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WHY DON'T INVENTORS PATENT?

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ABSTRACT

This paper argues that the ability to keep innovations secret may be a key determinant of patenting. To test this hypothesis, the paper examines a newly-collected data set of more than 7,000 American and British innovations at four world's fairs between 1851 and 1915. Exhibition data show that the industry where an innovation is made is the single most important determinant of patenting. Urbanization, high innovative quality, and low costs of patenting also encourage patenting, but these influences are small compared with industry effects. If the effectiveness of secrecy is an important factor in inventors' patenting decisions, scientific breakthroughs, which facilitate reverse-engineering, should increase inventors' propensity to patent. The discovery of the periodic table in 1869 offers an opportunity to test this idea. Exhibition data show that patenting rates for chemical innovations increased substantially after the introduction of the periodic table, both over time and relative to other industries.

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On May 8, 1886, Dr. John Stith Pemberton, a pharmacist in Atlanta, Georgia, produced the first batch of Coca-Cola. Pemberton carried a jug of his syrup down the street to Jacobs' Pharmacy, where it was placed on sale for five cents a glass, and, perhaps due to its light kick of cocaine, became a run-away success. Like most inventors of drinks and medicines, Pemberton decided not to patent; "a hopeful inventor would patent the label or trademark for his nostrum, but never its 'secret formula'" (Pendergrast 2000, p.9). Had Coca-Cola been patented, its recipe would have entered the public domain in 1903, and the Coca-Cola Company would have missed substantial growth. Between 1899 and 1920, the number of plants bottling Coke increased from 2 to more than 1,000; by the year 2000, Coca-Cola had become the world's most ubiquitous consumer product. The recipe for Coca-Cola, which was never patented, remains the world's most prominent commercial secret (Pendergrast 2000, p.348).[1]

It is well known that inventors do not patent all their innovations (e.g., Mansfield 1986), but why inventors do not patent is less well understood. This paper argues that inventors tend to avoid patents for innovations that they can keep secret, and that scientific breakthroughs, which improve competitors' ability to reverse-engineer, increase inventors' propensity to patent. The empirical analysis employs a newly-collected data set on 7,219 British and American innovations with and without patents at four world's fairs between 1851 and 1915. Exhibition data show that the ability to keep innovations secret is a key determinant of patenting, and that inventors' propensity to patent increases in response to scientific progress.

Surveys of inventors in the 19th and 20th centuries suggest that most inventors prefer secrecy to patenting (*Procès verbal* 1883; Levin et al. 1987; Cohen, Nelson, and Walsh 2000). Such surveys also reveal significant differences in inventors' attitudes toward patenting and

[1] Today, competing versions of the secret recipe are available in print and online (e.g., Pendergrast 2000, pp.456-7), but none of these recipes appear to be complete.

secrecy across industries. In the 19th century, chemists and dyers opposed patenting, while inventors of machinery appeared to favor patents (*Procès verbal* 1883).

Differences in the effectiveness of secrecy offer a compelling reason for such variation in inventors' attitudes. Secrecy carries little risk in industries where innovations are difficult to reverse-engineer, such as chemical dyes or carbonated drinks. Secrecy is, however, exceptionally risky for innovations that can be copied easily, such as the lockstitch of a sewing machine or the use of three-dimensional imaging in computer tomography. Compared with secrecy, patenting is more uniformly effective across industries, and inventors who weigh the risks and benefits of patenting should be more likely to patent in industries where secrecy is risky.

Fundamental advances in science and engineering, such as the introduction of the periodic table or the decoding of the human genome may also create powerful changes in patenting decisions. By introducing new tools of analysis, scientific breakthroughs boost inventors' ability to invent. But they also lower competitors' costs to reverse-engineer innovations. As a result, significant advances in science not only facilitate innovation, but also lower the effectiveness of secrecy and thereby increase inventors' propensity to patent. This paper uses 19th- and 20th-century exhibition data to test this hypothesis.

Alternative hypotheses of patenting have emphasized the role of innovative quality, urbanization, and differences in patent laws. Higher-quality innovations are more likely to be patented because they promise higher profits, which by themselves encourage patenting and also make innovations more attractive to potential imitators (Anton and Yao 2004). Urban inventors patent more because they are more familiar with the patent system (MacLeod 1988) and because they live in close proximity to many potential competitors who might copy their ideas (Mokyr 1995). Similarly, increases in the effectiveness of patenting should encourage patenting (Arora and Ceccagnoli 2006), and innovations from countries with cheap patents should be more likely to be patented, because a larger share of inventors has access to protection (Khan 2005).

Nineteenth-century exhibition data create a unique opportunity to examine the relative strength of these factors. As a complement to existing sources, exhibition data offer many advantages: Most importantly, they include innovations with and without patents, while existing sources are largely restricted to documenting patented inventions. Exhibition data also cover innovations across economic sectors, while patents have to omit certain industries. Moreover, comparable data on British and U.S. innovations in the 19th century make it possible to evaluate patenting choices in two countries with substantial differences in patent laws.[2] Finally, exhibition data include measures for the quality of innovations.

Exhibition data show that inventors patented only a small share of innovations. In 1851, only 11 percent of British innovations and 15 percent of U.S. innovations were patented. Such low patenting rates suggest that inventors predominantly relied on mechanisms *outside* the patent system to protect their intellectual property.

Moreover, exhibition data reveal that inventors' propensity to patent varies strongly across industries. For British innovations, patenting rates range from 5 percent in chemicals to 30 percent in manufacturing machinery. For U.S. innovations, differences across industries extend from 0 percent in chemicals to 40 percent in machinery. Such variation in patenting suggests that differences in the nature of technologies across industries, rather than the institutional characteristics of a patent system that are more uniform across industries, are the key determinant of patenting.

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[2] The Crystal Palace Exhibition offers a unique occasion to study the effects of patent laws (e.g., Moser 2005), because it preceded the major patent reforms of the 19th century, and prior to the Paris *Convention for the Protection of Industrial Property* in March 1883, patenting abroad was so expensive that inventors depended almost exclusively on domestic patents (Coryton 1855; Godson 1840; Penrose 1951).

The data confirm theoretical arguments about the effects of quality, patent laws, and urbanization, but they suggest that these effects are small compared with industry effects. Inventors in all industries are more likely to patent high-quality innovations, but they patent high-quality innovations in the same industries as all other innovations. In fact, quality appears to amplify inter-industry differences in inventors' propensity to patent. Similarly, U.S. inventors in all industries are slightly more likely to patent than British inventors, but, despite substantial differences in patent laws, they patent in the same industries as British inventors. Finally, urban inventors are more likely to patent than rural inventors, but rural-urban differences in patenting vary most strongly across industries. Thus, the data suggest that industry effects outweighed the influence of other factors.

Advances in analytic chemistry create an opportunity to test whether differences in appropriability conditions, and specifically in the effectiveness of secrecy, can help explain such industry effects. At the time of the Crystal Palace Fair, chemical innovations were impossible to reverse-engineer, easy to keep secret, and almost never patented. In the mid 19th century, however, the invention of analytic chemistry initiated substantial improvements in methods of chemical analysis and reverse-engineering (Asimov 1975; Maher 1988). In 1869, the publication of the periodic table introduced a research tool that greatly facilitated chemical analysis. Exhibition data show that inventors' propensity to patent chemicals increased substantially in response to this change. In 1851, none of the U.S. innovations in chemicals had been patented. By 1893, the share of patented innovations increased to 16 percent and to 18 percent in 1915. By the end of the 20th century, chemicals had developed into *the* most patent-friendly industry.

The remainder of this paper is structured as follows. Section I presents a model of inventors' 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 analyzes patenting rates across differences in quality, patent laws, levels of urbanization, and industries of use and estimates the relative strengths of these effects in OLS and logit regressions. Section IV employs the introduction of the periodic table as a test for the effects of scientific progress on patenting. Section V concludes.

I. A Simple Model of Inventors' Choice between Patenting and Secrecy

This section presents a simple formalization of the paper's main hypotheses. The key assumptions are that inventors weigh the risks and benefits of secrecy and patenting, and that the relative effectiveness of secrecy and patenting varies across industries. The model yields three predictions: (1) In industries where copying is easy, innovations are more likely to be patented. (2) Scientific advances, which facilitate reverse-engineering, weaken secrecy and encourage patenting. (3) Increases in the quality of innovations amplify differences across industries.

Inventors first choose whether to invest in R&D, and, if their research is successful, they decide whether to patent. Inventors invest in R&D if expected profits exceed the costs of R&D.

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

Π denotes expected profits, the parameter θ measures the share of profits that inventor manage to appropriate (i.e., keep for themselves), and $C^{R\&D}$ measures the costs of R&D. The non-exclusive nature of information prevents inventors from appropriating 100 percent of profits (Arrow 1962); the parameter θ is therefore typically smaller than 1, though it may be close to 1.[3]

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

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[3] In a model where patenting is the only mechanism to protect intellectual property, this first stage could be represented as a patent race (e.g., Gilbert and Newbery 1982; Horstmann, MacDonald and Slivinski 1985). In the current model, a patent race set-up is less suitable because one or all of the inventors may chose not to patent, or the race between two innovations could continue after a patent has been issued.

inventors choose between patenting and secrecy, where θ^{p} represents the effectiveness of patenting and θ^{s} the effectiveness of secrecy.[4]

The key assumption of this model 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 appropriate through secrecy. In contrast, innovations that are difficult to reverse-engineer, such as dyes, can be effectively protected by secrecy. Compared with secrecy, the effectiveness of patents depends less on the technological characteristics of innovations and is therefore typically less variable across industries. The parameter Δ_i measures the difference between the effectiveness of patents θ^{p} and the effectiveness of 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 C^{p}. Patenting costs include patent fees, attorney fees, and the cost of searching prior patents, while secrecy is assumed to carry 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

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

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

[4] 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 secrecy): $\theta^p + \theta^s = \theta$, such that $\theta \in (0,1)$. Friedman, Landes, and Posner (1991) argue that regulators should make legal protection of secrecy available to complement patents if the costs of maintaining secrecy are high (low θ^{s} in this model).

Equation (2) illustrates the main hypotheses: Inventors are more likely to patent innovations in industries where secrecy is relatively ineffective. Scientific advances that lower the effectiveness of secrecy encourage patenting.[5]

A. The Effects of Quality, Patent Laws, and Urbanization

While this paper focuses on technological determinants of patenting, previous literature has emphasized the quality of innovations (Anton and Yao 2004),[6] urbanization (MacLeod 1988; Mokyr 1995), and differences in patent laws (Khan 2005). These factors can also be examined in terms of equation (2). First, inventors might be more likely to patent high-quality innovations because such innovations are more profitable. Equation (2) further implies that an increase in quality, which raises profitability π_i, amplifies the effect of Δ_i on patenting. This suggests that differences in patenting across industries should be more pronounced for high-quality innovations. Inventors may also be more likely to choose patenting if they live in a country with strong patent laws. Strong laws are characterized by low patenting costs C^p and effective protection for patentees (high θ^p and high Δ_i). Both channels encourage patenting (e.g., Khan 2005).

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 innovations also suggest that

[5] Although secrecy is riskier in any given period, it may outlast a patent grant by *k* years. Then secrecy yields additional benefits (compared with 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 decisions in period 0. For example, patent renewal data reveal that few patents are renewed after their expiration date (Schankerman and Pakes 1986) which suggests that *k* is small. Moreover, any remaining profits after period *T* will be heavily discounted.

[6] Anton and Yao (2004) show that, in an environment where innovation creates asymmetric information, patent laws provide limited protection, and disclosure facilitates innovation, innovations that yield higher cost savings are more likely to be patented.

urban inventors may be more likely to patent because they are more familiar with the patent system (MacLeod 1988); this lowers C^p and increases patenting.

C. Case Studies Suggest Strong Differences in the Effectiveness of Secrecy

A wealth of anecdotal evidence suggests that the relative effectiveness of secrecy and patenting varies strongly across industries. On the one hand, secrecy appears to have been extremely risky for machines: Biographies of 19th-century inventors include many examples of machinery inventors who lost ideas to imitators. On the other hand, secrecy provided effective protection for chemicals and dyes.

