What do Inventors Patent?*

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Both theoretical and empirical analyses of innovation use patents as a proxy for innovation. Inventors, however, indicate that they prefer alternatives to patents, such as secrecy, to protect their intellectual property. This paper takes advantage of a unique historical data set of more than 7,000 British and American innovations at the Crystal Palace World Fair of 1851 to examine the relationship between patents and innovation. Exhibition data offer many advantages over contemporary sources. Most importantly, they include innovations with and without patents. Moreover, exhibition data are comparable across countries and across industries, and they include measures of the quality of innovation. The data suggest that the share of innovations that are patented may be much smaller than has been previously thought: in 1851, less than one in five inventors relied on patents to protect their intellectual property. Comparisons between Britain and the United States suggest that even the most fundamental differences in patent laws failed to raise the proportion of patented innovations. Moreover, the share of innovations that were patented varied significantly across industries. In 1851, only 5 percent of chemical innovations were patented, compared to 30 percent of innovations in machinery. These results are robust to comparisons across countries, across high- and average quality, and across rural and urban innovations.

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Theories of innovation have traditionally relied on the assumption that patent laws are the only means to protect intellectual property, and that all innovations are patented. William Nordhaus (1969), Paul Klemperer (1990), and Richard Gilbert and Carl Shapiro (1990) build on this notion to show that increases in the lifetime and the breadth of patents strengthen inventors incentives to innovate. Suzanne Scotchmer (1991) and Nancy Gallini (1992) employ the link between patenting and innovation to demonstrate that increases in patent length may lower levels of innovation if they reduce expected profits for future generations of inventors.

Empirical analyses of innovation have likewise relied almost exclusively on patent data to measure innovation. Jacob Schmookler (1966) and Kenneth Sokoloff (1988) use patents to show that inventive activity responds to profit incentives. Manuel Trajtenberg (1990) employs patent citations to measure the quality of inventions, and Rebecca Henderson, Adam Jaffe, and Manuel Trajtenberg (1993) examine the geographic concentration of patent citations to show that knowledge spillovers are localized. Since 2001, more than 240 studies have used the NBER patent data files that Bronwyn Hall, Adam Jaffe, and Manuel Trajtenberg (2001) made freely available online, as a measure of innovation.

Surveys of inventors, however, suggest that inventors rely on alternative mechanisms to protect intellectual property and that not all innovations may be patented.[1] Responses of more than 100 U.S. manufacturing firms in 1983 and nearly 1,500 firms in 1994 indicate that inventors' attitudes towards patenting vary across industries, and that inventors in most industries prefer secrecy to patents (Richard C. Levin, Alvin K. Klevorick, Richard R. Nelson, and Sidney G. Winter, 1987; Wesley M. Cohen, Richard R. Nelson, and John P. Walsh, 2000).[2] Nineteenth-century surveys and biographies reveal similar inter-industry differences in inventors' attitudes towards patenting across industries. A survey of 100 Swiss inventors in 1883 showed that chemists and dyers opposed patenting, while inventors of machinery favored it (*Procès verbal*…1883).

[1] Learning-by-doing (Kenneth Arrow, 1962) and the adoption of foreign inventions are examples of alternative and unpatented sources of innovation. Eric Schiff (1971) and Doron Ben-Atar (2004) document the adoption of foreign inventions in Switzerland and the United States. Patents may also overestimate innovation because only a small portion of patents develop into commercially viable innovations. For example, Peter Meinhardt's (1946, p. 246) survey of U.S., firms suggest that only between 5 to 20 percent of patents become economically useful innovations. Mark Schankerman and Ariel Pakes (1986, p. 8) analysis of patent renewal data is equally suggestive: more than half of all British patents are cancelled after eight years, and only 25 percent survive until their 13th year.

[2] Although survey results are informative, they may be biased if responses are influenced by the framing of the question, or if respondents reply strategically. For example, a firm that protects its inventions by secrecy may be reluctant to expose its lack of patents. Surveys that focus on R&D labs may be biased towards large firms and inventors in concentrated industries, and they omit or significantly under-sample inventors in highly innovative industries where most innovations are made by start-up firms.

Inter-industry differences in technological characteristics of inventions may cause such differences in attitudes. If alternative mechanisms to protect intellectual property exist, their effectiveness may depend on the technological characteristics of invention. For example, inventions are easy to keep secret in some industries but not in others; variation may be large enough to render secrecy ineffective in some industries. Patent protection, on the other hand, is effective independent of the nature of innovation. Yet patenting is costly; in addition to patent fees, the costs of researching prior art, and attorney's salaries, patenting requires that inventors surrender the property right in their ideas at the expiration of the patent. In contrast, alternative mechanisms have no stipulated expiration date and, in the case of secrecy, they are essentially free. Then inventors may use alternatives mechanisms, such as secrecy, in industries where they are effective, and rely on patents in the remaining industries.

Among 19th-century inventions, inventions in machinery were relatively easy to copy. In 1850, Isaac Singer took less than eleven days to reverse-engineer an early sewing machine prototype of Lerow & Blodgett's, and, with a few minor improvements, Singer then created his own version, which became an unprecedented commercial success. By 1880, one in three American households owned a sewing machine, but Lerow & Blodgett did not benefit much from these profits (Scott, 1880, p. 8; Fenster, 1994, pp. 46-50; Cooper, 1968, pp. 13 and 42). Thomas Hancock's experience with the "masticator" provides another illustration for the ease of copying and the risks of secrecy. Invented in 1820, the masticator was a cylinder studded with sharp teeth to gnaw up rubber scraps from glove and suspender manufacturing. Hancock went through great troubles to keep the masticator secret. For example, he code-named it the "pickle" and required workers to take an oath of silence. Word, however, did get out in 1832, and the masticator was copied almost immediately, almost completely dispersing Hancock's profits (Dragon, 1995, p. 222; Korman, 2002, pp. 26, 127-128).

On the other hand, inventions in dyes and other chemicals appear to have been extremely difficult to copy. For instance, indigo-colored clothing was found in graves of wealthy Roman settlers dating back to the 2nd century. Indigo-colored textiles were worth their weight in gold, but efforts to chemically imitate the color failed until 1878, when the German chemist von Baeyer managed to synthesize indigo. Other dyes were equally difficult to imitate. Turkey red, for example, was produced by a complex process of boiling yarn with alkali; steeping it in rancid oil, soda, and sheep dung; mordanting with alum and sumac; dyeing in a batch of madder, ox blood, and chalk; and finally washing to brighten the color (*Archive of the Society of Dyers and Colourists*, 2004). Chemical innovations such as alum, potash, naphthalene, quinine, caffeine, and tannin were equally difficult to copy.

If significant shares of innovations are not patented, patent policies may have consequences different from those commonly expected. If inventors rely heavily on alternative mechanisms, the introduction of patent laws in developing countries may fail to raise levels of innovation (Moser, 2006a). Moreover, if the use of patents varies heavily across industries, the introduction of patent laws may alter the direction of technical change, as patent laws raise the profitability of invention in industries that depend on patents relative to other industries (Moser, 2005). If patents encourage inventors to publicize and license their ideas, patenting may influence the geographic distribution of innovations within countries, as innovations diffuse more easily in patent-friendly industries and remain geographically concentrated in other industries (Moser, 2006b). Finally, if the use of patents varies across rural and urban areas, rural inventors, especially in developing countries with institutions that are strongly centralized, may be at a disadvantage.

Exhibition data create a unique opportunity to examine the use of patent protection across industries. Most importantly, exhibition data include innovations with and without patents. Moreover, exhibits cover innovations across all industries, from mining and chemicals, to metallurgy, engines, manufacturing machinery, textiles, and scientific instruments. They include important innovations, such as engines, which had to be excluded from patent data, because they could not be assigned to a specific industry (Schmookler, 1972, p. 89). Exhibition data enable cross-country comparisons because exhibits in all countries are selected according to the same criteria of "novelty and usefulness". Jurors assigned prizes to the best inventions; these awards for inventiveness provide a relatively straightforward measure for the quality of innovations.

