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Do Patent Laws Help to Diffuse Innovations?

Evidence from the Geographic Localization of Innovation and Production in 19th-Century England

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Patent laws are designed to encourage inventive activity and to facilitate the adoption and diffusion of innovations. Using data on innovations at 19th-century world fairs, Moser (2005) finds that patent laws may fail to raise levels of innovation if inventors rely on alternative means to protect intellectual property, and that instead of raising the number of innovations, the introduction of patent laws may change the direction of innovative activity. This paper examines whether patent laws fulfill the second function that is assigned to them; it asks whether patents help to diffuse innovations. Geographic data on the locations of 4,688 English innovations at the Crystal Palace Exhibition in 1851 and census data on the location of workers between 1841 and 1901 reveal that innovations are consistently more concentrated than production. Such data also show that industries that rely on alternative mechanisms to protect intellectual property tend to be significantly more concentrated. Industries that experience a shift towards patenting (and away from secrecy) after the Crystal Palace Exhibition become more geographically diffused between 1851 and 1901.

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Economists since Alfred Marshall have argued that knowledge of technical innovations tend to cluster geographically (Marshall, 1890; Simon Kuznets, 1963). Recent studies of patent data, such as Kenneth Sokoloff (1988) and Adam Jaffe, Manuel Trajtenberg, and Rebecca Henderson (1993) have provided empirical support for this idea by documenting the geographic clustering of U.S. patents. For the early 19th-century U.S., Sokoloff (1988) shows that inventive activity concentrated in cities and along major lines of transportation.[1] For the 20th-century U.S., Jaffe, Trajtenberg, and Henderson (1993) find that knowledge spillovers, as documented by patent citations, are highly localized. However, all such previous work has been restricted to studying the clustering of patents, without being able to examine the effects of patenting itself on the diffusion of innovations. This is a significant gap in the literature, if patents are charged with encouraging the diffusion of innovation and knowledge spillovers, especially if these spillovers are the driving force for economic growth, as Romer (1990) and Grossman and Helpman (1991) argue.[2]

This paper uses data on the geographic location of innovations at London's Crystal Palace Fair in 1851 to examine whether patent laws help to diffuse innovations. Geographic data on the locations of 4,688 English innovations at the Crystal Palace Exhibition in 1851 and census data on the location of workers between 1841 and 1901 reveal that innovations

[1] These findings are consistent with the theories of Hägerstrand (1952 and 1979) and Jacobs (1969) that the transfer of knowledge, and especially knowledge of a complex nature, requires repeated interaction, which is most likely to occur in close geographic proximity.

[2] A necessary condition for patent laws to strengthen the incentives for diffusion is that innovation responds to profit incentives. Previous research has established this fact. As early as 1883, surveys of inventors have suggested that inventive effort is motivated by expected profits (Procès-Verbal du Congres Suisse…1883, S.C. Gilfillan 1930, Joseph Rossman 1931). Zvi Griliches (1957) corroborates these findings in a pioneering empirical study of geographic patterns in the adoption of hybrid corn, which proves that the diffusion of innovations is responsive to market size. Jacob Schmookler (1966)'s study of U.S. patents in agriculture, petroleum, paper, and railroad equipment between 1800 and 1900 constructs further evidence for the importance of profit incentives as he shows that the number of U.S. patents for railway equipment increases with a short lag after sales of railway equipment. Zorina Khan and Sokoloff (1998) present further evidence for the responsiveness to demand from 19th-century patent data and the behavior of "great inventors".

are consistently more concentrated than production. Such data also show that industries that rely on alternative mechanisms to protect intellectual property tend to be significantly more concentrated. Industries that experience a shift towards patenting (and away from secrecy) after the Crystal Palace Exhibition become more geographically diffused between 1851 and 1901.

Patent laws may help to diffuse innovations geographically as they enable inventors to sell ideas to potential adopters at a different location. From 1840 to 1860, for example, Thomas Blanchard's practice of licensing and assigning the rights to build one's own Blanchard lathe were critical to the diffusion of the lathe from Massachusetts to Missouri and Arkansas (Carolyn C. Cooper, 1991, p. 170 and 195). In England, J. Macintosh's innovation of "improved rotary or revolving steam-pumps or engines for agricultural and other mills, marine engines, and locomotives, patented" could be useful in agriculture, on ships, and for locomotives throughout England (exhibit No. 28 in "engines"). By creating a saleable property right, patents help Macintosh's invention to bridge the geographic gap between its origins at 5 Gray's Square in London and the locations of its use, which are dispersed throughout the country. Licenses and assignments may increase innovation in receiving locations if adoption engenders further innovation through learning-by-doing. Thomas Blanchard, for example, benefited from his licensees who "in addition to paying fees, testifying in law suits, and helping to lobby congress, … constituted a pool of innovative talent." (Cooper 1991, p. 177)[3]

In addition to extending the geographic scope of adoption, patent laws may enhance the scope of knowledge spillovers by creating public and transferable records of new ideas.