Thomas Hancock's "masticator" is an example for the risks of secrecy. In 1820, Hancock invented a machine to recycle left-over rubber scraps from the manufacture of gloves and suspenders. This machine drastically reduced production costs; to keep it secret, Hancock hid it carefully and committed all his workers to an oath of silence. Yet, the masticator was revealed in 1832 and competitors were able to copy it almost immediately, quickly dispersing Hancock's profits (Dragon 1995, p.222; Korman 2002, pp.26 and 127-128).

Once imitators had copied and improved a new machine, many sought patents to protect it. For example, American mechanics visited English factories to study innovations in textile and paper-making machines, and patented improvements of these innovations in the United States (Wallace 1978, p.217). In 1850, it took Isaac Singer 11 days to reverse-engineer Lerow and Blogett's sewing machine. Protected by patents, Singer's improved machine became one of the 19th century's most profitable innovations (Scott 1880, p.8; Cooper 1968, pp.13 and 42).

On the opposite extreme, mid 19th-century inventors could safely rely on secrecy for chemicals and dyes because such inventions were practically impossible to reverse-engineer. For example, dyers in the Indus Valley had known how to produce the bright and fast madder red since 2600 B.C., but European dyers were unable to copy it. The production of madder red involved 30 secret steps, such as boiling yarn with alkali; steeping it in rancid oil, soda, and sheep dung; mordanting with alum and sumac; and dyeing in a batch of ox blood and chalk (Chenciner 2000, pp.174-204). Equally difficult to imitate, indigo had been known since the 2nd century A.D., when indigo-colored clothing, worth its weight in gold, adorned the graves of wealthy Roman settlers. Many tried to imitate this color, but it was not until 1878 that the German chemist von Baeyer managed to synthesize indigo. Other 19th-century chemicals, such as naphthalene, and quinine, and proved equally robust to analysis and imitation.

These examples suggest that secrecy offered poor protection for machines relative to other industries, such as chemicals and textile dyes. The following section introduces the exhibition data as a means to systematically analyze the effects of such variation on inventors' patenting decisions.

II. The Data

Exhibition data offer four major benefits: They capture innovations (1) with and without patents, (2) across industries, (3) across countries, and (4) they provide a measure for the quality of innovations. Most importantly, exhibition data include innovations with and without patents. This is particularly useful, because traditional sources, such as patents, can only measure innovations that inventors choose to patent.[7]

Another benefit of exhibition data is that they include innovations across all industries, while alternative data sources, such as patents, have to omit important sectors. Because patents are classified by functions rather than industries of use, many patent classes include innovations from a broad range of industries. The class "dispensing solids," for example, combines tooth

[7] Exhibition data measure *innovations*—commercially viable new or improved products and processes—rather than *inventions*—conceptions of such products and processes.

paste tubes with manure spreaders (Schmookler 1972, p.88). As a result, patent data exclude important innovations such as improvements in power plants and electric motors, which cannot be assigned to a specific industry (Schmookler 1972, p.89). Patent laws may also restrict protection in some industries. In Britain, for example, the government excluded chemicals from patenting from 1919 to 1949 and restricted the patenting of military technologies throughout the 19^{th} century (Davenport 1979, p.26; Khan 2005, p.36-7).

Exhibition data measure innovations across countries, regardless of domestic patent laws. With patent data alone, the effects of patent laws on patenting would be difficult to disentangle from differences in measurement. In the 19^{th} century, only "first and true" inventors were allowed to patent in the United States, while Britain granted patents to importers (Coryton 1855, pp.235-264). Innovations at the world's fairs provide comparable data for these two countries.

Finally, exhibition data include measures for the quality of innovations. This feature helps to address a serious limitation of patent data, which is that patented inventions 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", and U.S. patent No. 8,295, Francis Wilbar's "improvement in roof construction." By 1880, three of nine million U.S. households owned a sewing machine based on Singer's model (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 it as a predecessor (Trajtenberg 1990). If, however, only a portion of innovations are patented, citations 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 mechanisms other than patents to protect intellectual property. Exhibition data address this problem by including measures for the quality of innovations.

A. Description of the Exhibition Data

Exhibition data are drawn from the records of four world's fairs between 1851 and 1915: the Crystal Palace Exhibition in London in 1851, the American Centennial Exhibition in Philadelphia in 1876, the World's Columbian Exhibition in Chicago in 1893, and the Panama-Pacific International Exposition in San Francisco in 1915.[8] The first world's fair, the Crystal Palace Exhibition, was named after a 1,848-foot long greenhouse of cast-iron and glass (Frampton 1983, p.11). When it was built, 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. At a time when London had less than 2 million people, the Crystal Palace welcomed 17,062 exhibitors from 25 countries and 15 colonies, as well as 6 million visitors from all over the world (*Bericht* III 1853, p.674; Kretschmer 1999 p.101; Kroker 1975, p.146).

The American Centennial Exhibition and the series of U.S. world's fairs that followed it were the United States' response to the Crystal Palace. In 1876, exhibitors would walk 22 miles to see the 6 largest halls of the Centennial; 30,864 exhibitors from 35 countries displayed their innovations, and almost 10 million people came to visit (Kroker 1975, p.146). In 1893, the World's Columbian Exposition covered 716 acres of land and water in Jackson Park at Lake Michigan's shores, including 49 acres of exhibition space for 70,000 exhibitors from 45 countries. It attracted 27.5 million visitors. In 1915, the entire Marina and Presidio area in San Francisco (by today's Golden Gate) was converted to a fairground; it welcomed 30,000 exhibitors from 32 countries. Nineteen million visitors attended the San Francisco Exposition.

[8] Unfortunately, there are no complete lists of exhibits for later fairs. For the *Century of Progress Exposition* in Chicago in 1933, the only available catalogue is for art. For the *New York World's Fair* in 1939, the only catalogue is for the Polish Pavilion, which became a site of pilgrimage after Germany invaded Poland (Kretschmer 1999, p.216).

From the catalogues that guided visitors through these fairs and from the reports of national commissions, I have collected detailed data on 7,219 innovations from Britain and the United States. A typical entry in the catalogues includes the exhibitor's name, his home 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 class "Agricultural and Horticultural Machines and Implements." The data are divided into a total of 10 mutually exclusive industry classes, which span the entire spectrum of production: mining and metallurgy, chemicals, food processing, engines, manufacturing machinery, civil, military, and naval engineering, agricultural machinery, instruments, manufactures, and textiles.[9]

A few examples may help to illustrate the data. In the section on manufacturing machinery, visitors to the Crystal Palace saw the first sewing machines (U.S. exhibit 551, S.C. Blodgett) and power-loom lathes for the machine shops at Lowell (U.S. exhibit 447). The section on agricultural machinery displayed Cyrus McCormick's "Virginia grain reaper" as one of the highlights of the Crystal Palace (U.S. exhibit 73). Among the military innovations, visitors could admire Samuel Colt's "revolving cylinder handgun" (exhibit 321, Hartford, Connecticut). Chemical exhibits included "refined Indian blue," and a "newly invented black dye, particularly recommended for silk" (Britain's exhibit 78 and 69). Exhibits in manufactures ranged from hats and buttons, which had just begun to be mass produced, to "Locks on a new principle, applicable for all doors and gates" (Britain's exhibit 674).

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[9] I exclude exhibits of "art" such as drawings, paintings, sculptures, and the many water fountains that cooled the exhibition buildings, because they were typically not intended as exhibits of new technologies.

B. The Process of Selecting Exhibits

Uniform rules of selection ensured that exhibits were comparable across and within countries. All exhibits were chosen according to "novelty and usefulness." To ensure a broad-based selection of exhibits, national commissions nominated local representatives to solicit exhibits at the local level (*Bericht* 1853, pp.40 and 64). Britain, for instance, nominated 65 local commissions to identify exhibits for the Crystal Palace. Each local commissions established several collection points, and applicants were only required to pay for transport to their nearest local collection point. Inventors submitted a written application to their local commission, which specified "what is novell and important about the product, how its production shows special skillfulness and proves an original approach" (*Bericht* 1853, pp.50 and 117). A comprehensive system of evaluation and awards helped to enforce these criteria.

C. Identifying Patented Innovations

Exhibition data measure the patent status of 7,219 British and U.S. exhibits between 1851 and 1915. For the Crystal Palace fair in 1851, the data include all 6,377 British and all 550 U.S. exhibits. For three later fairs, the American Centennial Exhibition in Philadelphia in 1876, the World's Columbian Exposition in Chicago in 1893, and the Panama-Pacific International Exhibition in San Francisco in 1915, the data include all American chemical exhibits. This yields 139 chemical innovations in 1876, 63 chemical innovations in 1893, and 90 in 1915.

For British exhibits at the Crystal Palace, patented innovations can be identified from the descriptions in the exhibition catalogues. For example, J. Bendall's "universal self-adjusting cultivator … pat." denotes a patent. Exhibitors had strong incentives to report their patents truthfully: On the one hand, patents served as a stamp of approval that encouraged sales

(MacLeod 1988, p.85). On the other hand, jurors carefully checked all exhibits, so that exhibitors who reported fake patents faced a real risk of discovery.

U.S. exhibitors are matched by first name, last name, address, and the descriptions of their innovations. For example, I record the following entries 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

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 innovation. 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 (*U.S. Patent No. 7,066*, granted on February 5, 1850).[10]

D. High-quality Innovations

Awards to the most innovative exhibits provide a measure for the quality of innovations. International panels of 6 to 12 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 and 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). To identify award-winners, I have recorded detailed information on 745 British and 112 American awards from the reports of the German Commission to the Crystal Palace (*Bericht* 1853). Translated from the German, a typical entry looks like this:

[10] Google's new search engine (www.google.com/patents) facilitates this process for U.S. data in 1876, 1893, and 1915. This is particularly helpful because the exploding volume of U.S. patents after 1851 makes it virtually impossible to match exhibits manually with patent records. I have, however, matched all 1851 exhibits manually as well as electronically because Google's algorithm appears to miss some patents in the 1840s. Neither Google nor my manual search turns up any patents for chemical exhibits in 1851.

> 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

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

E. Urban Innovations

Measures of urbanization can be constructed by locating exhibits on 19th-century maps and matching towns with census data. Historical gazetteers like *Bartholomew's Gazetteer of the British Isles* (1887) are helpful for identifying towns whose names or borders have changed. For example, the *National Gazetteer of Great Britain and Ireland* (1868) reveals that Woodbridge is a market town and parish in the county of Suffolk. By this process, I can identify locations and city size for 5,317 British exhibits, 83.4 percent of all exhibits. Cities and towns that cannot be found are likely to be small. As an approximation, I assign them to towns with less than 10,000 inhabitants. Exhibits from London are defined as originating within the county (rather than the city) of London; this makes it possible to match current-day districts of London, such as Clerkenwell, Islington, and Westminster, to the city of London.

F. Potential Sources of Bias

There are three potential sources of bias in the exhibition data. Most importantly, the 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 (*Official Catalogue* 1851, p.210). If, however, the exhibition data under-represent innovations that were protected by secrecy, they will overestimate patenting rates.

The data may also underestimate large and heavy innovations that were too costly to transport to the fairs. Exhibition records suggest 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 exhibited as a model at the Crystal Palace (Rolt 1970, p.157). In 1851, 45 percent of Britain's 194 British exhibits in "Civil Engineering, Architecture, and Building Contrivances" were represented by models.

To check for bias due to transportation costs, I compare the locations of origin for British exhibits at the Crystal Palace with the locations of 835 British exhibits at the Centennial Exhibition in Philadelphia in 1876. If transportation costs bias the data toward London, the City's share of innovations should be lower at the American fair when differences in transportation costs within Britain 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 40.7 percent in 1876 compared with 39.1 percent in 1851.

Finally, the matching process may underestimate increases in patenting over time, particularly in chemicals. Under U.S. law, inventors can assign their patents to firms that want to market them. If these firms exhibit at the fair, matching exhibitors with patentees will miss some patents. Patent data for the state of Connecticut suggest that this bias is negligible for the Crystal Palace exhibition. Until 1851, only 1 in 454 patents, less than 0.2 percent of all Connecticut patents, were assigned (Figure 1).[11] Assignments did, however, become more common over time: By 1876, more than one third of all patents were assigned.

[11] High levels of economic and inventive activity make Connecticut a useful state to examine. The data start in 1836 because a fire at the U.S. Patent Office destroyed all earlier records.