A typical entry in the exhibition catalogues begins with the inventor's name, address, and country of origin, followed by a brief description of the innovation. From these records, I have constructed data for all 6,377 British and all 544 American innovations at the Crystal Palace exhibition in 1851. Contemporary records confirm that exhibition data are a useful measure of innovation. The reports of several national committees illustrate that national committees selected their most innovative products to be exhibited at the Crystal Palace. Participation was competitive; a uniform system of selection admitted less than one third of all applicants to exhibit at the fair. Most importantly, exhibition data measure innovation independently from differences in domestic patent laws. Exhibitors displayed innovations regardless of whether they could be patented at home, including many inventions that they had chosen not to patent.

I expand the information in the exhibition catalogues to differentiate innovations with and without patents, innovations of high quality, and urban innovations. For Britain, the descriptions in the exhibition catalogues distinguish patented innovations. For the United States, I construct comparable data by matching all U.S. exhibits with lists of U.S. patents in the *Annual Reports of the United States Patent Office* between 1841 and 1851. I identify innovations of high quality by matching entries in the exhibition catalogues with a list of 4,491 Crystal Palace exhibits that received awards for exceptional "quality and usefulness" (from the report of the German Commission to the Crystal Palace, *Bericht*, 1853). I use 19th-century maps, gazetteers, and dictionaries of place names to identify the location of each exhibit as well as the size of its originating city.

Exhibition data show that only a small share of innovations was patented, about 11 percent of British exhibits in 1851. They also reveal that patenting rates varied strongly across industries, from 5 percent in chemicals to 30 percent in manufacturing machinery. Inventors were slightly more likely to patent high-quality innovations; 15.8 percent of award-winning British innovations were patented. Similar to innovations of average quality, high-quality innovations were most likely to be patented in machinery, especially in manufacturing machinery, and less likely in chemicals. U.S. inventors were only slightly more likely to patent their inventions, at 15.5 percent, despite substantially lower costs of patenting in the American system. Similar to British inventors, American inventors chose to patent innovations in machinery, especially in manufacturing machinery and engines (44 percent), but not in chemicals (3 percent). Urban inventors were only slightly more likely to patent their innovations.

The remainder of this paper uses the exhibition data to examine patenting across industries. Section I introduces the exhibition data and describes the data's advantages and potential sources of bias. Section II presents evidence on differences in patenting rates across industries, across quality levels, between Britain and the United States, and across rural and urban areas, and examines these differences in logit and OLS regressions. Section III concludes.

I. The Data

Exhibition catalogues for the Crystal Palace Exhibition in London in 1851 serve as the main source of data for this study. The Crystal Palace Fair was named after a massive glass house, 1,848 feet in length, and after its revolutionary pre-fabricated design of wrought iron and glass.[3] At its time, the Crystal Palace was the largest enclosed space on earth; its exhibition halls covered 772,784 square feet in London's Hyde Park, an area six times that of St. Paul's Cathedral. In 1851, more than six million people came to visit, exceeding the combined populations of London, Paris, and Berlin. At the Crystal Palace, 17,062 exhibitors from 25 countries and 15 colonies displayed their innovations (see *Bericht III*, 1853, p. 674; Winfried Kretschmer, 1999, p. 101; Evelyn Kroker, 1975, p. 146). I use the catalogues that guide exhibitors through the fair to collect a new comprehensive data set on 19th-century innovations with and without patents.

A. The Process of Selecting Exhibits

A fine mesh of local selection committees and collection points ensured that urban and rural innovations had equal access to the fairs. National commissions delegated the authority to select exhibits to their branch commissions. Britain's Crystal Palace commission, for example, nominated 65 sub-commissions, consisting of two-to-ten academics and business people who selected exhibits at the local level (*Bericht,* 1852, pp. 37 and 90). In their applications, potential

[3] Kenneth Frampton (1983, p. 11) describes the Crystal Palace's significance in architectural history.

exhibitors reported “what is novel and important about the product, how its production shows special skillfulness and proves an original approach” *(Bericht*, 1853, pp. 50 and 117). Local commissioners chose the most promising exhibits, and national commissions double-checked their choices and addressed rare cases of overlap (*Bericht*, 1853, pp. 40 and 64). By requiring that exhibitors cover transportation costs only to local collection points, this system also ensured that exhibitors from all regions were represented at the fair.

A comprehensive system of awards enforced the selection criteria of novelty and usefulness. For each of 30 industry classes, international juries of six to twelve industry experts–university professors, business people, and practitioners, including Hector Berlioz in the musical department–evaluated and ranked all exhibits. Every exhibit was subject to intense scrutiny by these international juries. Signs such as “Not entered in the competition” were explicitly prohibited, making it impossible to opt out of the juries’ evaluation. At the Crystal Palace, 5,438 exhibits received awards (*Bericht III*, 1853, p. 707; Haltern, 1971, p. 155). Juries awarded Council Medals as gold medals to the most innovative exhibits, Prize Medals as silver medals to the second-most innovative exhibits, and Honorable Mentions as bronze medals. One percent of all exhibits received Council Medals, the highest honor for inventiveness; 18 percent received Prize Medals, the second-highest honor; and 12 percent received Honorable Mentions. Data on these awards creates a relatively straightforward way to adjust for the quality of innovations.

B. Advantages over Patent Data

Harold Dutton (1984) summarizes what critics have seen as the main weaknesses of patent data:

> The most serious is that patent statistics do not reflect the quantity of inventive output…Patent statistics, moreover, do not reflect the *quality* of inventive output because they treat the considerably varied nature and value of inventions equally. This, though, is

> less serious than is supposed: the problem of quality comparisons exists independently of patents.... Despite these limitations… patent data are the only index available to indicate the volume of inventive activity and should not be abandoned because they are imperfect (Harold I. Dutton, 1984, pp. 6-7).

Exhibition data, however, offer an alternative data source on innovation, which creates a unique opportunity to evaluate potential sources of bias in the patent data and determine their direction.[4]

Most importantly, exhibition data measure innovations with and without patents. This is a significant advantage if innovations originate from sources other than patented inventions, such as learning-by-doing or incremental increases in cumulative knowledge (Kenneth Arrow, 1962; Suzanne Scotchmer, 1991; and Joel Mokyr, 2002).[5] Exhibition data also include many important innovations that had to be omitted from the patent counts, such as power plant inventions, electric motors, and bearings (Schmookler, 1972, p. 89). These inventions had to be excluded from the patent data because patents are classified by functional principles and often cannot be assigned to a specific industry of use.[6]

Another benefit is that exhibits are subject to the same selection criteria across countries, whereas the definition of a patentable invention may vary across countries. For instance, in the 19th century only "first and true" inventors were allowed to patent in the United States, while other countries, including Britain, granted patents to the first importer of a new technology (Coryton, 1855, pp. 235-264).

Equally important is that exhibition data measure the quality of innovations, which is difficult to do with patent data. Griliches (1990, p. 1669) observes that the inability to

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

[5] Patents measure a relatively early input in the process of innovation, and only a small share of patented inventions reach later stages (Harold I. Dutton, 1984, pp. 6-7; Griliches, 1990, p. 1669). For the 20th century, firm-level surveys have found that only between 5 to 20 percent of patents become commercially viable innovations (Meinhardt, 1946, p. 256).