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[3] The diffusion effects of licensing may be larger than the effects of assigning patents because licenses can be granted to more than one adopter. Because licenses are rental agreements rather than a sale, they may also be more likely to transfer knowledge back to the original location, as Blanchard's example suggests.

The difficulty of accessing British patent records in the mid 19th century may have limited their effectiveness as a knowledge base of new ideas. If patent laws, however, succeeded in assuring inventors that their intellectual property was secure, they may have encouraged patentees to advertise in trade journals or other printed media. Such channels of diffusion were particularly salient in the mid-19th century, when a wave of trade journals such as the *Scientific American* and the *Mechanic's Magazine* rapidly expanded their circulation. If patenting helps to diffuse knowledge of new technologies in this manner, innovations in industries with high patenting rates should be more geographically dispersed and innovations in industries with low patenting rates should be more concentrated.

Geographic data on close to five thousand English innovations with and without patents create a unique opportunity to examine the relationship between patenting and the geographic diffusion of innovation. The records of innovations at the Crystal Palace list each exhibitor's name and address, which can be matched to registration counties with 19th century maps and gazetteers. I have recorded towns of origins and their respective counties for 4,688 English innovations and matched street addresses to districts for 2,391 innovations from the city of London. I use these data to draw maps of English innovations in the mid 19th century; such maps reveal that mid 19th century innovation clustered in London and other major cities.

If patents help to diffuse innovations and if innovations encourage economic activity, then increases in the use of patents should result in a diffusion of economic activity, and industries that patent more should be more diffused. I test this idea by measuring differences in the propensity to patent across industries and by comparing measures of geographic dispersion across industries with high and low propensities to patent. Moser (2004) uses references to patents in the British exhibition data to measure the use of patents across industries. Patenting rates, calculated as the share of innovations that are patented, range from 7 percent in textiles, 8 in food processing, and 11 in scientific instruments to more than 34 percent in manufacturing machinery, 28 in engines, and 24 percent in agricultural machinery. Differences in patent use across industries are robust to a comparison with American data, which I construct by matching all U.S. exhibits lists of all patents in the *Annual Reports of the United States Patent Office* between 1841 and 1851.[4] In addition to comparisons across countries and their widely divergent patent laws, inter-industry differences in the propensity to patent are robust to comparisons across rural and urban areas, and to adjustments for the quality of innovations.

Comparisons of geographic concentration across industries with low and high patenting rates suggest that patenting may help to weaken the geographic concentration of production. Industries that relied on secrecy, rather than patents to protect their intellectual property, such as scientific instruments, paper, textiles and chemicals, were significantly more geographically concentrated, while patent-friendly industries, such as manufacturing machinery, engines, and agricultural machinery were more dispersed. Comparisons of geographic concentration between 1841 and 1901 reveal that manufacturing machinery became less concentrated over time, even as geographic concentration increased for England as a whole. As scientific advances raised the usefulness of patents to protect innovations in chemicals and instruments after 1850, production in these industries became more dispersed.

[4] In England and the U.S., about 13 percent of mid 19th century innovations appear to have been patented. These similarities in patenting behavior between the British and American inventors are especially remarkable compared to the vast differences between the British and the American patent system. For example, a British patent was 60 more expensive than an American patent in 1851 (Lerner 2002). For a detailed comparison of the British and American patent system see Zorina Khan and Kenneth Sokoloff (1998).

Comparisons of the geographic concentration of production and innovations across industries reveal that innovations are consistently more concentrated than production. Innovations in industries with high patenting rates are more evenly distributed across England, while innovations in industries with little patenting, such as scientific instruments and chemicals, are very concentrated. For example, innovations in scientific instruments concentrate around the Strand and St. Martin in the Fields, as well as in Clerkenwell. The quality of innovations, which I measure through awards for inventiveness granted at the Crystal Palace, is significantly higher in London, and especially within these areas of concentration.

The remainder of this paper combines geographic data on Crystal Palace innovations with and without patents and census data on the location of economic activity to examine the strength of localized knowledge spillovers across industries, and to explore the relationship between patenting and knowledge spillovers. Section I introduces the exhibition data and section II describes the variation in the use of patents across industries. Section III combines exhibition data with census data to measure geographic concentration across industries with low and high patenting rates and over time. Section IV compares the geographic concentration of innovations across industries, and section V concludes.

I. The Data

In 1851, the Crystal Palace was the largest enclosed space on earth; its exhibition halls covered 772,784 square feet, an area six times that of St. Paul's Cathedral in London, and housed a total of 17,062 exhibitors from 25 countries and 15 colonies (see *Bericht III*, 1853 p. 674; Kretschmer, 1999 p. 101). It was the first world fair that allowed inventors and firms to exchange information on technological innovations across countries. At a time when London had less than two million inhabitants, more than six million people came to see the Crystal Palace (Evelyn Kroker, 1975 p. 146). Even those who stayed at home could read about the fairs in weekly updates in trade and general interest journals, such as *Scientific American* and the *Illustrated London News*, and peruse detailed reports by their national committees (e.g., *Bericht*, 1853). From the catalogues that guided visitors through the exhibition grounds, the reports of national commissions, the diaries of committee members such as Edgar Alfred Bowring (1850), and many letters of exhibitors and visitors to the fairs, I have collected data on each of 5,032 English exhibits, including brief descriptions of the innovation, its industry of use, the exhibitor's name and geographic location, down to the level of street addresses whenever possible, whether the exhibit was patented or not, and whether it exhibit received an award for exceptional inventiveness.