To address this issue, I match exhibitors with assignees as well as with regular patents. If assigned patents are harder to match than regular patents, the exhibition data may underestimate an increase in patenting over time. This bias will be strongest in industries where innovation shifts from individuals to firms. Exhibition data suggests that this might be the case for chemicals. Among U.S. chemical exhibits, the share of companies increased from 15 percent in 1851 to 44 percent in 1876 and 85 percent in 1915. Thus, any potential bias due to missed assignments will make it harder to detect an increase in inventors' propensity to patent chemicals.

III. Empirical Tests of Inventors' Patenting Decisions across Industries

This section uses the exhibition data to test competing hypotheses about patenting decisions. First, inventors should be more likely to patent innovations if secrecy is ineffective relative to patents (high Δ_i in Equation 2). Second, inventors might be more likely to patent innovations that are more profitable (high π_i). And third, the effects of weak appropriability through secrecy should be larger for innovations that are more profitable (the interaction between high Δ_i and high π_i). Finally, increases in the cost of patenting C^p may discourage patenting.

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

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

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

To test these predictions, I compare patenting rates across industries (which differ in the relative effectiveness of patenting and secrecy), across countries (with different patent costs), and across different levels of quality.

One problem with this specification is that both profitability and the effectiveness of secrecy may vary across industries. To identify the effects of differences in profitability (while holding appropriability constant), I compare award-winners and other innovations within the same industry. Consider two steam engines, for example, which would be similarly vulnerable to reverse-engineering. One of the engines is of average quality, while the other engine wins an award for exceptional "novelty and usefulness." The *award* variable allows me to check which of these two innovations was (on average) more likely to be patented.

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, 11 percent of British innovations were patented (Table 2). The share of patented innovations is only slightly higher in the American data at 15 percent. This suggests that inventors relied heavily on alternative mechanisms to protect their intellectual property.

B. Patenting Rates Vary Significantly Across Industries

Exhibition data suggest that inventors' propensity to patent varies strongly across industries. Compared with an average of 11 percent across all industries, and a median of 10 percent for individual industries, patenting rates for British inventors range from 5 percent in mining and in chemicals to 30 percent in manufacturing machinery (Table 3). Other industries with low patenting rates are textiles with 7 percent and food processing with 8 percent.

Innovations in all four industries with low patenting rates were difficult to copy. Dyes featured prominently among 19th-century innovations in both chemicals and textiles; secret recipes, such as the one for *Coca-Cola* made up many 19th-century innovations in food processing. Similarly, innovations in mining and metallurgy were heavily dependent on craft-based tacit skills that were virtually impossible to imitate (Harris 1976, p.49). Swiss watchmakers, for instance, found it impossible to produce steel that was tractable enough to imitate the tiny files of British makers (Landes 1983, p.232).

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

Another prediction of the model is that profitability encourages patenting. If this is true, award-winning exhibits should be patented at greater frequencies; because they are more "novel and useful" they will also, on average, be more profitable.

Exhibition data confirm that award-winning innovations were more likely to be patented. In 1851, 16 percent of British award-winning exhibits were patented, compared with 11 percent of all exhibits (Table 3, bottom row). Coefficients for the *award* variable in logit and OLS regressions validate these results. Marginal effects for logit regressions imply that award-winning innovations were between 8 and 12 percent more likely to be patented (Table 6); linear probability regressions confirm these effects with increases between 8 and 11 percent (Table 7).

The data also show that differences in the propensity to patent are robust to the quality of innovations: Manufacturing machines have the highest patenting rate for both high-quality and average exhibits, followed by agricultural machines and engines (Table 3). Similarly, mining and metallurgy has the lowest patenting rates among hiqh-quality and average exhibits, followed by chemicals and textiles.

D. Quality Amplifies Differences in the Propensity to Patent across Industries

The data make it possible to test another prediction of the model: Variation in appropriability matters most for highly profitable innovations. If this is true, differences in patenting rates across industries should be more pronounced for award-winning exhibits.

In industries where inventors tend to rely on secrecy instead of patents the effect of quality is relatively small. Among British innovations in mining and metallurgy, 5.4 percent of high-quality innovations are patented, compared with 5.0 percent of all exhibits (Table 3). In chemicals, 8 percent of award-winning exhibits are patented, compared with 5 percent of average exhibits. In textiles, 9 percent of high-quality innovations are patented (compared with 7 percent), and in food processing, 10 percent of high-quality exhibits are patented (compared with 8 percent).

In industries where inventors tend to patent, however, high-quality innovations are significantly more likely to be patented than average-quality innovations. Forty-seven percent of award-winning manufacturing machines were patented (compared with 30 percent Table 3), 39 percent of engines (compared with 25 percent), and 41 of agricultural machinery (compared with 20 percent). Thus, the data indicate that quality amplifies variation across industries in the propensity to patent.

E. Large Differences in the Costs of Patenting have Limited Effects

Finally, increases in the cost of patenting C^p should lower inventors' propensity to patent. The comparison between British and American innovations yields an approximate test for this hypothesis. In 1851, both countries had the same patent length T (14 years), but the costs of patenting 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 expensive 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."[12]

Even after a patent was granted, enforcement was by no means guaranteed. British courts were biased against patentees, and no patent could be considered safe until it had been upheld by a judge (Dutton 1984, p.84; Khan 2005, pp.33-36). In contrast, the U.S. system was more favorable to inventors and easier to navigate. Because the costs of patenting were so different in Britain and in the United States, comparing the two countries offers a useful test for the effects of patent costs: 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 slight difference between overall patenting rates in Britain and the United States already suggests that the effect of patent costs on patenting was much smaller than expected (15.3 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 did not patent a great deal more than British inventors.

Moreover, the data indicate that American inventors used – and passed up – patents in the same industries as British inventors. In industries where British inventors tended to avoid patents, the proportion of patented innovations was roughly equal in the United States and Britain. Six percent of U.S. textiles exhibits were patented in 1851 compared with 7 percent of British exhibits (Table 3), and 7 percent of exhibits in food processing (compared with 8 percent in Britain). None of the U.S. chemical exhibits were patented (compared with 5 percent of British innovations).

Similar to high quality, cheaper patents amplified variation across industries. Exhibition data show that U.S. inventors were even more likely to patent machinery than British inventors.

[12] From the *Collected Works* of Jeremy Bentham (1843), cited in Coulter (1991, p.76). Charles Dickens' gives another vivid description of the British system in a "Poor Man's Tale of a Patent" (Dickens 1870, p.150-157). Another difference between the British and U.S. system is that the U.S. law grants priority to the first inventor, while the British law favors the first inventor to file an application. Scotchmer and Green (1990) show that first-to-file encourages patenting, which may help explain the relatively small difference between the U.S. and British rates.

Forty-four percent of U.S. exhibits in manufacturing machinery were patented (compared with 30 percent in Britain, Table 3), 42 percent of engines (compared with 25 percent), 37 percent of agricultural machinery (compared with 20 percent), and 24 percent in civil, naval, and military engineering (compared with 13 percent).

F. (Some) Urban Inventors Patent More

Exhibition data yield mixed evidence for the hypothesis that urban inventors patent more. In Britain, urban inventors are consistently more likely to patent their innovations: 12 percent of exhibits in towns with more than 10,000 people are patented, compared with 7 percent in rural areas ("All Urban" versus "Rural" in Table 4). Moreover, urban patenting rates exceed rural rates in all industries. In engines, for example, 27 percent of urban innovations are patented, compared with only 11 of rural innovations, and in agricultural machinery 22 percent of urban innovations are patented compared with 13 percent or rural innovations. These results support the hypotheses that familiarity with the patent law and higher risks of imitation encouraged patenting in cities (MacLeod 1988; Mokyr 1995).

Interestingly, the effects of urbanization appear to be much stronger in Britain than in the United States. Rural inventors in the United States are *more* likely to patent than inventors in cities above 10,000 and above 100,000 people (excluding New York, Figure 2). Although the sample of American innovations is relatively small, this finding supports Khan's (2005) argument that cheaper patents and easy access encouraged the democratization of patenting and invention.

There is, however, no clear relationship between patenting and city size. Both British and U.S. inventors were most likely to patent in the largest cities: 13 percent of London's inventors chose to patent compared with 11 percent in other large cities, 10 percent in smaller cities, and 7 percent in rural areas (Table 4). Similarly, 19 percent of New York's inventors chose to patent, compared with 15 percent in other large cities, 11 percent in smaller cities and 16 percent in rural areas (Figure 2). The relationship between city size and patenting, however, varies strongly across industries. In 5 of 10 industries, London's inventors were more likely to use patents than inventors in smaller cities: mining and metallurgy, engines, agricultural machinery, instruments, and manufactures.[13] Data for the remaining industries, however, show no clear effects of urbanization. Even within the machinery sector, the influence of city size remains ambiguous. In agricultural machinery, inventors are significantly more likely to patent in London (32 percent compared with 13 percent in other large cities and 21 percent in smaller cities, Table 4). In manufacturing machinery, however, London's inventors are *less* likely to patent (28 percent compared with 30 percent in other large cities, and 37 percent in smaller cities). Finally, city size appears to have no effect on patenting in engines (27 percent in London and small cities, compared with 25 in larger cities).

G. Putting it all Together: OLS Regressions by Industry

Linear probability regressions by industry make it possible to compare the relative strength of these effects. A linear approximation of equation (2) with a positive interaction term between profitability π_i and relative appropriability Δ_i yields the regression equation

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

OLS regressions by industry suggest that industries of origin are the most important determinant of patenting. The constant term, which measures industry variation, is largest for manufacturing machinery, and significant for 8 of 10 industries (Tables 5).

[13] Alternative categorizations of city size (such as 50k, 20, 10k, 2k, or 1k) do not change these results systematically. Differences between London and the rest of Britain are strongest in mining and metallurgy: 19 percent of London's exhibits are patented, compared with 4 percent in other large cities, 2 percent in smaller cities and 3 percent in rural towns. This difference may, however, reflect differences in the nature of rural and urban innovations. Exhibitors from London tended to focus on improvements in the construction of mines, as well as machinery and mining equipment, while rural inventors concentrated on mining apparatus and applications of new ores.

The quality of innovations emerges as the second most important factor. Award-winning innovations are more likely to be patented in 7 of 10 industries. The effect is largest for machines, with 24 to 27 percent in agricultural machines (Table 5D), 24 to 26 percent in manufacturing machines (Table 5C), and 17 to 25 percent in engines (Table 5B).

Differences between British and U.S. innovations are significant in 5 of 10 industries; similar to quality, the effect is largest for machinery. Engines are 23 to 29 percent more likely to be patented in the United States than in Britain (Table 5B); agricultural machines are between 20 and 24 percent more likely to be patented (Table 5D), and for manufacturing machines the effect is 17 to 18 percent (Table 5C).[14]

Urbanization effects are significant in 6 of 10 industries. Innovations in agricultural machines are 19 to 22 percent more likely to be patented in London (Table 5D), and innovations in mining and metallurgy are 14 to 16 percent more likely to be patented in London (Table 5A). Innovations in civil, military, and naval engineering are 10 to 14 percent more likely to be patented in London (Table 5C), scientific instruments 5 to 7 percent (Table 5D), and manufactures 4 to 6 percent (Table 5E). Regressions reveal no significant effects for other cities except for engines and civil engineering. For engines, inventors in large cities were 14 to 15 percent more likely to patent, and inventors in smaller cities were 15 to 16 percent more likely to patent.[15]

Thus, OLS regressions by industry confirm that quality encouraged patenting, and that U.S. inventors were slightly more likely to patent their innovations. Both of these effects vary across industries and are strongest for machines. As a cross check for these findings, I repeat all tests as logits and linear probability regressions with data across all industries.

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[14] High costs of patenting are commonly assumed to favor patenting (and thereby R&D investments) in capital-intensive industries, such as manufacturing machinery or engines (e.g., Khan 2005, p.31). Exhibition data, however, suggest that U.S. inventors were even *more* likely to patent in these industries than British inventors, despite cheaper patents. This suggests that the strength of industry effects outweighed the influence of capital-intensity.

[15] Alternative specifications of the city variables and interactions with *awards* yield no significant results.

H. Regressions across Industries

Logit and OLS regressions across industries confirm that inventors were more likely to patent machinery than innovations in any other industry. Marginal effects of logit regressions imply that inventors of manufacturing machinery were 20 to 23 percent more likely to patent (than inventors of manufactures, Table 6). Inventors in engines and agricultural machinery were also more likely to use patents, with marginal effects of 16 to 17 percent and 12 to 15 percent respectively (Table 6). In contrast, chemical innovations were 7 to 12 percent *less* likely to be patented and textiles 4 percent (Table 6). OLS regressions confirm these findings (Table 7).

