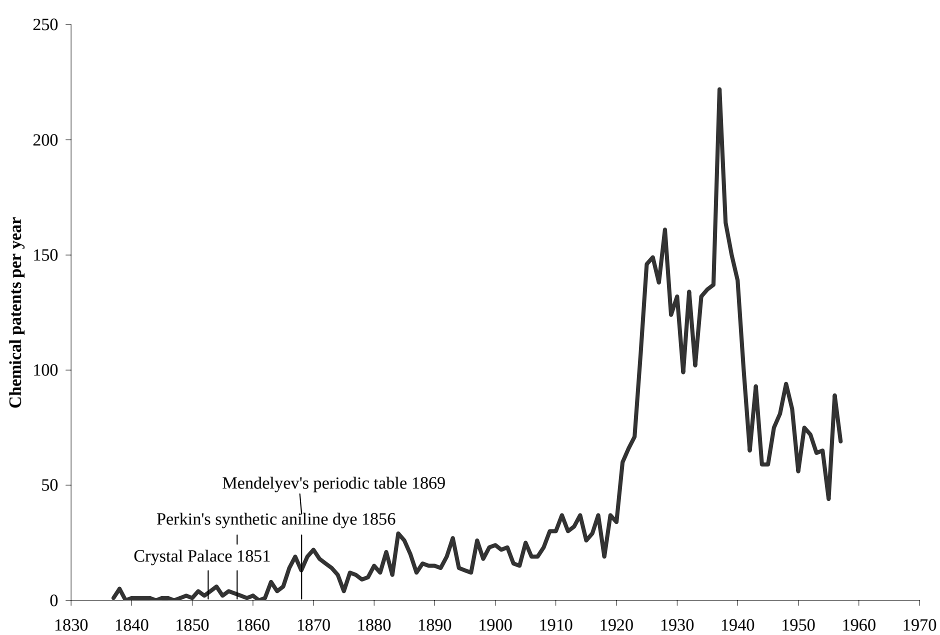
Notes: Data from the *Official Catalogue* (1851), and the United States Census of 1851. Patented exhibits are identified by matching exhibits with patents in the *Annual Reports of the United States Patent Office, 1841-1851*.

FIGURE 3 – U.S. AND BRITISH PATENTING RATES FOR INNOVATIONS IN CHEMICALS AND MANUFACTURING MACHINERY, 1851 - 1915



Notes: Data from the official catalogues for 1851, 1876, and 1915. Patented exhibits are identified by matching exhibits with patents in the *Annual Reports of the United States Patent Office, 1841-1915*.

FIGURE 4 – U.S. PATENTS PER YEAR RELATED TO TEXTILE DYES



Notes: Data are drawn from Schmookler (1972). Schmookler's patents include patents related to azo dyes, bleaching, printing, and miscellaneous patents related to textile dyeing.