A. Advantages over Patent Data

Empirical analyses of innovation typically rely on patent data, although patents may not be an ideal measure of innovations. In 1852, the *New York Daily Times* observes:

> There is no gain in the thousand and one useless articles patented yearly at Washington… Visit the patent office, and overhaul the records' and out of the many thousand inventions entered there, learn how few are in actual use" (*New York Daily Times*, April 26, 1852.)

In the 19th century, many countries did not require usefulness for patent grants (Coryton, 1855 pp. 235 and 239). For the 20th century, firm-level surveys have found that only between 5 and 20 percent of patents become economically useful (Meinhardt, 1950 p.256). These unfavorable proportions stem from the fact that patent data capture an early input in the process of innovation; only a small share of patented inventions develop into innovations in their later stages (Griliches, 1990 p. 1669, Harold I. Dutton, 1984 p. 6).[5]

As a further complication, patents are classified by functional principles and often cannot be assigned to a specific industry of use. For example, the functional class "dispensing liquids" includes holy water dispensers along with water pistols, while "dispensing solid" groups tooth paste tubes with manure spreaders (Schmookler, 1972 p. 88). As a result, empirical studies based on patent counts had to exclude important innovations such as power plant inventions and electric motors, because they could not be assigned to a specific industry (Schmookler, 1972 p. 89). Finally, Griliches (1990 p. 1669) observes that patented inventions differ greatly in quality. Manuel Trajtenberg (1990) addresses this problem by constructing measures of the value of patented inventions based on the number of succeeding patents that refer to them. However, historical citations data are extremely costly to collect and they may underestimate the quality of innovations in industries where patents undercount inventions.

Exhibition data, as a complement to 19th-century patent data, offer a way to address these concerns. Most importantly, exhibition data measure innovations regardless of whether they were patented or not, whereas patent data count only those inventions which inventors chose to patent. Uniform rules of selecting exhibits ensure that exhibits are comparable across countries, regardless of domestic patent laws. Exhibition data cover innovations in all industries, including those that were barred from patenting. Depending on an innovation's country of origin, exhibition data either include references to mark patented inventions or can

[5] The most prominent alternative to patent data, firms' expenditure on R&D (e.g., Sakakibara and Branstetter 2001), captures an even earlier stage of the innovation process (see Griliches 1990, p. 1671).

be matched with patent data to distinguish innovations with and without patents. Awards to the most innovative and useful exhibits provide a measure for the quality of innovation.

B. Description of the Exhibition Data

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

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

This exhibit is classified in the Crystal Palace industry class number 9, "Agricultural and Horticultural Machines and Implements" and in the Centennial class 670, "Agricultural Machinery and Instruments for Tillage." For the Crystal Palace data, 5,032, English exhibits have been classified according to 30 industries of use. Industry classes span the entire spectrum of production; they range from mining and minerals, chemicals, and food processing, to engines, manufacturing machinery, and scientific instruments.

Data on the geography of innovation are constructed from the home location of English exhibitors at the Crystal Palace Exhibition in 1851. Entries in the exhibition catalogues typically describe the innovation's town of origin, and sometimes its province or county. For exhibits from London and other large cities, many entries specify the exhibitor's street address, as well. To identify smaller settlements, entries include the names of nearby towns. For example, the English town of Bluntisham is listed as "Bluntisham, near St. Ives, Huntingdonshire." Mid 19th-century maps such as the *Times Handy Atlas*, genealogy websites, and dictionaries of geographic place names, including *Bartholomew's Gazetteer of the British Isles* (1887) and the *Getty Thesaurus of Geographic Place Names,* helped to identify registration districts, as well as longitudes and latitudes (to the third digit).[6] For example, J. Bendall's town "Woodbridge" is identified within the registration county of Suffolk, at latitude 52.100 and longitude 1.317. Such geographic data are available for 4,688 innovations, 93 percent of all English exhibits. Within the city of London, I have been able to match street addresses to registration districts for 2,297 innovations from London, 91 percent the city's innovations (Table 1). Such data indicate that innovations in mid 19th-century England concentrated in London and other major cities (Figure 1). Mapping innovations to districts in London suggests that innovations tended to concentrate geographically even within the city itself (Figure 2.)