Due to the small number of awards, interaction terms between awards and industries are not significant in logit regressions, but they are significant in OLS. Award-winning innovations in manufacturing machines were 15 to 16 percent more likely to be patented (Table 7). Combined with the effects of *award* and *manufacturing machinery*, this interaction term implies that award-winning manufacturing machines were 42 percent more likely to be patented than innovations in the control group, manufactures without awards (column II, Table 2). Similarly, award-winning exhibits of agricultural machines were 12 to 13 percent more likely to be patented and engines 8 percent, which implies an overall increase of 33 percent for agricultural machines and 34 percent for engines.

Data for award-winning British exhibits corroborate the finding that quality amplifies industry effects (Table 8). Marginal effects of logit regressions suggest that award-winning manufacturing machines were 28 percent more likely to be patented (Table 8, columns I-III). High-quality engines were 19 to 20 percent more likely to be patented and agricultural machinery 21 to 23 percent (Table 8, columns I-III). In contrast, high-quality chemicals and textiles were *less* likely to be patented, with marginal effects from -7 to -18 percent for chemicals and -8 percent for textiles (Table 8, columns I-III).

Regressions for U.S. data further strengthen these results (Table 9 and 10). Marginal effects indicate that innovations in manufacturing machinery were between 24 and 27 percent more likely to be patented (Table 9); OLS regressions confirm these increases (with 25 to 38 percent, Table 10). Similarly, engines were between 28 and 30 percent more likely to be patented and agricultural machinery 20 to 26 percent (Table 9). In comparison, exhibits in textiles were again 10 percent *less* likely to be patented.[16] American data also confirm that quality encourages patenting, with a 14 percent increase in logit regressions (Table 9) and a 12 to 16 percent increase in OLS (Table 10).[17] As comparisons of patenting rates across city have suggested (Figure 2), the effects of urbanization are ambiguous in the U.S. data.

In sum, the Crystal Palace data indicate that industries of origin are the key determinant of patenting, which outweighs the effects of other factors. Evidence from inventors' biographies suggests that differences in the ability to keep innovations secret may be the cause of such persistent industry effects. The following section takes advantage of an exogenous advance in science to examine the effects of changes in the effectiveness of secrecy on patenting.

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

If inventors' propensity to patent depends on the effectiveness of secrecy, patenting is likely to increase in response to fundamental advances in science and engineering. The chemical industry offers an opportunity to test this idea: In that industry, the advent of analytic chemistry in the mid 19th century introduced new tools of analysis, such as the periodic table, which drastically

[16] The dummy variable for chemicals is dropped because none of the U.S. exhibits in chemicals was patented.
[17] With 113 U.S. award-winners, there are too few observations to calculate reliable logits for U.S. awards. Dummy variables for chemicals and engines are dropped, but industry effects for manufacturing machinery remain robust.

improved competitors' ability to reverse-engineer innovations and thereby lowered the effectiveness of secrecy.

A. The Introduction of the Periodic Table in 1869

In the 1850s, "processes (of making chemicals and dyes) were simple and crude; exact knowledge was circumscribed and operations proceeded empirically" (Haber 1958, p.83). As a result, chemical innovations such as naphthalene or textile dyes were virtually impossible to copy. Crystal Palace data in the previous section has shown that they were also rarely patented.

Scientific breakthroughs in chemical analysis were about to change this. In 1839, the first laboratory for systematic chemical research was designed for Justus Liebig in Giessen, Germany. Over the next thirty years, other facilities were modeled after Liebig's lab.

> Liebig rightly attached great importance to the mastery of qualitative and quantitative analysis and he devised equipment which speeded up and simplified the procedure. The time taken for an analysis was cut from months or weeks to days (Haber 1958, p.64)

By the mid 19th century, more than 60 elements had been discovered, and chemists set out to determine their atomic weight, density, heat point, and other properties. This research yielded a collection of facts, but no rational ordering (Maher 1988, p.274).

In 1869, Dmitrii Mendeleev's ordered all known elements in the periodic table (Mendeleev 1869).[18] Mendeleev recognized that properties such as valence recur periodically if elements are organized by their atomic weight. He used gaps in periodic patterns to predict five unknown elements. Within a few years, three of Mendeleev's elements had been discovered (Asimov 1975, p.410; Maher 1988, p.274). This ability to predict chemical characteristics and systematically create chemical substances enabled 19th-century chemists to reverse-engineer innovations that had been securely protected by secrecy for hundreds of years.

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[18] Unlike other chemical treatises in Russian, Mendeleev's paper was translated almost immediately to German, the *lingua franca* of 19th-century chemistry (Scerri and Worrall 2001, p.414)

B. Madder Red and Indigo

Madder red was first produced from madder plants at Mohenjo-daro in the Indus Valley between 2600 and 1900 B.C. From Mohenjo-daro, the cultivation of madder spread to Asia Minor, Persia, Mesopotamia, North Africa, and Europe. By the mid 19th century, madder was grown in the south of France and in Alsace, the Palatinate, Holland, Silesia, Saxony, Tuscany, Sicily, and Boeotia. Even though they were in possession of the madder plant, Western growers failed to make their reds as bright and fast as Oriental dyers. In 1579, the English dyer Morgan Hubblethorne was sent to Persia for industrial espionage:

> …those cities and towns you must repair to, and you must use means to learn all the order of dyeing of those thrums, which are so dyed as neither raine, wine nor yet vinegar can staine…(Chenciner 2000, p.182)

As late as 1840, however, Western recipes included mystical substances like "not coagulated sheep blood [that] must be mixed with the water in the dyeing kettle right after the madder is added," and European efforts to copy madder red continued to fail (Chenciner 2000, p.193).

European chemists only began to crack the secret of madder red after 1869. In that year, Carl Graebe and Carl Lieberman synthesized one of its key components – alizarin. By 1876, Charles Strobel and Heinrich Caro had synthesized Alizarine orange and in 1878, Rudolf Nietzki was able to reproduce madder's scarlet shades (Brunello 1973, p.301).

Indigo experienced a similar fate. After more than 2,000 years of futile attempts at imitation, the German chemist Adolph Baeyer managed to synthesize indigo in 1880. On December 27, 1881, the U.S. Patent Office granted Baeyer Patent No. 251,671 for the "Preparation of New Material for the Manufacture of Artificial Indigo". At that time, Baeyer was able to specify the exact structure of synthetic indigo: ortho-dinitro-diacetenyl-phenyl. Once protected by a patent, Baeyer published the formula for indigo in 1883. Another 14 years later, in

1897, BASF established a commercially feasible manufacturing process, and by 1913 natural indigo had been almost entirely replaced by its synthetic cousin (Balfour-Paul 1998).[19]

C. Scientific Progress Increases the Propensity to Patent

Exhibition data show that such advances in the ability to analyze and reverse-engineer chemicals substantially increased inventors' propensity to patent. At the time of the Crystal Palace Exhibition in 1851, none of the United States' 32 chemical innovations had been patented (Table 3 and Figure 3). By 1876, only seven years after the introduction of the periodic table, 2.2 percent of U.S. chemical exhibits at the Centennial were patented (Figure 3).[20] The most significant increase occurred shortly thereafter: By 1893, 16 percent of U.S chemicals were protected by patents. In 1915, 18 percent of U.S. chemicals had been patented (Figure 3).

D. Chemical Patents Increase over Time and Relative to Other Industries

Patent data confirm that the number of chemical patents increased over time and relative to other industries. Between 1837 and 1869, less than a handful of U.S. patents, 0 percent of the total, were granted for dye stuffs (Figure 4). After 1869, however, inventors began to patent dyes. The share of dyes among U.S. patents increased to 0.1 percent in 1915, and, with significant fluctuations, to 0.5 percent in 1939 (Figure 4). 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). The full benefits of the periodic table may have materialized even later, as chemists became more familiar with new tools and developed practical applications.

[19] There was only one other patent for indigo until 1900, by Carl Duisberg in 1887 (U.S. Patent No. 368,078). Duisberg patented his process of creating a blue azo dye, and included a molecular model to clarify his specification.

[20] Chemists needed a few years to learn to use the periodic table and transfer their knowledge into praxis. As late as 1895, Henry Bowers 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." (Bowers 1895, p.431)

By the late 20th century, surveys suggest that chemicals had become *the* most patent-friendly industry. Edwin Mansfield's (1986) study 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 stated that patents were essential to developing and bringing to market more than 30 percent of their innovations. Similarly, Levin et al.'s (1987) survey of 650 manufacturing firms revealed that U.S. R&D labs in chemicals and pharmaceuticals found patents to be the most reliable mechanism to protect intellectual property. By 1994, chemicals and pharmaceuticals were the only 2 of 33 industries where firms considered patenting to be the most effective mechanism for protecting intellectual property (Cohen, Nelson, and Walsh 2000, p.10). Such reliance on patenting stands out against the near absence of patenting prior to the 1850s.

IV. Conclusions

This paper has used exhibition data for more than 7,000 innovations with and without patents to examine the patenting decisions of inventors. Three major findings have emerged from these data: (1) Inventors patent only a small share of innovations, (2) inventors' propensity to patent varies strongly across industries, and (3) scientific breakthroughs, which facilitate reverse-engineering, increase inventors' propensity to patent. Although innovative quality, urbanization, and lower patent costs also encourage patenting, the observed effects are relatively small.

These findings have important implications for patent policies. First, if only a small share of inventors chooses patent protection when patents are available, introducing patent laws in developing countries may have much weaker effects on domestic invention than one would expect, because most inventors have already found ways to protect their intellectual property by alternative means and do not need patents. Moreover, in industries where inventors are less dependent on patent protection, such as the software industry, the disadvantages of broad and far-reaching patents, including a higher risk of litigation, may outweigh the benefits of patents.

More generally, the adoption of patent laws may shift the focus of inventive activity and change international patterns of comparative advantage: Without patent laws, inventors focus on a small number of industries where they can use alternative mechanisms to appropriate the returns from R&D (Moser 2005). When patent laws are introduced, invention becomes profitable in a much broader range of industries because patents can create intellectual property where alternative mechanisms have failed. Without patent laws, differences in appropriability conditions determine inventors' choice of industry; with patent laws other factors become more important for determining the most profitable area for R&D. Thus, the introduction of patent laws may shift the focus of innovation to an entirely new set of industries.

Finally, fundamental advances in science may change what is the optimal policy for encouraging innovation. Scientific breakthroughs, such as the publication of the periodic table and the decoding of the human genome, facilitate reverse-engineering as they create powerful new tools of analysis. As a result, they not only increase the returns from invention, but also lower the effectiveness of secrecy, as one of the key mechanisms to appropriate returns from R&D. The findings of this paper suggest that inventors respond by patenting a larger share of innovations. This shift, however, intensifies existing pressures on the patent system. Innovation policies that integrate trade secrecy protection as a complementary policy instrument may help to alleviate such pressures on the patent system and thus encourage innovation.

REFERENCES

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

Anton, James D. and Dennis A. Yao. "Little Patents and Big Secrets: Managing Intellectual Property." *RAND Journal of Economics* 25.1 (2004): 1-22.

Arora, Ashish and Marco Ceccagnoli. "Profiting from licensing: The role of patent protection and commercialization capabilities." *Management Science* 52.2 (2006): 293-308.

Arrow, Kenneth. "The Economic Implications of Learning by Doing." *Review of Economic Studies* 29 (1962): 155-73.

Asimov, Issac. *Asimov's biographical encyclopedia of science and technology: the lives and achievements of 1510 great scientists from ancient times to the present chronologically arranged.* Pan Macmillan, 1975.

Balfour-Paul, Jenny. *Indigo.* London, UK: British Museum, 1998.

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.

Bowers, Henry. "The Chemical Industry." *1795-1895, One Hundred Years of American Commerce*. Ed. Depew, Chauncey M., LL.D. Philadelphia: D.O. Haynes Co., 1895. II volumes, 429-432.

Brunello, Franco. *The Art of Dyeing in the History of Mankind*. Vicenza: 1973.

Chenciner, Robert. *Madder Red, A History of Luxury and Trade. Plant Dyes and Pigments in World Commerce and Art*. Richmond, UK: Curzon, 2000.

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

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.

Dickens, Charles. *Hard Times for these Times.* New York: Hurd and Houghton, 1870.