[6] The functional class "dispensing liquids" includes holy water dispensers along with water pistols, while "dispensing solid" groups toothpaste tubes with manure spreaders (Schmookler, 1972, p. 88).

distinguish high- from low-quality patents is a major weakness of the patent data.[7] For example, patent counts assign equal weight to Isaac Singer's "Improvement of the Sewing Machine" (U.S. patent No. 8,294, granted on August 12, 1851) and the patent that immediately follows it, Francis Wilbar's improvement in roof construction by suspending both inclined sides from the ridge timber (U.S. patent No. 8,295, granted on the same day). These patents vary strongly in their quality and importance. By 1880, John Scott observes that "the Sewing Machine modestly hides itself away beneath the three million of the nine million roofs of America" (Scott 1880, p. 6), but Wilbur's design found little use. Manuel Trajtenberg (1990) addresses the problem of quality differences by constructing measures of the value of patented inventions based on the number of succeeding patents that refer to them. However, citation measures may underestimate the quality of innovations if inventors are less likely to patent their inventions in some industries than in others. As a complement to patent data, exhibition data can help to address these concerns.

C. Description of the Data

A typical entry in the exhibition catalogues includes a brief description of the innovation along with its exhibitor's name and place of origin. For example, Britain's exhibit number 32 in the class "agricultural machinery" is described as:

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

[7] Without an effective system of examining prior art, patents may also vary in their degree of novelty. In 1864, a study for the Royal Commission found that a quarter of recent patents were potentially invalid because they failed to meet a standard of novelty (Hewish, 2000, p. 80). In a study commissioned by the Fry Committee in 1901, 42 percent of 900 British patents were found to have been anticipated by earlier patents (Davenport, 1979, p. 48). The committee was given examples of identical inventions that had been patented repeatedly in the previous two decades: 8 patents for soda water, 7 for pneumatic heads on crutches, and 14 for channels on billiard tables to return balls to players (*Parliamentary Papers*, 1901, XXIII, pp. 541-2, 632, cited in MacLeod, 1988).

I have classified all 6,377 British and 544 American entries in the *Official Catalogue* into 30 industry classes.[8] In this list of nearly 7,000 innovations, I identify innovations with and without patents.

In the British data, patented innovations can be identified directly from the entries in the exhibition catalogues; the descriptions of exhibits include “patented” or “pat.” to distinguish patented exhibits. J. Bendall, for example, listed his patent after the description of his cultivator as “A universal self-adjusting cultivator… pat.” Such records would create a perfect measure of patented innovations if exhibitors stated “patent” if and only if they held a patent. As an approximation, this seems plausible; exhibitors with patents had reason to advertise their patents because it raised the value of their innovations. For example, Christine MacLeod (1988, p. 85) finds that patents increased consumers’ valuation for proprietary medicines in early 18th-century England. On the other hand, exhibitors without patents were unlikely to claim patents because they would have been discovered easily. All exhibits were subject to intense scrutiny by the international juries, and exhibitors could reasonably expect jurors to check the patent records.

Among American exhibits, patented innovations are identified by matching exhibitors at the Crystal Palace with records on U.S. patents in the *Annual Reports of the United States Patent Office* between 1841 and 1851.[9] Exhibitors are matched by first name, last name, address, and the descriptions of their innovations. For example, the following entries are counted as a match:

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

[8] American inventors contributed 549 exhibits to the Crystal Palace fair. Five exhibitors were expatriates in London, and, because they were subject to British rather than American conditions, I exclude them from this analysis. I also exclude all exhibits in the Crystal Palace class “art”, which includes drawings, paintings, sculptures, and the many water fountains that adorned the Crystal Palace. The descriptions of exhibits in the catalogues do not distinguish process from product innovations, and adding this distinction *ex post* would be fairly subjective. Cohen, Nelson, and Walsh (2000, p. 8) however, find a close link between inventors' attitudes towards patenting process and product innovations within industries.

[9] Ideally, I would also identify U.S. exhibits that list patents and compare this measure with the matches between patents and exhibits. Unfortunately, descriptions of American exhibits do not list references to patents.

and

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

To be defined as a match, the exhibitor and patentee must have the same last name, and the patent must at least be related to the exhibit, if not identical. 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 some of the nutrients of meat and vegetables in a bread-like substance (United States Patent No. 7,066, granted on February 5, 1850). If exhibits and patents are not identical, this matching procedure may lead me to overestimate true patenting rates. As a robustness check, I keep track of all potential matches and repeat all tests with alternative matching rules.[10]

I identify innovations of high quality by matching entries of exhibits in the *Official Catalogue* (1851) with lists of award-winning innovations in the reports of the German Commission to the Crystal Palace (*Bericht*, 1853). Translated from the German original, a typical entry in the report of the German Commission looks like this:

> Britain, industry class 18, exhibit 78, Mercer, John: Process of modifying cotton fibers through exposure to acidic alkali, which sets off remarkable changes in the physical and chemical characteristics of cotton fibers. Council Medal[11]

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[10] If an original patentee assigns his patent to another individual who then exhibits it, my matching procedure underestimates U.S. patenting rates. To assess the strength of this potential bias, I pick a state with high economic activity in the 19th century, Connecticut, and identify the proportion of patents that were assigned between 1836 and 1860. I begin collecting the data in 1836 because a fire in the patent office in 1836 destroyed a large share of the earlier records. The Connecticut data suggest that less than 4.5 percent of patents, 75 of Connecticut's 1,714 patents, were assigned at issue. Until 1851 only one of Connecticut's 454 patents had been assigned to new owners, corresponding to approximately 0.2 percent. This suggests that a potential bias as a result of missed assignments will be very small.

[11] The original reads "Prozess der Modifikation der Baumwollfaser durch ätzendes Alkali, wodurch die physischen und chemischen Eigenschaften derselben aus eine merkwürdige Weise verändert und verbessert werden."

I have recorded these data for 4,491 award-winning innovations across all countries and matched awards to exhibition data for 1,745 British innovations and 112 American innovations. Exhibitors and award-winners are matched by country, name, exhibit number, and the description of the award.

I use mid 19th -century maps such as the *Times Handy Atlas*, cholera maps, gazetteers like *Bartholomew's Gazetteer of the British Isles* (1887) and dictionaries of geographic place names to identify the locations of innovations. For example, the *National Gazetteer of Great Britain and Ireland (1868)* identifies Bendall's location "Woodbridge" as a market town and parish in the county of Suffolk. I obtain population data from the British and the U.S. census records of 1851 to measure the size of each city and account for the influence of urbanization.

D. Potential Sources of Bias in the Exhibition Data

There are, however, potential sources of bias in the exhibition data. Space restrictions and transportation costs appear to be the most important distortions for the number of innovations. At the Crystal Palace, Britain's national commission relied on its subjective assessment of a country's importance as an innovator to allocate its exhibition space. Yet, when the United States Commission to the Crystal Palace thought that U.S. exhibitors would be short on space, it asked the British Commission for more room and was granted its request (Haltern, 1971, p. 150).

Heavy and fragile innovations, which would otherwise have been under-represented due to transportation costs, could be exhibited as models or as blueprints. Of 194 British exhibits in class 7, "Civil Engineering, Architecture, and Building Contrivances," 88 exhibits, or 45 percent, were represented by models. For example, T. Powell of Monmouthshire, Britain, exhibited a

"Model for apparatus used for shipment of coals from boats or waggons (sic) at Cardiff dock"; A.Watney of Llanelly, Wales, exhibited "Models of anthracite blast furnaces." Among the engineering exhibits there was a model of the suspension bridge that was being constructed across the river Dnieper in Kiev. Robert and Alan Stevenson (grandfather and uncle to Robert Louis Stevenson) displayed models of lighthouses for the Bell Rock and for Skerryvore (Rolt, 1970, p. 157).