A comprehensive system of local commissions and collection points ensured that the best technologies from both rural and urban inventors were presented at the fair. National commissions typically delegated the authority to select exhibits to local branch commissions. Britain's national commission for the Crystal Palace nominated 65 local commissions to select exhibits at the local level. Local committees typically consisted of two to ten scientists and businessmen, representing the area's main industries (*Bericht*, 1852 pp. 37 and 90). In their applications to local commissions, potential exhibitors were required report "what is novel and important about the product, how its production shows special skillfulness and proves an original approach" *(Bericht,* 1853 pp. 50 and 117). National commissions double-checked the local choices, accepting the majority of them (*Bericht,* 1853 pp. 40 and 64). Subsidies for transport costs helped to ensure equitable representation, as exhibitors were only required to cover transportation costs to local collection points.

[6] The Getty Thesaurus of Geographic Place Names can be accessed at http://getty.edu/research/. Also see http://www.iath.virginia.edu/mhc/Archive/Data, and http://www.multimap.com.

Awards to the most innovative exhibits helped to enforce the selection criteria. International panels of between six and twelve researchers and businessmen ranked all exhibits according to their "novelty and usefulness" and awarded prizes to the top 30 percent. All exhibits were included, and no one could excuse himself from the jury's evaluation. Signs such as "Not entered in the competition" were explicitly prohibited (*Bericht*, 1853 pp. 29, 50, 98 and 111). At the Crystal Palace, 5,438 exhibits received awards (*Bericht*, 1853 p. 707; Utz Haltern, 1971 p. 155). Juries awarded Council Medals, the highest honor, to 1 percent of all exhibits, Prize (or silver) Medals to 18 percent, and Honorable Mentions to 12 percent of all exhibits (*Bericht*, 1853 p. 707; Haltern, 1971 p. 155). Detailed information on more than 1,800 award-winners has been recorded in the reports of the German Commission to the Crystal Palace (*Bericht*, 1853), and I have matched this information with the exhibits in the British exhibition catalogue to construct a measure for the quality of innovations.

C. Potential Weaknesses of the Exhibition Data

There are however potential sources of bias in the exhibition data: they may underestimate large and heavy innovations that were difficult to transport to London as well as those innovations that were protected by secrecy and inventors feared to disclose at the fairs. 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 at Cardiff dock"; A.Watney of Llanelly, Wales, exhibited "Models of anthracite blast furnaces." Among the engineering exhibits there was a model of the suspension bridge that was being constructed across the river Dnieper in Kiev. Robert and Alan Stevenson (grandfather and uncle to Robert Louis Stevenson) displayed models of lighthouses for the Bell Rock and for Skerryvore (see L.T.C. Rolt, 1970 p. 157).

As a further check of the geographic component of the data, I compare the location of exhibits at the Crystal Palace with the location of exhibits at the American Centennial Exhibition in Philadelphia in 1876. If differences in transport cost within England bias the geographic distribution of innovation in favor of the city, this bias should be lower for an exhibition on American soil, because differences in transportation costs within Britain become negligible in comparison to the costs of transatlantic shipment. However, there are only small differences in the relative presentation of rural and urban exhibits at the two fairs. The share of exhibits from London is 50.4 percent in 1851 and 48.9 in 1876, and the shares of principal towns are 29.7 and 32.0 percent. Rural innovations accounted for 19.9 percent in 1851 and 19.2 in 1876.[7]

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 omitted from the patent counts. Contemporary records suggest that this fear of imitation was the most serious concern for exhibitions whose host country did not have patent laws, such as 19th-century Switzerland. Even at Swiss exhibitions, however, only one in hundred exhibits withdrew their applications after legal protection was refused (*Procès-verbal du Congres Suisse*, 1883

[7] Data were created in an identical manner to the process described above from the catalogue of the 1876 exhibition. Ideally, I would use these data to examine changes in the geography of innovations over time, but Britain's presence at the Centennial is very small. In 1876, Britain contributed 1,121 exhibits, and distributing these data across 16 industries and 42 counties creates many cells with zero observations.

p. 68).[8] Exhibitors 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 (see *Official Catalogue, First Edition*, 1851 p. 210). P. Claussen of London, an inventor and patentee, exhibited "Samples of flax in all its stages, from straw to cloth, prepared by the exhibitor's process" (*Official Catalogue*, 1851 p. 28). In addition, a system of registration, which was available to all exhibitors, acted as a cheap and fast patent system; at the Crystal Palace only 500 of 13,750 exhibitors took advantage of it (*Bericht III*, 1853 pp. 697-701). If exhibition data undercount innovations that were protected by secrecy they may overstate the importance of patent protection.

D. Is Patenting Endogenous to the Localization of Innovation?

In addition to potential weaknesses of the exhibition data, this study may be compromised if the geographic distribution of innovations determined the nature of the British patent law. Historical records alleviate these concerns for the 19th century. For example, Edith Penrose (1951) finds that mid 19th century patent laws were configured without much consideration for their effects on specific industries (Penrose 1951, p.19). Such analyses document that the influence of innovation on patent laws was limited prior to the exhibitions:

[8] Switzerland adopted a rudimentary draft of patent laws in 1888, which Schiff (1971) calls "the most incomplete and selective patent law ever enacted in modern times" (Schiff 1971, p. 93).