Dragon, Andrea. "Wild Men. The First Twenty-five Years of the Rubber Industry." *Essays in Economic and Business History* 8 (1995): 217-229.

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

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

Friedman, David D., William M. Landes and Richard A. Posner. "Some Economics of Trade Secret Law." *Journal of Economic Perspectives* 5.1 (1991): 61-72.

Gilbert, Richard J. and David M. G. Newbery. "Preemptive Patenting and the Persistence of Monopoly." *The American Economic Review* 72.3 (1982): 514-526.

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, UK: Saunders and Benning, Law Booksellers, 1840.

Griliches, Zvi. "Patent Statistics as Economic Indicators." *Journal of Economic Literature* 28.4 (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.

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

Harris, John R. "Skills, Coal, and British Industry in the Eighteenth Century,“ *History* 61.292 (1976), 167-82.

Horstmann, Ignatius, Glenn M. MacDonald and Alan Slivinski. "Patents as Information Transfer Mechanisms: To Patent or (Maybe) Not to Patent." *The Journal of Political Economy* 93.5 (1985): 837-858.

Khan, B. Zorina. *The Democratization of Invention: patents and copyrights in American economic development, 1790-1920.* Cambridge, UK: Cambridge University Press, 2005.

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

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.

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

Levin, Richard C., Alvin K. Klevorick, Richard R. Nelson, Sidney G. Winter, Richard Gilbert, and Zvi

Griliches. "Appropriating the Returns from Industrial R&D." *Brookings Papers on Economic Activity* 3 (1987): 783-831.

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

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

Maher, Patrick. "Prediction, Accommodation, and the Logic of Discovery." *Philosophy of Science Association* 1 (1988): 273-285.

Mansfield, Edwin. "Patents and Innovation, and Empirical Study." *Management Science* 32 (1986): 173-181.

Mendeleev, Dmitri, "Űber die Beziehungen der Eigenschaften zu den Atomgewichten der Elemente." *Zeitschrift für Chemie* 7 (1869): 405-6.

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

Moser, Petra. "How Do Patent Laws Influence Innovation? Evidence from Nineteenth-Century World's Fairs." *American Economic Review* 94.4 (2005): 1214-1236.

Moser, Petra and Tom Nicholas. "Was Electricity a General Purpose Technology? Evidence from Historical Patent Citation." *American Economic Review* 94.2 (2004): 388-394.

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

Pendergrast, Mark. *For God, Country, and Coca-Cola*, *The Definite History of the Great American Soft Drink and the Company that Makes It*. New York: Basic Books, 2000.

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

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

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

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.

Scerri, Eric R. and John Worrall. "Prediction and the Periodic Table." *Studies in History and Philosophy of Science* 32.3 (2001): 407-452.

Schankerman, Mark and Ariel S. Pakes. "Estimates of the Value of Patent Rights in European Countries During the Post-1950 Period." *The Economic Journal* 96.384 (1986): 1052-1076.

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

Scotchmer Suzanne, and Jerry Green. “Novelty and Disclosure in Patent Law.” *The RAND Journal of Economics*, 21.1 (1990): 131-146.

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

Trajtenberg, Manuel. “A Penny for Your Quotes: Patent Citations and the Value of Innovations.” *RAND Journal of Economics* 21.1 (1990): 172-187.

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

Wallace, Anthony F. C. *Rockdale: the Growth of an American Village in the Early Industrial Revolution.* New York, NY: Knopf, 1978.

TABLE 1 – STATISTICS ON THE WORLDS' FAIRS OF 1851, 1876, 1893, AND 1915

	EXHIBITION			
	Crystal Palace	**Centennial**	**World's Columbian**	**Panama- Pacific**
Location	London	Philadelphia	Chicago	San Francisco
Year	1851	1876	1893	1915
Countries	40	35	45	32
Exhibitors	17,062	30,864	70,000	30,000
Visitors	6,039,195	9,892,625	27,500,000	19,000,000
Area (in acres)	25.7 for exhibition buildings	71.4 for buildings and grounds	717 for grounds 49 for buildings	635 for buildings and grounds
Prominent Exhibits	MacCormick's grain reaper, Colt's revolving handgun, steam engines, typewriter	Corliss steam engine, telephone, Edison's quadruplex telegraph	Electric escalator, electric elevated railway, floodlights, Ferris wheel	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%
United States	550	84	15.3%

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

	Britain				United States	
	All Exhibits		Award-winners		All Exhibits	
Industry	**Total**	**% Pat.**	**Total**	**% Pat.**	**Total**	**% Pat.**
Mining and metallurgy	418	5.0%	74	5.4%	52	7.7%
Chemicals	136	5.1%	75	8.0%	32	0.0%
Food processing	140	7.9%	73	9.6%	70	7.1%
Engines	406	24.6%	80	38.8%	31	42.0%
Manufacturing machinery	242	29.8%	70	47.1%	32	43.8%
Civil, mil., naval engineering	559	13.4%	88	15.9%	17	23.5%
Agricultural machinery	261	19.9%	37	40.5%	27	37.0%
Scientific instruments	581	9.6%	139	15.8%	74	16.2%
Manufactures	1,955	10.2%	601	16.3%	98	15.3%
Textiles	1,679	6.8%	522	8.6%	117	6.0%
All industries	6,377	11.1%	1,759	15.6%	550	15.3%

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." Exhibitors have been matched with lists of award-winners in the report of the German Commission to the Crystal Palace (*Bericht* 1853).

TABLE 4 – PATENTING RATES IN LONDON VERSUS THE REST OF BRITAIN

	London		Large Cities (>100k)		Small Cities (10-100k)		All Urban (>10k)		Rural (<10k)	
Industry	**Total**	**% Pat**	**Total**	**% Pat**	**Total**	**% Pat**	**Total**	**% Pat**	**Total**	**% Pat**
Mining and metallurgy	64	18.8%	47	4.3%	153	2.0%	264	6.4%	154	2.6%
Chemicals	49	6.1%	30	6.7%	27	7.4%	106	6.6%	30	0.0%
Food processing	44	11.4%	22	0.0%	33	12.1%	99	9.1%	41	4.9%
Engines	185	27.0%	85	24.7%	89	27.0%	359	26.5%	47	10.6%
Manuf. machinery	71	28.2%	81	29.6%	49	36.7%	201	30.8%	41	24.4%
Civ., mil., naval eng.	251	18.3%	79	19.0%	113	6.2%	443	15.4%	116	6.0%
Ag. machinery	53	32.1%	45	13.3%	96	20.8%	194	22.2%	67	13.4%
Instruments	331	12.1%	88	8.0%	90	3.3%	509	9.8%	72	8.3%
Manufactures	836	11.8%	504	9.3%	376	9.0%	1716	10.5%	239	8.0%
Textiles	608	6.9%	446	5.8%	416	8.2%	1470	6.9%	209	6.2%
All industries	2492	13.4%	1427	10.5%	1442	10.3%	5361	11.8%	1016	7.4%

Notes: Data from *Official Catalogue* (1851). Innovations with patents are identified in the descriptions of exhibits in the *Catalogue*. Locations are identified using 19^{th}-century maps, gazetteers, and census data.

TABLE 5.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**
Award	-0.03	-0.013	0.00	0.00	0.047	**0.071***	**0.063+**	**0.057+**
	[0.032]	[0.028]	[0.028]	[0.028]	[0.043]	**[0.035]**	**[0.033]**	**[0.032]**
U.S.	0.031	0.033	0.05	0.051	-0.027	-0.015	-0.028	-0.024
	[0.034]	[0.034]	[0.033]	[0.033]	[0.051]	[0.049]	[0.045]	[0.043]
London	**0.137****	**0.157****	**0.157****	**0.162****	0.022	0.059	0.059	0.015
	[0.037]	**[0.032]**	**[0.032]**	**[0.030]**	[0.061]	[0.044]	[0.044]	[0.036]
Large city (>100k)	-0.004	-0.003	0.004	-	0.058	0.061	0.059	-
	[0.033]	[0.033]	[0.033]	-	[0.045]	[0.045]	[0.045]	-
City (10-100k)	-0.014	-0.014	-0.012	-	0.07	0.074	0.074	-
	[0.024]	[0.024]	[0.024]	-	[0.049]	[0.049]	[0.049]	-
Award * U.S.	**0.304***	**0.286***	-	-	-0.045	-0.068	-	-
	[0.134]	**[0.133]**	-	-	[0.106]	[0.103]	-	-
Award * London	0.078	-	-	-	0.064	-	-	-
	[0.068]	-	-	-	[0.072]	-	-	-
Constant	**0.037***	**0.034+**	**0.03+**	**0.025***	-0.022	-0.037	-0.032	0.015
	[0.018]	**[0.018]**	**[0.018]**	**[0.012]**	[0.044]	[0.041]	[0.040]	[0.028]
Observations	470	470	470	470	168	168	168	168
R-squared	0.07	0.07	0.06	0.06	0.05	0.05	0.05	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 at 5%; and ** significant at 1 percent.

TABLE 5.B – U.S. AND BRITAIN, LINEAR PROBABILITY REGRESSION
INDEPENDENT VARIABLE IS 1 FOR A PATENTED EXHIBIT AND 0 OTHERWISE

	Food processing				Engines			
	I	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**
Award	0.046	0.036	0.027	0.03	**0.247****	**0.181****	**0.172****	**0.17****
	[0.055]	[0.045]	[0.038]	[0.038]	**[0.070]**	**[0.054]**	**[0.053]**	**[0.054]**
U.S.	0.037	0.032	0.021	0.014	**0.285****	**0.271****	**0.247****	**0.225****
	[0.056]	[0.054]	[0.043]	[0.042]	**[0.086]**	**[0.086]**	**[0.085]**	**[0.083]**
London	0.059	0.042	0.043	0.049	**0.201****	**0.169***	**0.165***	0.052
	[0.076]	[0.055]	[0.054]	[0.049]	**[0.070]**	**[0.067]**	**[0.067]**	[0.043]
Large city (>100k)	-0.058	-0.057	-0.054	-	**0.146***	**0.146***	**0.138+**	-
	[0.053]	[0.052]	[0.051]	-	**[0.071]**	**[0.071]**	**[0.071]**	-
City (10-100k)	0.018	0.018	0.019	-	**0.155***	**0.153***	**0.149***	-
	[0.049]	[0.049]	[0.049]	-	**[0.073]**	**[0.073]**	**[0.073]**	-
Award * U.S.	-0.039	-0.029	-	-	**-0.732+**	-0.667	-	-
	[0.089]	[0.083]	-	-	**[0.443]**	[0.441]	-	-
Award * London	-0.031	-	-	-	-0.158	-	-	-
	[0.098]	-	-	-	[0.109]	-	-	-
Constant	0.047	0.051	0.055	0.047	0.054	0.069	0.076	**0.189****
	[0.045]	[0.042]	[0.041]	[0.033]	[0.061]	[0.060]	[0.060]	**[0.031]**
Observations	210	210	210	210	437	437	437	437
R-squared	0.02	0.02	0.02	0.01	0.06	0.05	0.05	0.04

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 at 5%; and ** significant at 1 percent.

TABLE 5.C – U.S. AND BRITAIN, LINEAR PROBABILITY REGRESSION
INDEPENDENT VARIABLE IS 1 FOR A PATENTED EXHIBIT AND 0 OTHERWISE

	Manufacturing machinery				Civil, military, and naval engineering			
	I	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**
Award	**0.241****	**0.243****	**0.258****	**0.259****	0.035	0.053	0.064	0.061
	[0.075]	**[0.064]**	**[0.062]**	**[0.061]**	[0.048]	[0.040]	[0.039]	[0.039]
U.S.	0.146	0.147	**0.178***	**0.173***	0.016	0.02	0.088	0.136
	[0.097]	[0.096]	**[0.088]**	**[0.087]**	[0.103]	[0.102]	[0.086]	[0.085]
London	0.028	0.03	0.032	-0.004	**0.131****	**0.14****	**0.141****	**0.097****
	[0.093]	[0.085]	[0.085]	[0.064]	**[0.041]**	**[0.039]**	**[0.039]**	**[0.029]**
Large city (>100k)	0.029	0.029	0.03	-	**0.141****	**0.142****	**0.138****	-
	[0.079]	[0.079]	[0.079]	-	**[0.048]**	**[0.048]**	**[0.048]**	-
City (10-100k)	0.076	0.076	0.076	-	0.019	0.021	0.022	-
	[0.089]	[0.089]	[0.089]	-	[0.045]	[0.045]	[0.045]	-
Award * U.S.	0.186	0.184	-	-	0.246	0.228	-	-
	[0.233]	[0.229]	-	-	[0.187]	[0.186]	-	-
Award * London	0.007	-	-	-	0.063	-	-	-
	[0.147]	-	-	-	[0.089]	-	-	-
Constant	**0.194****	**0.193****	**0.188****	**0.224****	0.044	0.038	0.037	**0.081****
	[0.070]	**[0.069]**	**[0.068]**	**[0.039]**	[0.034]	[0.033]	[0.033]	**[0.021]**
Observations	274	274	274	274	576	576	576	576
R-squared	0.08	0.08	0.07	0.07	0.04	0.04	0.04	0.02

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 at 5%; and ** significant at 1 percent.