Another potential weakness of the exhibition data is that they may underreport innovations that are easy to copy, if such innovations were not displayed for fear of imitation. Thus, exhibition data may be biased against innovations that are also omitted from the patent counts. Exhibitors, however, may have felt less dependent on legal protection because they found ways to advertise without disclosing the secrets of their innovations. Rather than exhibiting a new piece of machinery or describing a new process, inventors often chose to display samples of their final output. For example, Drewsen & Sons of Silkeborg, Jutland, exhibited "Specimens of paper, glazed by a machine constructed by the exhibitor," instead of the machine itself, which he kept secret (*Official Catalogue, First Edition*, 1851, p. 210). In addition, a system of registration, which was available to all exhibitors, acted as a cheap and fast patent system; yet, at the Crystal Palace only 500 exhibitors took advantage of it (*Bericht III,* 1853, pp. 697-701). If exhibition data undercount innovations that were protected by secrecy, they may overstate the share of innovations that are patented and underestimate inter-industry differences in the use of patenting.

III. Innovations With and Without Patents

The data indicate that only a small share of innovations was patented: 11.1 percent of British innovations in 1851 (bottom row, *All Industries*, Table 2). Moreover, the proportion of patented innovations varied strongly across industries. Only 5 percent of chemicals and 7 percent of textiles innovations appear to have been patented, compared to nearly 30 percent of manufacturing machinery. Among the exhibits of manufacturing machinery, visitors to the Crystal Palace found a new “machine for setting the teeth of saws” (exhibit 242, G. Vaughn, Marylebone) and a “curvilinear sawing machine for ships' timbers…” (exhibit 417, C.M Barker, London). Among the chemicals exhibits, they saw “Colours produced by the combination of fatty acids with metallic oxides and peroxides” (exhibit 78, C. Humfrey, Southwark), “samples of ultramarine”, “refined Indian blue”, and a “newly invented black dye, particularly recommended for silk” (exhibits 69, C. Lee, London). Exhibits of textile innovations included cloths of brighter and more permanent colors, such as “blue cloth… and black beaver cloths” (exhibit 12, Bull and Wilson, London).

Exhibition data in Table 2 also suggest that British innovations in food processing were slightly less likely to be patented than average innovations, with a patenting rate of 8 percent compared to 11 percent across all industries. Typically, such inventions were akin to recipes, including the first version of the meat biscuit (a vile predecessor of the *PowerBar*), but also more palatable attempts at producing milk chocolate, bouillons, and infant formula. Exhibits included “preserved provisions” for military and scientific expeditions (exhibit 12, J.H. Gamble, London) and methods of food preservations for household use, such as “meats, preserved without the use of salt” (exhibit 23, G.H. Underwood, Pendleton, Manchester) and “tart fruits, jams, jellies, &c. hermetically sealed, which retain for years their flavour and quality” (exhibit 11, Copland, Barnes, & Co., Eastcheap).[12] British innovations in scientific instruments experienced similarly low patenting rates, at less than 10 percent. Optical and medical devices (such as false teeth and a metal corset for curing scoliosis), marine clocks, improvements in the accuracy of pocket watches, barometers, and theodolites formed the majority of Britain's entries.

A. Do Differences in the Quality of Innovations Influence Patenting?

Jurors evaluated the degree of novelty and usefulness for all exhibits, and ranked all exhibits according to these measures of the quality of innovations. Novelty and usefulness, however, may also influence inventors' propensity to patent. Innovations of high quality may be more likely to be patented, because their expected payoffs are higher and, therefore, more likely to exceed the costs of patenting. Moreover, secrecy may carry greater risks for high-quality innovations, because they promise larger payoffs, which increases competitors' incentives to copy them. To examine whether differences in quality influence patenting, I match entries of exhibitors in the *Official Catalogue* (1851) with award-winning innovations in the reports of the German Commission (*Bericht*, 1853).

Data on award-winning innovations suggest that innovations of high quality were slightly more likely to be patented than innovations of average quality: 15.8 percent of award-winning innovations were patented in 1851, compared to 11.1 percent of average innovations (Table 2, columns II and IV). Inventors patented high-quality innovations in the same industries as average innovations: manufacturing machinery is the industry with the highest proportion of both high-quality and average-quality patented inventions, followed by agricultural machinery and engines. Likewise, inventors appear to have been averse to patenting in the same industries:

[12] Improvements in crops, such as J. Sutton's "purple-topped yellow hybrid turnip, valuable for late sowing…" (exhibit 112, Reading) and T. Fordham's "samples of improved white wheat, weigh 66 lbs per bushel and prolific beans" (exhibit 94, Snelsmore Hill East), were also included in this class.

innovations in mining and metallurgy have the lowest patenting rates for innovations of high- as well as average-quality, followed by chemicals and textiles.

Separating awards into gold, silver, and bronze yields further evidence that high-quality innovations were patented more frequently. Twenty-seven percent of exhibits that received gold medals were protected by patents (Table 3, column IV), compared with 18 percent of exhibits that won silver and 10 percent of exhibits that won bronze. There are too few observations to allow systematic comparisons of gold, silver, and bronze awards across industries, but comparisons of patenting rates broadly confirm that machinery innovations were more likely to be patented, while chemicals, food processing, textiles, and scientific instruments were patented less frequently.

The data also suggest that differences in quality amplify existing differences in patenting across industries. In patent-averse industries, differences between high- and average-quality innovations are relatively small, with 6 percent of high-quality innovations in mining and metallurgy (Table II, compared to 5 percent of average quality), 8 percent of chemicals (compared to 5.1 percent of average quality), 9 percent of textiles (compared to 7 percent), and 10 percent in food processing (compared to 8 percent). Only in one patent-averse industry, scientific instruments, is there a noticeable difference between the 16 percent patent rate for high-quality innovations and the 10 percent rate for those of average quality. On the other hand, there are sizeable differences between high- and average-quality innovations in patent-friendly industries. Almost 50 percent of award-winning innovations in manufacturing machinery were patented (compared with 30 percent of average quality), 40 percent of engines (compared with 25 percent), and 41 percent of agricultural machinery (compared with 20 percent).

These results strengthen evidence for the hypothesis that the determinants of patenting are strongly related to industry-specific characteristics of invention. The following section examines whether cross-industry differences are robust to cross-national variation, including significant differences in patent laws.

B. Do Effective Patent Laws Encourage Patenting?

The mid-19th century offers a unique opportunity to explore the effects of patent laws on patenting. In most countries, an initial set of patent laws, which had been adopted relatively *ad hoc* was still in place. Cross-country differences in patent laws were larger than at any other time, and, prior to the Paris *Convention for the Protection of Industrial Property* in March 1883, patenting abroad was prohibitively expensive and discriminatory, so that inventors depended almost exclusively on domestic patent protection (Coryton, 1855; Godson, 1840; Penrose, 1951).[13]

Differences between the British and American patent system were especially pronounced. In 1851, the fees for a British patent carried to full term were equivalent to $37,000 per year in 2000 U.S. dollars, compared to $618 in the United States (Lerner, 2000). American inventors could mail their applications to the patent office, whereas British inventors faced a long, drawn-out, and costly process that involved extortion by many bureaucrats.[14] Jeremy Bentham (1843) describes how exorbitant costs and bureaucratic excess discouraged British inventors:

> 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

[13] Moser (2005 and 2006a) exploits national differences in patent laws for 12 Northern European countries in 1851 and 10 Northern European countries in 1876 to examine the effects of patent laws on the direction of technical change and on the number of innovations.
[14] In 1851, the lifetime of patents was identical in Britain and the United States at 14 years in both countries.

> his life. He finds himself caught in a snare which the law, or rather extortion which has obtained the force of the law….[15]

In the United States, however, low costs and easy access encouraged inventors from all backgrounds to patent their inventions (e.g., Naomi Lamoreaux and Kenneth Sokoloff, 1996, p. 12687). For the early and mid 19th-century United States, Zorina Khan and Kenneth Sokoloff (1998) reason that lower costs of patenting strengthened the incentives to invent relative to Britain and thus helped to lay the foundations for American economic growth.