> In 1839 Brougham's Act was amended for a minor technical reason, and in 1844, the Judicial Committee of the Privy Council was empowered to extend patents up to a period of fourteen years. Neither of these changes appears to have resulted from pressure applied by the invention interest. (Dutton 1984, p.57)[9]

But the diffusion of innovations may also have influenced the patenting decisions of individual inventors. This is most likely if the location of innovations corresponds closely to the location of economic activity. For example, innovators in geographically diffused industries may be more likely to patent because patents create transferable intellectual property, which allows these innovators to sell their ideas in a geographically dispersed market. Conversely, inventors in geographically concentrated industries may more likely to patent because they perceive the risks of imitation to be higher. In either case, pre-existing patterns of geographic dispersion would influence inter-industry variation in the propensity to patent. To account for this possibility, I integrate data from the British Census of Manufacturing in 1851 to control for the location of manufacturing at the time of the Crystal Palace Fair.

E. Census Data on the Location of Economic Activity from 1841 to 1901

Clive Lee (1979) has assigned British census returns from 1841 to 1971 to 28 *Standard Industry Classes* and 42 English registration counties. I use Lee's counts of England's total labor force including both male and female workers, to measure the geographic concentration of production from 1841 until 1901.[10] At the time of the Crystal

[9] Dutton (1984, p. 64) explains the limited involvement of 19th-century inventors: "Patent laws were technically complex and intrinsically uninteresting. Many inventors were probably too ignorant to offer any interference and few MPs were able or willing to master the subject…Secondly, the invention interest was not sufficiently unified, and remained organized on a local basis only, right through to the late 1840s."

[10] In 1901, the U.K. census switched its boundaries for England and Wales from registration to administrative counties. In 1891, a similar change occurred in Scotland, when census boundaries changed from registration to civil counties.

Palace fair in 1851, Lee counts 7,598,246 workers in the census, including 1,174,057 in miscellaneous services and 383,922 that cannot be classified. I assign 5,738,566 of these workers to 16 mutually exclusive industry classes that match the Crystal Palace classification.[11] This allows me to gauge the diffusion of innovations relative to the diffusion of workers, and to examine the relationship between patenting and changes in the diffusion of economic activity across industries and over time.

Endogeneity may compromise analyses of the effects of patenting on the dispersion of production if geographic dispersion influences patenting rates, rather than patents influencing dispersion. Historical records, however, suggest that geographic concentration may have increased, rather than decreased inventors' propensity to patent. For example, Christine Macleod (1988) finds that the vast majority of all English patents were granted to townspeople. Macleod observes that urban patents consisted of relatively small improvements or changes in design, suggesting that urban patentees may have been more aware of the patent system. For the 20th century U.S., Allan Pred (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) and Ogburn and Duncan (1964) suggest that patents per capita increase with the size of cities. To account for the possibility that pre-existing patterns of geographic concentration may

[11] This classification system differs from Moser's (2005) classification because the current paper has to match the industry classes in the exhibition data with the British census records. Along with miscellaneous services and "unassigned", the matched classification omits distributive trade (70,527 workers), insurance, banking, and finance (4,838 workers), professional and scientific services (226,436 workers). The latter class includes physicians, dentists, and midwives, along with clergy and barristers. Although the exclusion of medical staff may lead to an underestimate of people capable of producing scientific instruments, including the other two professions would probably lead to a more serious overestimate.

influence patenting rates, I compare patenting rates across industries with changes in the geographic diffusion of innovations and production over time.

II. Variation in the Use of Patents across Industries

Moser (2004) uses exhibition data to measure inventors' propensity to patent across industries and countries. For Britain's innovations, patented innovations are identified from references to patents in the descriptions of innovations in the exhibition catalogues. For example, J. Bendall's "universal self-adjusting cultivator,…pat." is recorded as a patented exhibit. Patenting rates are constructed by dividing the number of exhibits with references to patents by the total number of exhibits. References to patents will be most accurate if exhibitors report patents truthfully. As an approximation, this seems reasonable: exhibitors benefited from reporting the patents that they owned and jurors carefully checked all exhibits, so that fraudulent references faced a real risk of discovery.

As a robustness check for the British data, Moser (2004) calculates patenting rates for American exhibits. Proxies for the American data are constructed by an alternative method to get a better test of the British data: For American innovations, patented exhibits are identified by matching all 549 American exhibitors at the Crystal Palace with patents granted between 1841 and 1851 from the *Annual Report of the Unites States Patent Office*. For example, "U.S. patent No. 4387; Otis, Benjamin H.; Dedham, Mass; Mortising machine; granted Feb. 20, 1846", from the *Annual Report* for 1846, and "U.S. exhibit 23; Otis, B.H.; Cincinnati, Ohio; Boring and mortising machine" from the *Official Catalogue* (1851), identify a match.