TABLE 5.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**
Award	**0.274****	**0.268****	**0.241****	**0.245****	**0.107***	**0.074***	**0.091****	**0.091****
	[0.074]	**[0.072]**	**[0.067]**	**[0.067]**	**[0.050]**	**[0.030]**	**[0.028]**	**[0.028]**
U.S.	**0.244****	**0.244****	**0.203***	**0.198***	0.053	0.046	**0.078+**	**0.098***
	[0.091]	**[0.090]**	**[0.082]**	**[0.081]**	[0.047]	[0.046]	**[0.043]**	**[0.040]**
London	**0.216****	**0.212****	**0.208****	**0.185****	**0.068+**	0.055	0.056	**0.048+**
	[0.074]	**[0.073]**	**[0.073]**	**[0.062]**	**[0.041]**	[0.037]	[0.037]	**[0.025]**
Large city (>100k)	0.011	0.011	0.005	-	0.038	0.035	0.039	-
	[0.071]	[0.071]	[0.071]	-	[0.043]	[0.043]	[0.043]	-
City (10-100k)	0.048	0.048	0.05	-	-0.016	-0.021	-0.016	-
	[0.061]	[0.060]	[0.060]	-	[0.046]	[0.045]	[0.045]	-
Award * U.S.	-0.232	-0.226	-	-	0.133	**0.166+**	-	-
	[0.212]	[0.211]	-	-	[0.103]	**[0.094]**	-	-
Award * London	-0.087	-	-	-	-0.051	-	-	-
	[0.297]	-	-	-	[0.062]	-	-	-
Constant	**0.098***	**0.099***	**0.104***	**0.127****	0.037	0.045	0.039	**0.047***
	[0.049]	**[0.048]**	**[0.048]**	**[0.030]**	[0.036]	[0.034]	[0.034]	**[0.020]**
Observations	288	288	288	288	655	655	655	655
R-squared	0.09	0.08	0.08	0.08	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 at 5%; and ** significant at 1 percent.

TABLE 5.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**
Award	**0.077****	**0.095****	**0.098****	**0.097****	**0.059****	**0.026+**	**0.028***	**0.028***
	[0.019]	**[0.015]**	**[0.015]**	**[0.015]**	**[0.017]**	**[0.013]**	**[0.013]**	**[0.013]**
U.S.	0.055	**0.062+**	**0.079***	**0.077***	-0.001	-0.012	-0.004	-0.007
	[0.036]	**[0.036]**	**[0.032]**	**[0.032]**	[0.028]	[0.028]	[0.025]	[0.025]
London	**0.041+**	**0.055***	**0.055***	**0.04****	0.024	-0.004	-0.004	0.001
	[0.023]	**[0.022]**	**[0.022]**	**[0.014]**	[0.021]	[0.019]	[0.019]	[0.013]
Large city (>100k)	0.016	0.015	0.015	-	-0.017	-0.015	-0.015	-
	[0.023]	[0.023]	[0.023]	-	[0.020]	[0.020]	[0.020]	-
City (10-100k)	0.023	0.025	0.025	-	0.003	0.005	0.005	-
	[0.024]	[0.024]	[0.024]	-	[0.020]	[0.020]	[0.020]	-
Award * U.S.	0.094	0.076	-	-	-0.002	0.031	-	-
	[0.077]	[0.076]	-	-	[0.056]	[0.056]	-	-
Award * London	0.048	-	-	-	**-0.091****	-	-	-
	[0.031]	-	-	-	**[0.028]**	-	-	-
Constant	**0.047***	**0.04***	**0.039***	**0.055****	**0.056****	**0.065****	**0.064****	**0.06****
	[0.020]	**[0.020]**	**[0.020]**	**[0.010]**	**[0.017]**	**[0.017]**	**[0.017]**	**[0.009]**
Observations	2053	2053	2053	2053	1796	1796	1796	1796
R-squared	0.03	0.03	0.02	0.02	0.01	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 at 5%; and ** significant at 1 percent.

TABLE 6 – BRITISH AND U.S. EXHIBITS IN 1851, LOGIT REGRESSIONS (MARGINAL EFFECTS)
DEPENDENT VARIABLE IS 1 FOR PATENTED EXHIBITS

	I	II	III	IV	V	VI
Award	**0.123****	**0.124****	**0.124****	**0.102****	**0.081****	**0.081****
	[0.026]	**[0.022]**	**[0.022]**	**[0.014]**	**[0.010]**	**[0.010]**
US	**0.082+**	**0.089+**	**0.087****	**0.085****	**0.077****	**0.077****
	[0.045]	**[0.047]**	**[0.023]**	**[0.023]**	**[0.019]**	**[0.019]**
London	**0.076****	**0.083****	**0.082****	**0.081****	**0.066****	**0.041****
	[0.028]	**[0.016]**	**[0.015]**	**[0.015]**	**[0.013]**	**[0.008]**
Large city (>100k)	0.024	**0.029***	**0.029***	**0.030***	**0.030***	-
	[0.028]	**[0.014]**	**[0.013]**	**[0.013]**	**[0.013]**	-
Small city (10-100k)	0.03	**0.032***	**0.032***	**0.031***	**0.030***	-
	[0.028]	**[0.014]**	**[0.014]**	**[0.014]**	**[0.014]**	-
Award * US	0.011	0.006	-0.011	-0.011	-	-
	[0.031]	[0.031]	[0.024]	[0.023]	-	-
Award * London	**-0.030***	**-0.033****	**-0.032****	**-0.032****	-	-
	[0.013]	**[0.012]**	**[0.012]**	**[0.011]**	-	-
Mining and metallurgy	-0.03	-0.018	-0.02	**-0.035***	**-0.036****	**-0.039****
	[0.030]	[0.021]	[0.018]	**[0.014]**	**[0.013]**	**[0.013]**
Chemicals	**-0.120****	**-0.075****	**-0.086****	**-0.065****	**-0.066****	**-0.066****
	[0.005]	**[0.024]**	**[0.015]**	**[0.013]**	**[0.013]**	**[0.013]**
Food processing	0.018	-0.001	-0.025	**-0.039***	**-0.040***	**-0.042****
	[0.064]	[0.040]	[0.027]	**[0.015]**	**[0.015]**	**[0.015]**
Engines	0.089	**0.162****	**0.171****	**0.158****	**0.158****	**0.158****
	[0.067]	**[0.030]**	**[0.029]**	**[0.024]**	**[0.024]**	**[0.024]**
Manufacturing machinery	**0.228***	**0.197****	**0.203****	**0.210****	**0.209****	**0.208****
	[0.092]	**[0.042]**	**[0.039]**	**[0.031]**	**[0.031]**	**[0.031]**
Civ., mil., naval engineering	0	**0.065****	**0.065****	**0.047****	**0.048****	**0.045****
	[0.039]	**[0.022]**	**[0.021]**	**[0.017]**	**[0.017]**	**[0.017]**
Agricultural machinery	**0.115+**	**0.144****	**0.147****	**0.144****	**0.142****	**0.139****
	[0.069]	**[0.036]**	**[0.034]**	**[0.029]**	**[0.029]**	**[0.028]**
Instruments	0.002	-0.002	0	-0.002	-0.003	-0.004
	[0.042]	[0.017]	[0.017]	[0.013]	[0.013]	[0.013]
Textiles	0.029	-0.014	-0.019	**-0.037****	**-0.038****	**-0.038****
	[0.034]	[0.013]	[0.012]	**[0.009]**	**[0.009]**	**[0.009]**
Award * Mining	**-0.053****	**-0.050***	**-0.048+**	-	-	-
	[0.020]	**[0.024]**	**[0.025]**	-	-	-
Award * Chemical	0.096	0.085	0.157	-	-	-
	[0.164]	[0.163]	[0.206]	-	-	-
Award * Food processing	**-0.044+**	-0.042	-0.032	-	-	-
	[0.024]	[0.030]	[0.034]	-	-	-
Award * Engines	-0.01	-0.008	-0.012	-	-	-
	[0.022]	[0.025]	[0.023]	-	-	-
Award * Manuf. machinery	0.01	0.016	0.014	-	-	-
	[0.029]	[0.033]	[0.031]	-	-	-
Award * Civ., mil., nav. eng.	-0.03	**-0.037+**	**-0.036+**	-	-	-
	[0.020]	**[0.019]**	**[0.019]**	-	-	-
Award * Agricult. machinery	0.012	0.008	0.009	-	-	-
	[0.037]	[0.037]	[0.036]	-	-	-
Award * Instruments	-0.006	-0.002	-0.001	-	-	-
	[0.024]	[0.027]	[0.026]	-	-	-
Award * Textiles	**-0.040****	**-0.041****	**-0.039****	-	-	-
	[0.013]	**[0.014]**	**[0.014]**	-	-	-

(CONTINUED ON THE NEXT PAGE)

TABLE 6 (CONTINUED)

	I	II	III	IV	V	VI
USA * Industry	Yes	Yes	No	No	No	No
London * Industry	Yes	No	No	No	No	No
Large city * Industry	Yes	No	No	No	No	No
Small city * Industry	Yes	No	No	No	No	No
Observations	6,895	6,895	6,927	6,927	6,927	6,927
Percent predicted correctly	86.7%	88.6%	88.6%	88.6%	88.6%	88.6%
Pseudo R-squared	0.09	0.08	0.08	0.08	0.08	0.08

Notes: Data from the *Official Catalogue* (1851), the *Annual Reports of the United States Patent Office* (1841 - 1851) and (*Bericht* 1853). Manufactures is the omitted industry class. Standard errors are in brackets; + denotes significance at 10 percent; * significance at 5%; and ** significance at 1 percent. An outcome is defined as correctly predicted if the predicted probability of patenting is at least 0.5 for a patented exhibit.

TABLE 7 – BRITISH AND U.S. EXHIBITS IN 1851, LINEAR PROBABILITY REGRESSIONS
DEPENDENT VARIABLE IS 1 FOR PATENTED EXHIBITS