Data on U.S. innovations with and without patents, however, reveal that, despite the significant advantages of the U.S. patent system, American inventors were only slightly more likely to take advantage of patent protection than were British inventors. Among American exhibits at the Crystal Palace, only 15.5 percent were patented compared to 11 percent of British exhibits (Table 4, bottom row). These differences seem trivial considering the substantial benefits of the American patent law.

Another similarity between the American and British data is that American innovations were patented--and not patented--in the same industries. Exhibits of machinery, especially of manufacturing machinery and engines, were significantly more likely to be patented, while chemicals and textiles were rarely patented. In industries that tended to avoid patents, the proportion of patented innovations was roughly equal in the United States and Britain: 3 percent of U.S. chemical innovations were patented (compared to 5 percent of British innovations), 6

[15] From the *Collected Works* of Jeremy Bentham (1843), cited in Coulter (1991, p.76). See Charles Dickens' "Poor Man's Tale of a Patent" for another vivid illustration of inventors' frustration with the British application process. Another characteristic that distinguished the U.S. system from the British was a provision, introduced in 1836, which authorized the Patent Office to examine applications for originality. Throughout much of the 19th-century, the United States was the only country that restricted patent grants to "first and true inventors," whereas other countries would also grant patents to the first importer of a new technology (Machlup, 1958).

percent of textiles (compared to 7 percent), and 7 percent of innovations of food processing (compared to 8 percent).[16]

Inter-industry differences in patenting increase for American innovations, as they did for high-quality innovations. Forty-four percent of American exhibits in manufacturing machinery were patented (compared to 30 percent of British exhibits), 43 percent of U.S. engines (compared to 25 of British engines), 37 percent of agricultural machinery (compared to 20 percent), and 36 percent of exhibits in military and naval engineering (compared to 12 percent). American exhibits in manufacturing machinery included S.C. Blodgett's sewing machines (exhibit 551, New York) and power-loom lathes from the machine shops at Lowell, Massachusetts (447, Lowell Machine Shop, Lowell). The class agricultural machinery, displayed Cyrus McCormick's "Virginia grain reaper", which became one of the highlights of the exhibition (U.S. exhibit 73). Among the military innovations visitors could admire Samuel Colt's revolving cylinder handgun, the "revolver" (exhibit 321, Hartford, Connecticut). All of these innovations in machinery were protected by patents.

C. Do Urban Inventors Patent More?

Another factor that may influence patenting is urbanization. Max Weber (1921), Torsten Hägerstrand (1952), and Jane Jacobs (1969) argue that cities are more innovative. Allan Pred (1966) and Kenneth Sokoloff (1986) analyze patents per capita to substantiate this argument. For the 19th century, Sokoloff (1986) finds that patenting per capita was highest in the cities of the Northeast and along navigable waterways. For the 20th century United States, Allan Pred

[16] Exhibits in instruments are more likely to be patented in the United States, although some of this difference might be due to differences of composition of innovations within the class of "instruments". Nautical and astronomical clocks, along with instruments for measuring distance feature prominently in the British data, while American innovations include medical instruments as well as pianos, which were patented more frequently.

(1966) reports that patents per person in the 35 largest cities exceeded the national average by a factor of four. Similarly, Robert Higgs (1971) finds a positive correlation between overall levels of urbanization and the number of U.S. patents between 1870 and 1930, and Rose (1948) suggests that patents per capita increase with the size of cities.

Christine MacLeod (1988) and Joel Mokyr (1995), however, reason that the concentration of patents in urban areas may reflect a concentration of patenting rather than invention. Joel Mokyr (1995, p. 31) argues that urban inventors may be more likely to patent because the proximity of urban settings intensifies fears of competition and motivates inventors to patent their inventions. For the 17th and 18th centuries, Christine MacLeod similarly observes that urban patents consisted of relatively small improvements or changes in design, which suggests that urban patentees may have been more aware of the patent system, and more likely to patent their inventions, rather than being more inventive (MacLeod, 1988, p. 31). Exhibition data, however, show that patenting rates were only slightly higher for urban than for rural innovations. Figure 1 compares patenting rates across locations of different sizes for the American data. These data reveal no obvious relationship between city size and patenting. Fifteen percent of innovations from towns with less than 1,000 inhabitants were patented, compared to 17 percent in cities larger than 400,000 (Philadelphia and New York). Moreover, medium-sized cities ranging from 5,000 to 50,000 had lower patenting rates than rural areas. Inventors in cities with 100,000 and 400,000 people patented a smaller share of innovations that did rural inventors.

In the British data, 13 percent of London's innovations were patented compared to 11 percent of innovations in the rest of England.[17] When data are divided by industries, only

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

innovations in mining and machinery are more likely to be patented in London. In mining, 18 percent of London's innovations are patented, compared to 3 percent elsewhere. An odds-ratio test shows that this difference is statistically significant at a p-value of 0.002. Exhibition data also suggest a perceptible difference in patenting rates for machinery innovations, with 22 percent patented in London compared to 17 percent elsewhere; the p-value for this difference is 0.018. This increase in patenting for machinery mirrors the amplified propensity to patent high-quality innovations in machinery. In three of the remaining industries (instruments, textiles, and other manufactures), patenting rates are almost identical for London and the rest of England. For innovations in chemicals and food processing, patenting rates are lower in London than they are in the rest of England, although these differences are not statistically significant.[18]

Income differences are another potential determinant of patenting. Although I have no reliable income data that would allow a systematic test, the geographic distribution of patenting within the city of London may serve as a rough check for the influence of income differences on patenting. High- and low-income districts in London were separated by the Thames, with districts north and in close proximity to the river generally being better off (e.g., *The National Gazetteer of Great Britain and Ireland*, 1868; Charles Booth, 1891; and John Snow, 1936)[19]. The areas around Westminster and St. George and Hanover Square were particularly well–to-do. A map of patenting rates across districts of London suggests that differences in patenting rates did not correspond to differences in income. Inventors in the wealthiest northern districts were

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

[19] Charles Booth's (1891) poverty maps of London in 1889 are probably the best true-to-scale survey of income and social conditions in 19th-century London. John Snow (1854) mapped cholera cases and water pumps in London to prove that cholera is a water-borne disease.

not significantly more likely to patent their inventions (Figure 1). Patenting rates were highest in St. George in the East and Wandsworth, districts of below-average to average income.[20]

D. Linear Probability and Logit Regressions for the Propensity to Patent

Linear probability and logit regressions allow me to verify inter-industry differences in patenting while controlling for variation in quality and urbanization. I run these regressions separately for all British innovations, for all award-winning British innovations and for all American innovations. The dependent variable equals one for patented innovations and zero otherwise. Industry dummies, population, city size, and a dummy to distinguish award-winning innovations are explanatory variables. Manufactures, which is the largest category, serves as the omitted industry class.[21]

Regression results in Table 6 confirm pronounced inter-industry differences in patenting.[22] Marginal effects of logit regressions imply that the probability of being patented was between 12 and 13 percent higher for manufacturing machinery (Table 6 column IV, V, and VI). OLS regressions, as a crosscheck for the logit regressions, show an even larger effect, of 20 to 21 percent (Table 6, column I to III). Inventors of other types of machinery were also more likely to patent their inventions; the marginal effect on patenting measures 10 to 17 percent for engines, 8 to 14 percent for agricultural machinery, and 4 to 7 percent for innovations of civil, military and naval engineering (Table 6, columns I-VI). On the other hand, innovations in textiles and chemicals were significantly less likely to be patented. Marginal effects in Table 6

[20] Maps of the distribution of patenting for individual industries yield comparable results.
[21] Manufactures is the broadest class; it includes hats and buttons, which had just begun to be mass produced, along with finished metal products, such as A. Horton's "Locks on a new principle, applicable for all doors and gates" (exhibit 674, Ashburton) or E. Cotterill's "patent climax detector locks" (exhibit 307, Ashted, near Birmingham), as well as improved furniture, such as R.A. Savage's "alarm bedstead and bedsteads for invalids" (exhibit 56, 15 St. James' Sq., London).
[22] Probit regressions yield similar results to logits in all specifications.

reveal that inventors were between 6 and 8 percent less likely to patent chemical innovations (compared to manufactures), and between 4 and 5 percent less likely to patent textiles. Coefficients for food processing and scientific instruments are negative but not statistically significant for the British data. The data also confirm that inventors were more likely to patent high-quality innovations (a 7 to 9 percent increase in Table 6, columns I to VI).