Comparisons of American and English patenting rates reveal remarkable similarities in patenting behavior, despite important differences between the American and the British patent laws. Although the upfront costs of patenting were extremely high in Britain (at the equivalent of 37,000 1998 U.S. dollars, Lerner 2000) but modest in the U.S. (at 618 U.S. dollars), the share of innovations that were patented was similar in Britain and in the U.S.: 13.3 percent in England compared to only 14.2 percent in the United States.[12] Moreover, English and American inventors chose to patent (and not to patent) in the same industries. In Britain and the U.S., innovations in machines, such as new types of engines, manufacturing machinery or agricultural tools, were patented more frequently than innovations in any other industry. One third of American innovations in engines, manufacturing machinery, and agricultural machinery were patented, compared to one seventh across all industries. In Britain, these same industries had the highest patenting rates, despite significant differences in patent laws. One third of British innovations in manufacturing machinery were patented and about one fourth of innovations in engines and agricultural machinery. In contrast, inventors chose to patent between three and ten percent of innovations in scientific instruments, food processing, chemicals, textiles, and mining. The patenting behavior of 1,803 award-winning exhibitors corroborates the patterns of cross-industry variations in the overall data: patenting rates are close to 20 percent for machinery, but significantly lower in other industries, such as scientific instruments and chemicals.[13]

[12] Across the British Isles, including Scotland, Ireland, and Wales, 11.1 percent of exhibits are patented..
[13] Aggregation may conceal even larger differences in the propensity to patent. Innovations in "textiles", for example, includes dye stuffs innovations, that were extremely difficult to reverse-engineer and therefore less dependent on patent protection, along with advances in weaving and other types of innovations that were copied with much greater ease, and therefore more likely to be patented. Similarly, "instruments" includes telegraphs and improvements to the pianoforte which were easy to imitate, along with optical and scientific instruments, which could be protected by secrecy.

In sum, Moser (2004) documents that the use of patents varies across industries. If patents help to diffuse innovations, and if innovations promote economic activity, then innovations and economic activity in industries that patent more should be more evenly diffused. The following sections combine exhibition counts with census data to explore this idea.

III. Patenting and the Geographic Diffusion of Economic Activity from 1841 to 1901

This section applies statistics that customarily measure market power to gauge the strength of geographic concentration across industries. An industry's geographic Herfindahl-Hirschman index (HHI) is calculated by squaring each county's share of the total number of innovations, summing across all counties, and multiplying by 100. This creates an index of geographic concentration that ranges from 0 (complete diffusion) to 100 (complete concentration).[14]

$$HHI \equiv 100 \sum_j \left(\frac{X_{ij}}{\sum_j X_{ij}} \right)^2$$

where X_{ij} represents the number of exhibits from industry i and county j.

A. Patenting and the Geographic Diffusion of Production across Industries

Comparisons of patenting rates and geographic concentration in Table 2 and Figure 3 suggest that production in patent-friendly industries tended to be slightly more diffused. The three most concentrated industries – scientific instruments, textiles, and paper – were renowned for secrecy and had among the lowest patenting rates (Table 2, columns I and III,

[14] The HHI increases as the number of counties or district decreases, but these numbers are constant in my data.

and Figure 3). Inventors in paper-making, for example, were less likely to patent than inventors in any other industry (with a patenting rate of 3 compared to 13 percent across all industries), and the production of paper was more concentrated than that of any other industry (with a geographic HHI of 21 compared to 6 across all industries). Similarly, less than 7 percent of textiles innovations were patented, and textiles were the second most concentrated industry (with a geographic HHI of 20). Scientific instruments, as the third-most concentrated industry, were also less likely to be patented, especially in comparison to other classes of machinery innovations (with a patenting rate of 11 percent and an HHI of 16). Manufacturing machinery, the most patent-friendly industry, was distributed more evenly, albeit more concentrated than the average industry (with a geographic HHI of 12 and a patenting rate of 34 percent). Across all industries, the coefficient of linear correlation between patenting and geographic concentration was negative at -0.33.[15]

These correlations are consistent with the idea that patent laws help to diffuse innovations, but they cannot account for the many alternative factors that may determine the geography of innovations and production; they are especially sensitive to the fact that pre-existing patterns of geographic concentration may influence inventors' propensity to patent. The following paragraphs attempt to address these problems by examining changes in geographic concentration of industries over time.

B. Changes in Patenting and Geographic Concentration between 1841 and 1901

Section II has argued that the usefulness of patents depends on the technological characteristics of innovations and that these characteristics vary across industries.

[15] Alternative measures of concentration yield similar results. For example, the correlation between patenting and C3, the share of an industry's work force that live in three counties with the largest number of workers, is negative as well, at -0.23.