	I	II	III	IV	V	VI
Award	**0.108****	**0.106****	**0.107****	**0.09****	**0.08****	**0.08****
	[0.020]	**[0.016]**	**[0.016]**	**[0.011]**	**[0.009]**	**[0.009]**
US	**0.07***	**0.071***	**0.066****	**0.067****	**0.069****	**0.07****
	[0.034]	**[0.033]**	**[0.016]**	**[0.016]**	**[0.015]**	**[0.014]**
London	**0.062****	**0.071****	**0.07****	**0.069****	**0.061****	**0.041****
	[0.023]	**[0.012]**	**[0.012]**	**[0.012]**	**[0.011]**	**[0.008]**
Large city (>100k)	0.018	**0.026***	**0.026***	**0.026***	**0.027***	-
	[0.025]	**[0.012]**	**[0.012]**	**[0.012]**	**[0.012]**	-
Small city (10-100k)	0.027	**0.028***	**0.027***	**0.027***	**0.026***	-
	[0.025]	**[0.012]**	**[0.012]**	**[0.012]**	**[0.012]**	-
Award * US	0.045	0.041	0.021	0.018	-	-
	[0.036]	[0.036]	[0.035]	[0.035]	-	-
Award * London	-0.023	-0.03	-0.029	**-0.03+**	-	-
	[0.021]	[0.018]	[0.018]	**[0.018]**	-	-
Mining and metallurgy	-0.006	-0.005	-0.01	**-0.027+**	**-0.029+**	**-0.033***
	[0.032]	[0.019]	[0.018]	**[0.016]**	**[0.016]**	**[0.016]**
Chemicals	-0.071	-0.045	**-0.072***	**-0.079****	**-0.08****	**-0.082****
	[0.065]	[0.039]	**[0.034]**	**[0.025]**	**[0.025]**	**[0.025]**
Food processing	0.021	0.009	-0.021	**-0.049***	**-0.048***	**-0.052***
	[0.051]	[0.036]	[0.031]	**[0.023]**	**[0.023]**	**[0.023]**
Engines	0.038	**0.139****	**0.152****	**0.162****	**0.162****	**0.161****
	[0.047]	**[0.019]**	**[0.018]**	**[0.016]**	**[0.016]**	**[0.016]**
Manufacturing machinery	**0.151****	**0.158****	**0.173****	**0.214****	**0.214****	**0.213****
	[0.051]	**[0.025]**	**[0.023]**	**[0.020]**	**[0.020]**	**[0.020]**
Civil, military, naval engineering	-0.001	**0.055****	**0.056****	**0.046****	**0.047****	**0.044****
	[0.036]	**[0.016]**	**[0.016]**	**[0.015]**	**[0.015]**	**[0.015]**
Agricultural machinery	0.069	**0.109****	**0.118****	**0.132****	**0.132****	**0.13****
	[0.042]	**[0.022]**	**[0.021]**	**[0.020]**	**[0.020]**	**[0.020]**
Instruments	0.001	-0.003	-0.001	-0.002	-0.003	-0.003
	[0.040]	[0.017]	[0.016]	[0.014]	[0.014]	[0.014]
Textiles	0.026	-0.008	-0.013	**-0.035****	**-0.035****	**-0.035****
	[0.029]	[0.012]	[0.012]	**[0.010]**	**[0.010]**	**[0.010]**
Award * Mining	**-0.104***	**-0.09***	**-0.087***	-	-	-
	[0.042]	**[0.041]**	**[0.041]**	-	-	-
Award * Chemicals	-0.04	-0.042	-0.02	-	-	-
	[0.053]	[0.052]	[0.050]	-	-	-
Award * Food processing	**-0.087+**	**-0.082+**	-0.065	-	-	-
	[0.047]	**[0.047]**	[0.046]	-	-	-
Award * Engines	**0.075+**	**0.075+**	0.063	-	-	-
	[0.041]	**[0.041]**	[0.041]	-	-	-
Award * Manufacturing machinery	**0.155****	**0.159****	**0.152****	-	-	-
	[0.045]	**[0.044]**	**[0.044]**	-	-	-
Award * Civil, mil., and naval eng.	-0.038	-0.047	-0.045	-	-	-
	[0.039]	[0.038]	[0.038]	-	-	-
Award * Agricultural machinery	**0.131***	**0.115***	**0.12***	-	-	-
	[0.055]	**[0.054]**	**[0.054]**	-	-	-
Award * Instruments	-0.006	0	0	-	-	-
	[0.033]	[0.032]	[0.032]	-	-	-
Award * Textiles	**-0.072****	**-0.072****	**-0.07****	-	-	-
	[0.022]	**[0.022]**	**[0.022]**	-	-	-

(CONTINUED ON THE NEXT PAGE)

TABLE 7 (CONTINUED)

	I	II	III	IV	V	VI
Constant	**0.036+**	**0.03***	**0.03***	**0.036****	**0.039****	**0.06****
	[0.021]	**[0.013]**	**[0.012]**	**[0.012]**	**[0.012]**	**[0.008]**
USA * Industry	Yes	Yes	No	No	No	No
London * Industry	Yes	No	No	No	No	No
Large city * Industry	Yes	No	No	No	No	No
Small city * Industry	Yes	No	No	No	No	No
Observations	6,927	6,927	6,927	6,927	6,927	6,927
R-squared	0.07	0.07	0.07	0.06	0.06	0.06

Notes: Data from the *Official Catalogue* (1851), the *Annual Reports of the United States Patent Office* (1841 - 1851) and (*Bericht* 1853). Manufactures is the omitted industry class. Standard errors are in brackets; + denotes significance at 10 percent; * significance at 5%; and ** significance at 1 percent.

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

	Logit (I-III)			OLS (IV-VI)		
	I	II	III	IV	V	VI
London	**0.082***	**0.090****	0.023	**0.111***	**0.076****	0.022
	[0.041]	**[0.032]**	[0.018]	**[0.044]**	**[0.025]**	[0.018]
Large city (>100k)	0.027	**0.060+**	-	0.03	**0.047+**	
	[0.038]	**[0.033]**	-	[0.044]	**[0.026]**	
Small city (10-100k)	0.073	**0.136****	-	0.086	**0.108****	
	[0.054]	**[0.042]**	-	[0.053]	**[0.028]**	
Mining and metallurgy	**-0.139****	**-0.096****	**-0.097****	-0.102	**-0.109***	**-0.107***
	[0.009]	**[0.024]**	**[0.025]**	[0.077]	**[0.044]**	**[0.043]**
Chemicals	**-0.179****	**-0.071***	**-0.074***	-0.102	**-0.08+**	**-0.084+**
	[0.012]	**[0.029]**	**[0.029]**	[0.086]	**[0.043]**	**[0.043]**
Food processing	0.008	**-0.059+**	**-0.059+**	0.009	-0.068	-0.067
	[0.076]	**[0.031]**	**[0.032]**	[0.090]	[0.043]	[0.043]
Engines	0.073	**0.186****	**0.197****	0.08	**0.217****	**0.223****
	[0.116]	**[0.054]**	**[0.055]**	[0.111]	**[0.042]**	**[0.042]**
Manufacturing machinery	0.059	**0.278****	**0.282****	0.064	**0.307****	**0.31****
	[0.108]	**[0.063]**	**[0.063]**	[0.107]	**[0.044]**	**[0.044]**
Civil, mil., naval engineering	-0.011	0.008	-0.002	-0.011	0.008	-0.002
	[0.055]	[0.039]	[0.037]	[0.071]	[0.040]	[0.040]
Agricultural machinery	0.159	**0.206***	**0.231****	0.17	**0.233****	**0.249****
	[0.142]	**[0.082]**	**[0.081]**	[0.111]	**[0.060]**	**[0.060]**
Instruments	0.044	-0.01	-0.011	0.048	-0.011	-0.012
	[0.082]	[0.029]	[0.029]	[0.086]	[0.033]	[0.033]
Textiles	-0.013	**-0.084****	**-0.079****	-0.013	**-0.086****	**-0.078****
	[0.048]	**[0.018]**	**[0.018]**	[0.059]	**[0.021]**	**[0.021]**
Constant	-	-	-	**0.102****	**0.104****	**0.156****
	-	-	-	**[0.037]**	**[0.024]**	**[0.015]**
London * Industry	Yes	No	No	Yes	No	No
Large city * Industry	Yes	No	No	Yes	No	No
Small city * Industry	Yes	No	No	Yes	No	No
Observations	1,759	1,759	1,759	1,759	1,759	1,759
Percent predicted correctly	81.4%	84.4%	84.4%	-	-	-
(Pseudo) R-squared	0.08	0.11	0.09	0.011	0.08	0.08

Notes: Data from the *Official Catalogue* (1851), the *Annual Reports of the United States Patent Office* (1841 - 1851) and (*Bericht* 1853). Manufactures is the omitted industry class. Standard errors are in brackets; + denotes significance at 10 percent; * significance at 5%; and ** significance at 1 percent. An outcome is defined as correctly predicted if the predicted probability of patenting is at least 0.5 for a patented exhibit.

TABLE 9 – U.S. EXHIBITS 1851, LOGIT REGRESSIONS (MARGINAL EFFECTS)
DEPENDENT VARIABLE IS 1 FOR PATENTED EXHIBITS

	I	II	III	IV
Award	0.018	0.138	**0.137****	**0.140****
	[0.073]	[0.099]	**[0.049]**	**[0.049]**
Large city (>100k)	0.039	0.013	0.012	-
	[0.061]	[0.034]	[0.034]	-
Small city (10-100k)	-0.005	-0.049	-0.046	-
	[0.076]	[0.037]	[0.037]	-
Mining and metallurgy	0.024	-0.058	-0.047	-0.054
	[0.097]	[0.050]	[0.048]	[0.046]
Food processing	0.022	-0.06	**-0.080***	**-0.085***
	[0.093]	[0.052]	**[0.035]**	**[0.034]**
Engines	0.238	**0.300***	**0.278***	**0.285****
	[0.203]	**[0.120]**	**[0.109]**	**[0.108]**
Manufacturing machinery	0.324	**0.243***	**0.271***	**0.273****
	[0.239]	**[0.118]**	**[0.106]**	**[0.106]**
Civil, military, and naval engineering	**-0.136****	0.037	0.054	0.059
	[0.021]	[0.114]	[0.094]	[0.097]
Agricultural machinery	0.312	**0.263***	**0.219***	**0.203+**
	[0.246]	**[0.130]**	**[0.109]**	**[0.105]**
Scientific instruments	**-0.511****	-0.011	0.004	0.011
	[0.047]	[0.055]	[0.048]	[0.050]
Textiles	0.02	**-0.095***	**-0.098****	**-0.099****
	[0.081]	**[0.043]**	**[0.033]**	**[0.034]**
Award * Industry	Yes	Yes	No	No
Large city * Industry	Yes	No	No	No
Small city * Industry	Yes	No	No	No
Observations	495	517	518	518
Percent predicted correctly	78.2%	85.5%	84.7%	84.7%
Pseudo R-squared	0.08	0.18	0.15	0.014

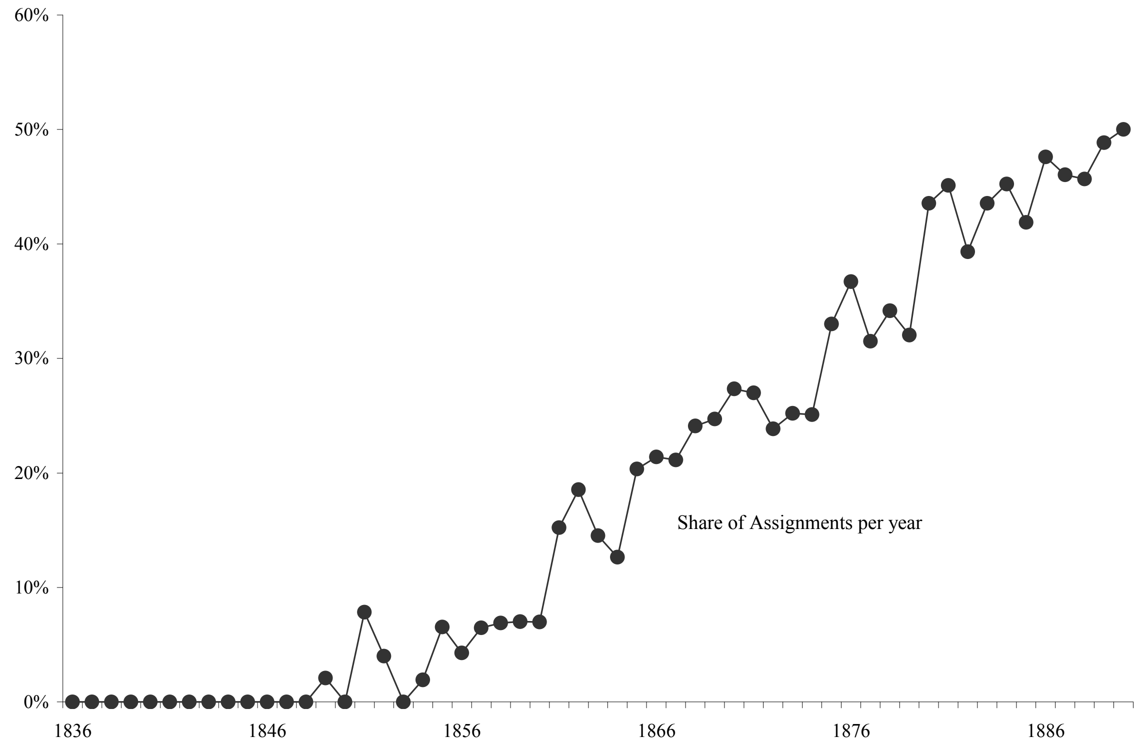
Notes: Data from the *Official Catalogue* (1851), the *Annual Reports of the United States Patent Office* (1841 - 1851) and (*Bericht* 1853). In logit regressions, chemicals has been dropped because none of the U.S. exhibits in chemicals were patented. Manufactures is the omitted industry class. Standard errors are in brackets; + denotes significant at 10 percent; * significant at 5%; and ** significant at 1 percent. An outcome is defined as correctly predicted if the predicted probability of patenting for a patented exhibit is at least 0.5.