Logit and OLS regressions confirm that cross-industry differences in patenting increase with the quality of innovations. Marginal coefficients in Table 7 suggest that award-winning innovations in manufacturing machinery were between 18 and 35 percent more likely to be patented (18 percent for logit regressions in columns IV to VI, and 35 percent for OLS regressions in column I to III, compared to 12 and 20 percent for innovations of average quality). Similarly, award-winning innovations in engines and agricultural machinery were more likely to be patented with marginal effects of 15 to 26 percent for engines, and 15 to 30 percent for agricultural machinery (compared with 10 to 12 percent for engines, and 8 to 11 percent for agricultural machinery of average quality). In textiles, the propensity to patent decreased by 10 to 12 percent for textiles (Table 7, columns I to VI) and by approximately 8 percent for chemicals (Table 7, columns II and III, OLS regressions only).

Regressions for American innovations confirm the patterns of inter-industry variation in patenting in the British data. Innovations in manufacturing machinery were between 17 and 31 percent more likely to be patented (31 percent for OLS regressions in column I, 17 to 18 percent in columns V to VI of Table 8). Similarly, innovations in engines were between 18 and 30 percent more likely to be patented (30 percent in column I and 18 percent in columns V to VI). Innovations in agricultural machinery had between 14 and 24 percent higher patenting rates. In contrast, exhibits in textiles and chemicals were less likely to be patented (between 10 and 12 percent for textiles, and approximately 10 percent for chemicals, Table 8, column I) although, due to the small number of observations, the effect is not statistically significant for chemicals. Similar to British innovations, American innovations appear to be more likely if they are of high quality; innovations of high-quality have between 10 and 15 percent higher patenting rates than innovations of average-quality (15 percent for OLS and 10 to 12 percent for logit regressions).[23]

By contrast to the strong support for inter-industry variation, the exhibition data yield weaker evidence for rural-urban differences in patenting. In the British data, a coefficient of 0.008 for the size of the originating city (measured as the logarithm of population, Table 6, columns I and IV) indicates that the propensity to patent increased by 6 percent for an inventor in a town of 5,000 people compared to a single rural inventor, and by 11 percent for an inventor in London (equivalent to an increase in population of approximately 2.4 million). These effects, however, disappear as population data are divided into categories of urbanization; coefficients for cities from 5,000 to 100,000 people, 100,000 to 400,000, above 400,000, and for the city of London, are not significant (Table 6, columns II, III, V, and VI).[24] In the U.S. data, there are no distinguishable patterns in patenting across levels of urbanization or across cities.

In sum, results from OLS and logit regressions confirm that patenting varied strongly across industries for 19th century innovations. Moreover, industries where inventors had a high propensity to patent experienced a further increase in patenting for innovations of high quality. Inventors in the United States patented (and did not patent) in the same industries as in Britain, and the tendency to patent was amplified in industries with high propensities to patent. Urban inventors may have been more likely to patent, but rural-urban differences are small compared to

[23] With 113 award-winning innovations from the United States, the number of observation is too small to calculate logit regressions, and industry dummies for chemicals and engines are dropped. The strong positive effect on manufacturing machinery, however, remains robust in logit regressions of American innovations of high-quality.
[24] Alternative cut-off points for "rural innovations" and urban categories yield similar results.

cross-industry variation. The following section contrasts these results on 19th century patenting rates with the available data on contemporary patents to evaluate the effects of scientific progress on patenting

E. Does Scientific Progress Influence the Use of Patents?

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

In 1851, chemicals inventions, such as alum, potash, naphthalene, along with many dyes including indigo, madder, and turkey red, were difficult to reverse-engineer and rarely patented. Eighteen years later, Dimitri Mendeleyev's structuring of the elements changed the nature of chemical invention.[25] The periodic table, as a tool of analysis, set in motion a "second scientific revolution" that made it much easier to analyze and thereby reverse-engineer inventions (Haber, 1958).

There are no data for the 20th century that allow comparisons of innovations with and without patents similar to the exhibition data, but comparisons of patent counts across industries and over time suggest that patenting became more effective as a mechanism to protect chemicals. By the 1920s, 15 percent, or 277 of 1,867 U.S. patents that were assigned to publicly traded companies, occurred in chemicals (Moser and Nicholas, 2004, p. 390). Surveys of R&D labs are

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

equally suggestive of an increase in the relative effectiveness of patenting to protect chemical inventions. Edwin Mansfield's (1986) survey of 100 U.S. manufacturing firms in 12 industries finds that firms in chemicals and pharmaceuticals considered themselves to be heavily dependent on patent protection. Firms in those industries responded that patents were essential to developing and bringing to market more than 30 percent of their inventions. Levin, Klevorik, Nelson, and Winter's (1987) survey of 650 manufacturing firms reveals that U.S. R&D labs in chemicals and pharmaceuticals find patents to be the most reliable mechanism to protect intellectual property. By 1994, chemicals and pharmaceuticals are the only industries (among a total of 33 industries) where inventors cite patenting as the most effective mechanism to protect intellectual property (Cohen, Nelson, and Walsh, 2000, p. 10). The emphasis on patent protection in chemicals and pharmaceuticals stands in stark contrast with the low propensities to patent chemicals in the mid 19^{th} century, prior to the introduction of the periodic table.

VI. Conclusions

Traditional analyses use patents as a proxy for innovation. Inventors, however, express strong preferences for alternative mechanisms such as secrecy. This paper has introduced a new historical data set of more than 7,000 British and American exhibits at the Crystal Palace Fair in 1851 to examine the relationship between patents and innovations. The data suggest that a surprisingly small proportion of innovations are patented: In 1851, less than 12 percent of British inventors relied on patents to protect their intellectual property. Even in the United States, where patent protection was significantly cheaper and much less bureaucratic than in Britain, less than 16 percent of innovations appear to have been patented.

Most importantly the exhibition data show that patenting rates vary significantly across industries. In 1851, only 5 percent of chemical innovations were patented, compared to 30 percent of innovations in machinery. Inter-industry differences in patenting are robust to comparisons across Britain and the United States: American inventors patent (and don't patent) in the same industries as do British inventors. These results suggest that inter-industry variation in the nature of technologies outweighs the influence of cross-national variation, including the most substantive differences in patent laws.

Cross-industry differences in patenting are equally robust to adjustments for the quality of innovations. Innovations of high quality are slightly more likely to be patented overall, but inventors patent high-quality innovations in the same industries where they patent average-quality innovations. In fact, increases in the quality of innovation appear to intensify existing variation in patenting across sectors. In industries with high propensities to patent, such as manufacturing machinery, inventors become even more likely to patent innovations of high-quality. These results indicate that improvements in the quality of innovations amplify existing differences in the propensity to patent across industries.

In contrast to the strong evidence for variation across industries, the data yield little evidence of variation in the propensity to patent across rural and urban areas. While variation across industries consistently influences patenting, variation in city size has no clear effect on patenting neither in Britain nor in the United States. This finding strengthens the results of empirical studies which have interpreted higher patents per capita in cities as evidence for greater inventiveness in cities. For specific industries, however, there are noticeable differences between patenting in London and patenting in the rest of Britain. Specifically, inventors are significantly more likely to patent machinery innovations in London than in the rest of Britain.