Technological characteristics may, however, also vary over time, as advances in scientific knowledge alter the nature of innovation. For example, chemicals innovations in the mid-19th century including alaun, potash, napthaline, quinine, caffeine, and tannin were strongly dependent on natural resources, which made them difficult to codify and almost impossible to reverse-engineer. For dye-stuffs, Holmyard (1958) notes that "Chemistry had not sufficiently advanced, before about 1850, to unravel the usually complicated structures of colouring-matters." As a result, most inventors chose to keep their inventions secret, and chemical innovations had low patenting rates, around 7 percent in 1851. By the late 20th century, however, surveys of American research labs found that chemical innovations were one of two industries where inventors consider patent protection to be most useful (Cohen, Nelson, and Walsh 2002). This change from secrecy to patenting occurred after the Crystal Palace Fair, as chemical innovation became more and more science-based, until Dimitri Mendelyev revolutionized the process of chemical innovation with his publication of the periodic table in 1869. Scientific advances between 1851 and 1869 made it easier to describe and codify chemical inventions in a patent application, but such progress also lowered the barriers to imitation. As a result, inventors found it both easier and more important to patent their ideas.

Scientific instruments, and especially watch-making, experienced a similar shift towards patenting after the Crystal Palace Exhibition. In the 1840s, innovation focused on making watches as thin and as accurate as possible. Time trials in Geneva, Neuchâtel, and Greenwich and other major watch-making centers measured and advertised the accuracy of watches by individual makers (David Landes 1983, pp. 290-91). Swiss makers learned to produce movements and plates that measured little over a millimeter and produced entire watches that measured only two or three (Landes 1983, p.267). Once the problem of size and accuracy were solved, the focus of innovation shifted towards production for a larger market, which was achieved by relocating production from individual makers to larger shops, equipped with machine tools and powered by water or even steam. By 1870, one tenth of the work force was employed in such proto-factories (Landes 1983, p. 295)[16]. With mechanization, innovations in manufacturing machinery and engines became more important, and such innovation depended on patent protection.

Measures of geographic diffusion between 1841 and 1901 suggest that the geographic diffusion of production in these industries increased with their dependency on patents. Figure 4 shows that England's labor force became more concentrated between 1841 and 1901. Manufacturing begun at a medium level of geographic concentration (with a geographic HHI of 12 in 1841) and after a slight increase in concentration between 1841 and 1851, switched to a course of steady diffusion, lowering its level of concentration to a geographic HHI of 10 in 1901. In contrast, the production of chemicals innovations becomes more concentrated between 1841 and 1851 (falling from 9 to 13 in terms of the HHI) as chemicals become less dependent on natural resources and innovations rely more and more on specialized knowledge. After 1851 the production of chemicals becomes increasingly diffused, and the HHI of geographic concentration falls back to 10 in 1901. In contrast, scientific instruments, which are less dependent on natural resources, start at a higher level of concentration in 1841 (with a geographic HHI of 15) and continue to become more concentrated until 1861. After 1861, however, production diffuses rapidly, until, by 1901, instruments reach the same levels of diffusion as manufacturing machinery.

[16] Also see *Procès-Verbal du Congres Suisse*…(1883): 34-35). Gerard L'Estrange Turner (1998) describes a similar shift towards mechanization at the time of the Crystal Palace for other types of scientific instruments.

Such changes in geographic concentration lend support to the hypothesis that patent laws help to diffuse innovations. The application of new technologies may, in turn, engender opportunities for further innovation through learning-by-doing and chance discoveries. If learning-by-doing is the main driver of innovation, the geographic concentration of innovation should parallel the geographic concentration of production fairly closely. Patents may, however, also help to diffuse innovations by encouraging inventors to publicize their ideas beyond their local communities and thereby further diffuse contribute to the diffusion of innovations. The following section uses exhibition data to examine the diffusion of innovations.

IV. Patenting and the Geographic Diffusion of Innovations

Measures of the geographic concentration of innovations reveal that innovations were consistently more concentrated than production. Across all industries, the geographic HHI was 26 for innovations compared to 6 for workers; for individual industries, HHIs ranged from 10 for agricultural machinery to 57 for paper (Table 2, row 3 and Figure 5). Only in textiles was innovation more concentrated than production, with a geographic HHI of 18 for innovations compared to 21 for workers. Such differences between the concentration of innovation and production indicate that the localization of innovations exceeds the localization of production, which may be interpreted as evidence for the existence of localized knowledge spillovers.

Innovations in industries with little patenting are significantly more concentrated than production, suggesting that the localization of knowledge spillovers is strongest in industries with secrecy. Technological advances are more concentrated in scientific instruments and textiles than in any other industry (with geographic HHIs of 49 and 57) and innovations in both industries innovations significantly more concentrated than production (16 for instruments and 21 for paper, Table 2, column I).[17] Similarly, chemical innovations are concentrated relative to other industries and relative to the location of chemical workers (with an HHI 33 for chemical innovations compared to 26 across all industries and 12 for chemical workers). Even in food processing innovations are more concentrated than workers (with a geographic HHI of 22 compared to 7 for production) and the HHI value for food processing is only slightly below the average across all industries, despite the industry's dependency on natural resources.[18] In comparison, technological advances in the patent-friendly industries are more evenly distributed, at HHIs of 21, 28, and 10 for manufacturing machinery, engines, and agricultural machinery.