TABLE 10 – U.S. EXHIBITS 1851, OLS REGRESSIONS
DEPENDENT VARIABLE IS 1 FOR PATENTED EXHIBITS

	I	**II**	**III**	**IV**
Award	0.067	**0.158+**	**0.121****	**0.121****
	[0.099]	**[0.083]**	**[0.037]**	**[0.037]**
Big city (>100k)	0.071	0.014	0.016	-
	[0.089]	[0.035]	[0.035]	-
Small city (10-100k)	0.002	-0.047	-0.045	-
	[0.103]	[0.043]	[0.042]	
Mining and metallurgy	0.038	-0.049	-0.049	-0.057
	[0.112]	[0.062]	[0.058]	[0.058]
Chemicals	-0.061	**-0.125+**	**-0.153***	**-0.146***
	[0.160]	**[0.075]**	**[0.069]**	**[0.069]**
Food processing	0.045	-0.053	**-0.09+**	**-0.095+**
	[0.108]	[0.062]	**[0.053]**	**[0.053]**
Engines	**0.284***	**0.31****	**0.284****	**0.288****
	[0.127]	**[0.073]**	**[0.070]**	**[0.070]**
Manufacturing machinery	**0.376****	**0.249****	**0.289****	**0.291****
	[0.143]	**[0.075]**	**[0.069]**	**[0.069]**
Civil, military, and naval engineering	-0.196	0.038	0.066	0.073
	[0.208]	[0.105]	[0.089]	[0.089]
Agricultural machinery	**0.355***	**0.253****	**0.228****	**0.221****
	[0.150]	**[0.081]**	**[0.073]**	**[0.073]**
Scientific instruments	-0.09	-0.012	0.003	0.012
	[0.127]	[0.058]	[0.052]	[0.052]
Textiles	0.052	-0.077	**-0.099***	**-0.097***
	[0.099]	[0.053]	**[0.046]**	**[0.046]**
Constant	0.079	**0.123****	**0.129****	**0.127****
	[0.077]	**[0.047]**	**[0.044]**	**[0.035]**
Award * Industry	Yes	Yes	No	No
Large city * Industry	Yes	No	No	No
Small city * Industry	Yes	No	No	No
Observations	550	550	550	550
R-squared	0.19	0.16	0.14	0.14

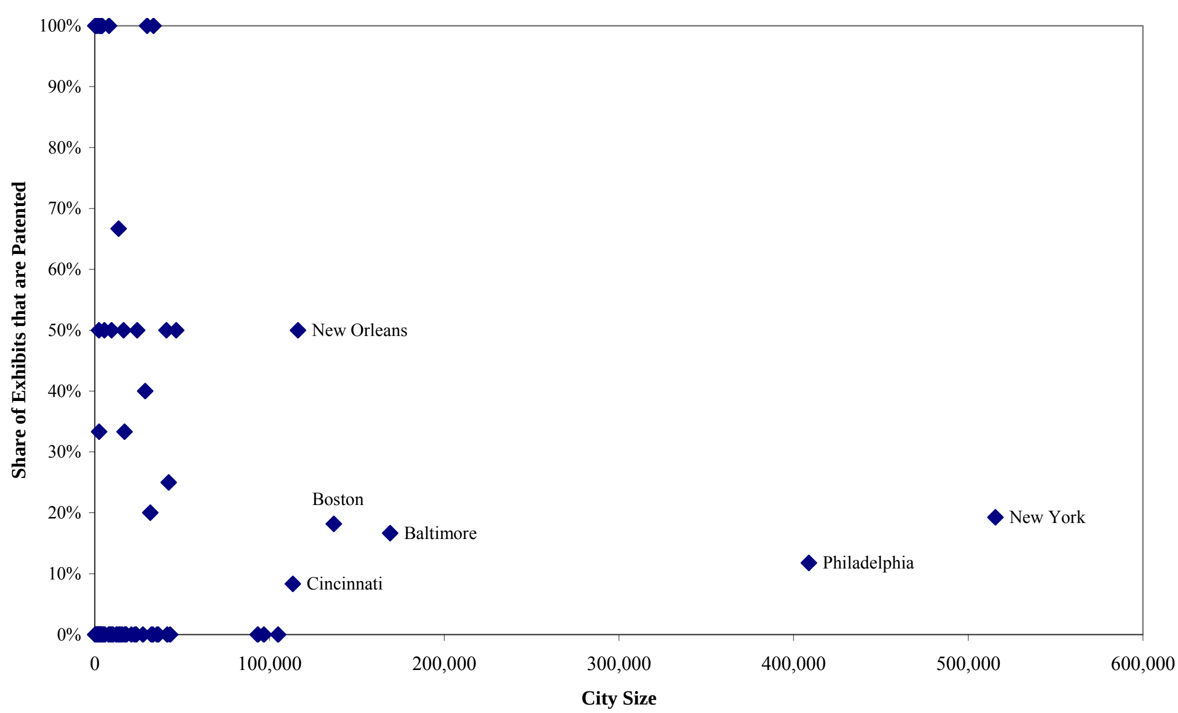
Notes: Data from the *Official Catalogue* (1851), the *Annual Reports of the United States Patent Office* (1841 - 1851) and (*Bericht* 1853). In logit regressions, chemicals has been dropped because none of the U.S. exhibits in chemicals were patented. Manufactures is the omitted industry class. Standard errors are in brackets; + denotes significant at 10 percent; * significant at 5%; and ** significant at 1 percent. An outcome is defined as correctly predicted if the predicted probability of patenting for a patented exhibit is at least 0.5.

FIGURE 1 – ASSIGNMENTS OF PATENTS IN THE STATE OF CONNECTICUT



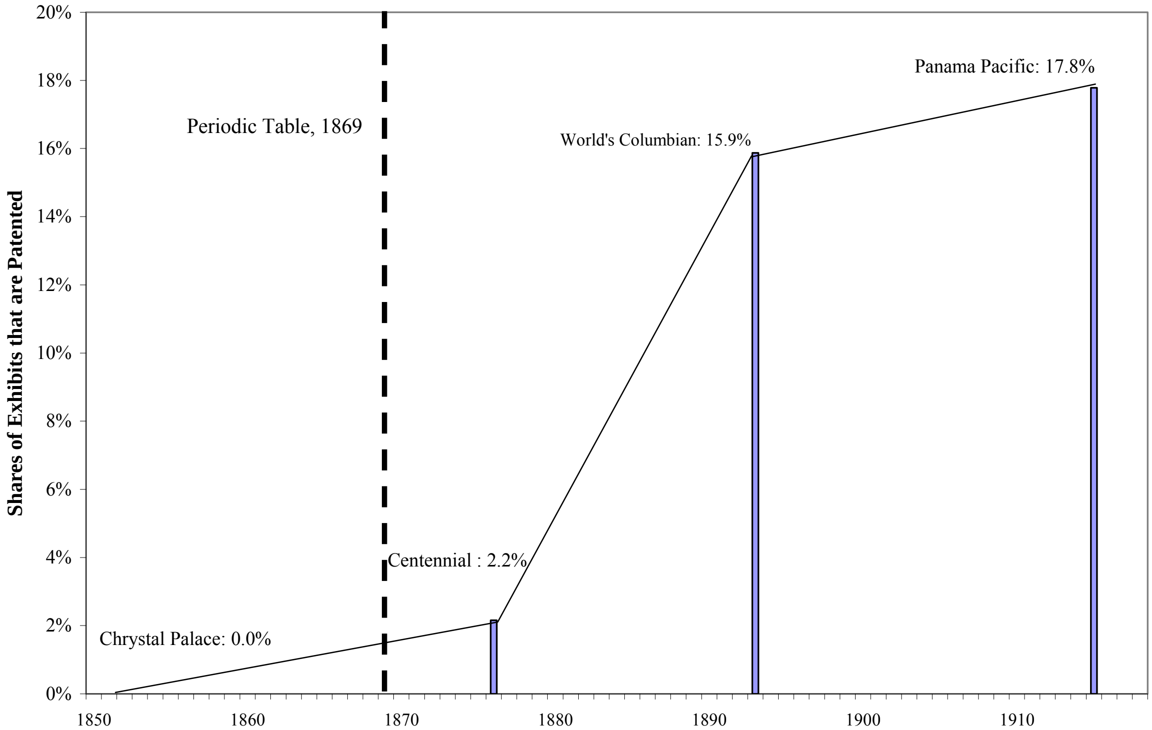
Notes: Data from the *Annual Reports of the United States Patent Office, 1836-1890*, all patents issued or assigned to residents of the State of Connecticut, including patents issued or assigned to companies.

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



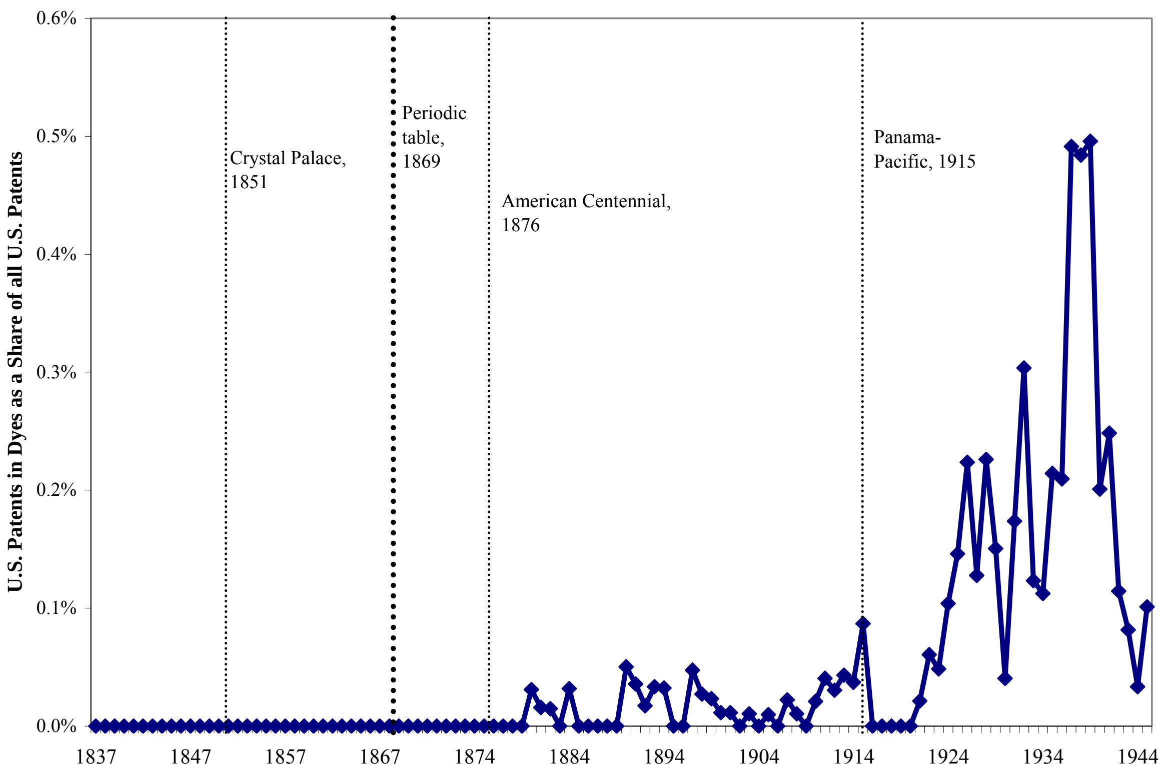
Notes: Data from the *Official Catalogue* (1851), and the United States Census of 1851. Patented exhibits are identified by matching exhibits with patents in the *Annual Reports of the United States Patent Office, 1841-1851*. Excluding New York, 15.1 percent of innovations in cities with more than 100,000 people were patented, 10.4 percent in cities with more than 10,000 people, and 15.5 percent of innovations in rural towns.

FIGURE 3 – U.S. PATENTING RATES FOR INNOVATIONS IN CHEMICALS 1851 – 1915



Notes: Data from the official catalogues for 1851, 1876, 1893, 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 – PATENTS FOR DYES AS A SHARE OF ALL U.S. PATENTS



Notes: Patents of dye stuffs compared to all other U.S. patents classified by Schmookler (1972).