This finding suggests that, similar to quality differences, urban density may amplify a pre-existing propensity to patent, which varies with the nature of technological change across industries.

In sum, these results suggest that differences in the technological characteristics of innovations across industries play the most important role in determining the patenting decisions of inventors. Low patenting rates provide strong evidence that alternatives to patent offer effective protection for intellectual property. Robust differences in patenting across industries indicate that their relative effectiveness varies across sectors. In some industries, such as chemicals and dyes, innovations are easy to keep secret, while innovations in other industries, such as machinery, may be sufficiently easy to imitate so that secrecy becomes impossible. Patent protection offers an alternative to secrecy that is available regardless of the technological characteristics of inventions. Inventors rely on patenting, despite its costs, if alternative mechanisms, such as secrecy, are weak.

If technological characteristics are a significant determinant of patenting, scientific progress is likely to boost patenting rates. Improvements in analytical tools intensify patenting as they weaken the effectiveness of secrecy and, at the same time, make it easier to describe and distinguish innovations in a patent grant. Between 1851 and the late 20th century, the periodic table initiated such a shift for chemicals, which evolved from one of the most prominent secrecy industries to *the* most patent-friendly industry. Today, the decoding of the genome may initiate an equally radical shift towards patenting for bio-technology inventions.

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

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

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

TABLE 2 –PATENTING RATES FOR BRITISH EXHIBITS IN 1851

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

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

TABLE 3 – AWARD-WINNING BRITISH INNOVATIONS IN 1851

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

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

TABLE 4 – PATENTING RATES FOR BRITISH AND AMERICAN EXHIBITS IN 1851

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

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

TABLE 5 – PATENTING RATES IN LONDON VERSUS THE REST OF BRITAIN, WITH ODDS RATIO TESTS

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

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

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

		OLS			**Logit**	
	I	**II**	**III**	**IV**	**V**	**VI**
Quality	**0.087**	**0.076**	**0.076**	**0.076**	**0.066**	**0.066**
	[8.09]**	**[7.91]****	**[7.94]****	**[9.30]****	**[8.96]****	**[9.01]****
City Size						
Population in logs	**0.008**	-	-	**0.008**	-	-
	[2.88]**	-	-	**[3.05]****	-	-
Rural [between 5,000 and 100,000]	-	0.028	-	-	0.030	-
	-	[-0.43]	-	-	[-0.44]	-
City above 100,000	-	0.022	-	-	0.025	-
	-	[-0.34]	-	-	[-0.36]	-
City above 400,000	-	0.030	-	-	0.032	-
	-	[-0.45]	-	-	[-0.48]	-
London	0.006	0.056	-	0.005	0.056	-
	[-0.43]	[-0.84]	-	[-0.45]	[-0.82]	-
Industry Classes						
Mining and metallurgy	-0.02	**-0.036**	**-0.041**	-0.030	**-0.051**	**-0.056**
	[-1.19]	**[2.82]****	**[3.26]****	[-1.23]	**[2.49]***	**[2.75]****
Chemicals	**-0.057**	**-0.065**	**-0.068**	-0.063	**-0.077**	**-0.08**
	[2.28]*	**[3.23]****	**[3.42]****	[-1.75]	**[2.26]***	**[2.36]***
Food processing	-0.023	-0.034	-0.038	-0.021	-0.034	-0.038
	[-0.74]	[-1.42]	[-1.62]	[-0.66]	[-1.2]	[-1.36]
Engines	**0.170**	**0.153**	**0.154**	**0.114**	**0.102**	**0.103**
	[7.09]**	**[6.93]****	**[6.95]****	**[8.79]****	**[8.60]****	**[8.69]****
Manufacturing machinery	**0.212**	**0.204**	**0.198**	**0.131**	**0.125**	**0.119**
	[6.53]**	**[6.87]****	**[6.67]****	**[8.46]****	**[9.01]****	**[8.64]****
Civil, military, and naval engineering	**0.065**	**0.049**	**0.044**	**0.057**	**0.044**	**0.040**
	[3.53]**	**[3.08]****	**[2.82]****	**[4.06]****	**[3.43]****	**[3.14]****
Agricultural machinery	**0.139**	**0.116**	**0.111**	**0.106**	**0.088**	**0.082**
	[4.73]**	**[4.57]****	**[4.37]****	**[6.28]****	**[5.85]****	**[5.56]****
Scientific instruments	-0.002	-0.003	0.000	-0.003	-0.004	0.000
	[-0.16]	[-0.2]	[-0.03]	[-0.22]	[-0.26]	[-0.02]
Textiles	**-0.041**	**-0.036**	**-0.037**	**-0.05**	**-0.042**	**-0.044**
	[4.18]**	**[3.94]****	**[4.07]****	**[4.07]****	**[3.84]****	**[3.92]****
Constant	-0.030	0.044	**0.078**	**-0.332**	**-0.249**	**-0.215**
	[-0.83]	[-0.67]	**[11.96]****	**[9.54]****	**[3.71]****	**[31.92]****
Observations	5,439	6,377	6,377	5,439	6,377	6,377
R-square	0.06	0.05	0.05	0.0725	0.0648	0.0629
Log Likelihood				-1834.97	-2079.27	-2083.41

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

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

		OLS			Logit	
	I	**II**	**III**	**IV**	**V**	**VI**
City Size						
Population in logs	-0.002	-	-	-0.002	-	-
	[-0.21]	-	-	[-0.22]	-	-
Rural [between 5,000 and 100,000]	-	-0.177	-	-	-0.094	-
	-	[-0.63]	-	-	[-0.57]	-
City above 100,000	-	-0.235	-	-	-0.146	-
	-	[-0.83]	-	-	[-0.88]	-
City above 400,000	-	-0.243	-	-	-0.155	-
	-	[-0.86]	-	-	[-0.93]	-
London	-0.008	-0.225	-	-0.009	-0.137	-
	[-0.3]	[-0.8]	-	[-0.31]	[-0.82]	-
Industry Classes						
Mining and metallurgy	**-0.089**	**-0.112**	**-0.107**	-0.104	**-0.147**	**-0.143**
	[2.01]*	**[3.45]****	**[3.48]****	[-1.53]	**[2.36]***	**[2.30]***
Chemicals	-0.063	**-0.079**	**-0.082**	-0.067	-0.092	-0.096
	[-1.39]	**[2.26]***	**[2.38]***	[-1.19]	[-1.77]	[-1.84]
Food processing	-0.067	-0.068	-0.065	-0.072	-0.073	-0.07
	[-1.49]	[-1.84]	[-1.72]	[-1.26]	[-1.52]	[-1.43]
Engines	**0.262**	**0.238**	**0.240**	**0.167**	**0.146**	**0.149**
	[4.18]**	**[4.11]****	**[4.16]****	**[4.81]****	**[4.75]****	**[4.85]****
Manufacturing machinery	**0.352**	**0.306**	**0.309**	**0.211**	**0.181**	**0.183**
	[5.22]**	**[5.00]****	**[5.03]****	**[5.68]****	**[5.71]****	**[5.74]****
Civil, military, and naval engineering	0.041	0.002	-0.003	0.033	0.002	-0.003
	[-0.71]	[-0.04]	[-0.07]	[-0.75]	[-0.05]	[-0.07]
Agricultural machinery	**0.306**	**0.215**	**0.243**	**0.187**	**0.126**	**0.151**
	[3.22]**	**[2.68]****	**[2.96]****	**[3.67]****	**[3.04]****	**[3.57]****
Scientific instruments	-0.002	0.000	-0.004	-0.002	0.000	-0.003
	[-0.06]	[-0.01]	[-0.11]	[-0.04]	[-0.01]	[-0.11]
Textiles	**-0.097**	**-0.087**	**-0.084**	**-0.12**	**-0.102**	**-0.099**
	[4.75]**	**[4.53]****	**[4.40]****	**[4.50]****	**[4.29]****	**[4.17]****
Constant	**0.193**	0.387	**0.162**	**-0.178**	-0.059	**-0.197**
	[2.15]*	[-1.37]	**[11.32]****	**[2.01]***	[-0.36]	**[17.49]****
Observations	1,470	1,745	1,745	1,470	1,745	1,745
R-square	0.09	0.08	0.08	0.0876	0.0825	0.0766
Log Likelihood				-613.01	-697.48	-701.98

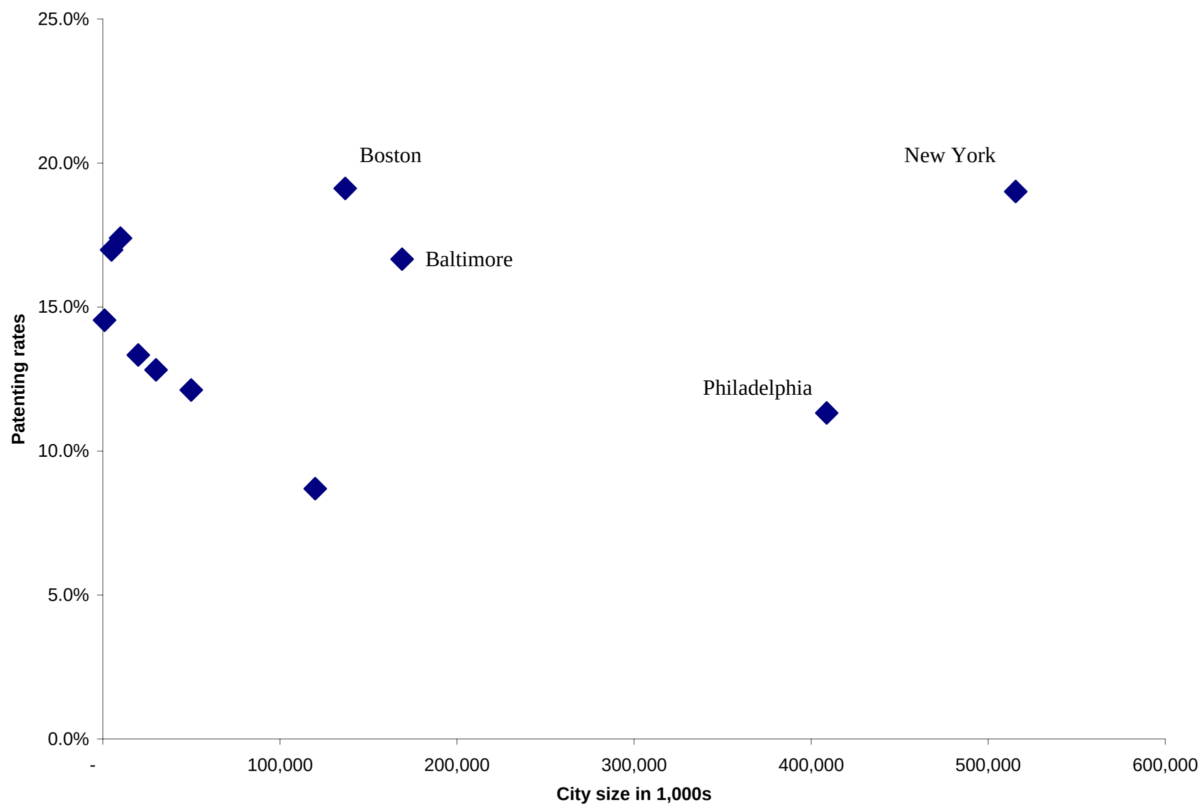
Notes: I have collected data on exhibits in the *Official Catalogue* (1851) and assigned each exhibit to an industry class according to the original classification scheme in 1851. Patented exhibits are identified in the descriptions of innovations in the *Official Catalogue*. I construct a measure of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

TABLE 8 – U.S. EXHIBITS, LINEAR PROBABILITY AND LOGIT REGRESSIONS (MARGINAL EFFECTS), DEPENDENT VARIABLE IS 1 FOR PATENTED EXHIBITS

		OLS			**Logit**	
	I	**II**	**III**	**IV**	**V**	**VI**
High quality	**0.146**	-0.06	-0.085	**0.124**	**0.101**	**0.103**
	[3.25]**	[-0.32]	-0.4	**[3.78]****	**[3.22]****	**[3.25]****
City Size						
Population in logs	0.003	-	-	0.001	-	-
	[-0.31]	-	-	[-0.1]	-	-
Town between 5,000 and 100,000	-	-0.052	-	-	-0.038	-
	-	[-0.67]	-	-	[-0.74]	-
City above 100,000	-	0.013	-	-	0.003	-
	-	[-0.16]	-	-	[-0.06]	-
City above 400,000	-	0.340	-	-	-0.003	-
	-	[-0.98]	-	-	[-0.06]	-
Industry Classes						
Mining and metallurgy	-0.049	-0.780	-0.829	-0.057	-0.051	-0.058
	[-0.93]	[-1.04]	[-1.05]	[-0.84]	[-0.83]	[-0.93]
Chemicals	**-0.105**	-0.900	-0.868	-0.158	-0.178	-0.175
	[2.12]*	[-1.13]	[-1.13]	[-1.47]	[-1.64]	[-1.62]
Food processing	-0.091	-0.756	-0.813	-0.106	-0.099	-0.104
	[-1.91]	[-1.11]	[-1.11]	[-1.74]	[-1.74]	[-1.81]
Engines	**0.297**	-0.471	-0.477	**0.179**	**0.178**	**0.18**
	[2.98]**	[-0.59]	[-0.6]	**[3.41]****	**[3.50]****	**[3.51]****
Manufacturing machinery	**0.309**	-0.469	-0.462	**0.177**	**0.169**	**0.169**
	[3.07]**	[-0.6]	[-0.6]	**[3.40]****	**[3.47]****	**[3.49]****
Civil, military, and naval engineering	0.14	-0.737	-0.652	0.093	0.050	0.052
	[-1.16]	[-0.89]	[-0.87]	[-1.39]	[-0.73]	[-0.76]
Agricultural machinery	**0.238**	-0.468	-0.527	**0.144**	**0.142**	**0.136**
	[2.27]*	[-0.65]	[-0.68]	**[2.59]****	**[2.59]****	**[2.53]***
Scientific instruments	0.033	-0.791	-0.732	0.028	0.011	0.015
	[-0.58]	[-0.97]	[-0.96]	[-0.63]	[-0.25]	[-0.34]
Textiles	**-0.099**	-0.789	-0.829	**-0.123**	**-0.111**	**-0.114**
	[2.38]*	[-1.11]	[-1.11]	**[2.29]***	**[2.16]***	**[2.21]***
Constant	0.084	0.755	0.913	**-0.227**	**-0.203**	**-0.212**
	[-0.82]	[-1.17]	[-1.14]	**[2.54]***	**[4.36]****	**[7.17]****
Observations	485	545	545	485	545	545
R-square	0.14	0.01	0.01	0.155	0.1427	0.1399
Log Likelihood				-179.35	-203.72	-204.37

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

FIGURE 1 – CITY SIZE AND PATENTING RATES IN THE UNITED STATES IN 1851



Notes: Data on patenting rates were collected from exhibits in the *Official Catalogue* (1851) and assigned to industry classes according to the original classification scheme in 1851. Patented exhibits are identified by matching names of exhibitors and descriptions of inventions with patents in the *Annual Reports of the United States Patent Office*. Information on the location of exhibits in the catalogue was matched to 19th century maps and dictionaries of geographic place names; population data are drawn from the United States Census of 1851.

FIGURE 2 – PATENTING ACROSS THE CITY OF LONDON