Patterns of geographic concentration for textiles contradict these patterns, but the high level of aggregation may conceal a link between patenting and innovations across a finer division of the textile industries. For example, innovations in silk, an industry that was famed for its reliance on secrecy, were also relatively concentrated (with patenting rates of 2.6 percent and an HHI of 35, Table 3), while innovations in cotton and flax, which are patented with greater frequency (11.4 and 15.6) percent, were among the most

[17] Scientific instruments tended to be concentrated even within the city of London, clustering in the districts of St. George and Hanover St., the Strand, and Clerkenwell. The quality of innovations was highest in areas of geographic concentration: Twenty-five percent of London's exhibits in scientific instruments receive awards for inventiveness, compared to 19 percent in other cities and only 7.5 percent in rural England. Within London, the percentage of prize-winners is largest in concentrated locations: close to 40 percent of exhibits from the district "Strand and St. Martin in the Fields" received medals for inventiveness. Innovations in chemicals also concentrate in urban areas and the quality of innovations appears to be higher within cities. Almost half of all exhibited innovations in chemicals originate in London. Exhibits per capita in rural areas are only one tenth of exhibits per capita in London. Exhibits per capita in other towns are half of London's value. The quality of urban innovations is equally remarkable: 64 percent of urban chemical exhibits receive awards, and 54 percent of those from London. In comparison, awards distinguish only 35 percent of chemical exhibits from rural areas.

[18] For mining innovations, the strong dependency on natural resources weakens the link between patents and geographic concentration. Mining innovations have the second lowest patenting rate, but they are significantly more diffused than innovations in other industries (with a geographic HHI of 14 compared to 26. However, even in mining, innovations tend to be more concentrated than production.

geographically diffused (with HHI's of 25 and 27, respectively). The coefficient of correlation between patenting and concentration is -0.57 across all types of textiles.[19] Historical accounts of the location of production suggest that innovations in patent-friendly textiles were significantly more concentrated than production. Production of cotton, for example, appears to have been extremely concentrated: Only one of five Lancashire weaving towns was over 30 miles away from Oldham, the largest spinning town in Lancashire (Tim Leunig 2001); in 1896, 82.8 percent of all spindles were recorded in the neighborhood of that city.[20] These comparisons suggest that even within the textiles sector, innovations were more concentrated than production, and that patent use helped to diffuse inventions.

V. Conclusions

This paper has used geographic data on the locations of 4,688 English innovations at the Crystal Palace Exhibition in 1851 and census data on the location of workers between 1841 and 1901 to examine whether patent laws help to diffuse innovations throughout the economy. If patent laws succeed in fulfilling this function, innovations and economic activity should be less clustered in industries that patent more. Comparisons of exhibition data and census data across industries show that innovations are consistently more concentrated than production, and that innovations and production are most concentrated in industries that make little use of patents, such as instruments, chemicals, and paper-making. As scientific advances increase the usefulness of patents in these industries, instruments and

[19] Within London, however, textiles innovations are more concentrated than innovations in other industries: Close to half of all innovations occur in one of three districts, Hanover Square, Shoreditch, and Whitechapel, which are adjacent to each other (districts 3, 14, and 16 in Figure 2). Scientific instruments and chemicals, which have the second and third lowest share of patented inventions, are also extremely concentrated (with HHI's of 8 and 9 compared to concentration ratios of 37 and 38). The coefficient of linear correlation between patenting and geographic concentration is -0.45 across industries.

[20] Similarly, a "weaving district" - comprising the Accrington, Bacup, Blackburn, Burnley, and Preston districts contained 66.4 percent of all looms (D. Famie 1979).

chemicals become more geographically diffused. Such results indicate that patent laws succeed in facilitating the diffusion of innovations and economic activity.

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TABLE 1 – SHARE OF EXHIBITS WITH COUNTY INFORMATION

	All	Assigned to counties or districts	
	Exhibits	Total	Share
England	5,032	4,688	93.2%
London	2,529	2,297	90.8%
Province	2,503	2,391	95.5%

Notes: Data were constructed by matching addresses of exhibitors as reported in the *Official Catalogue… (1851)* to registration counties and London's district using 19th-century maps, gazetteers, and the *Getty Thesaurus of Geographic Place Names*.

TABLE 2 — PATENTING RATES AND GEOGRAPHIC CONCENTRATION

	Geographic concentration (HHI)		Patenting rates
	Workers	Innovations	(at least 1 patent)
Mining	14.14	7.54	5.0%
Chemicals	33.16	11.87	7.4%
Food processing	22.42	7.14	8.3%
Agricultural machinery	9.74	2.99	23.9%
Manufacturing machinery	21.40	12.14	34.2%
Hardware	24.32	12.06	16.2%
Engines	33.41	10.02	27.8%
Construction	34.22	6.16	15.6%
Military	34.69	11.78	14.7%
Scientific instruments	49.22	15.87	10.7%
Textiles	18.47	20.29	6.6%
Clothing	33.78	7.35	11.3%
Paper	56.87	20.60	3.1%
Leather	40.45	10.22	10.9%
Glass	27.91	13.84	11.1%
Furniture	38.73	7.79	7.4%
Total	**25.95**	**5.60**	**13.3%**

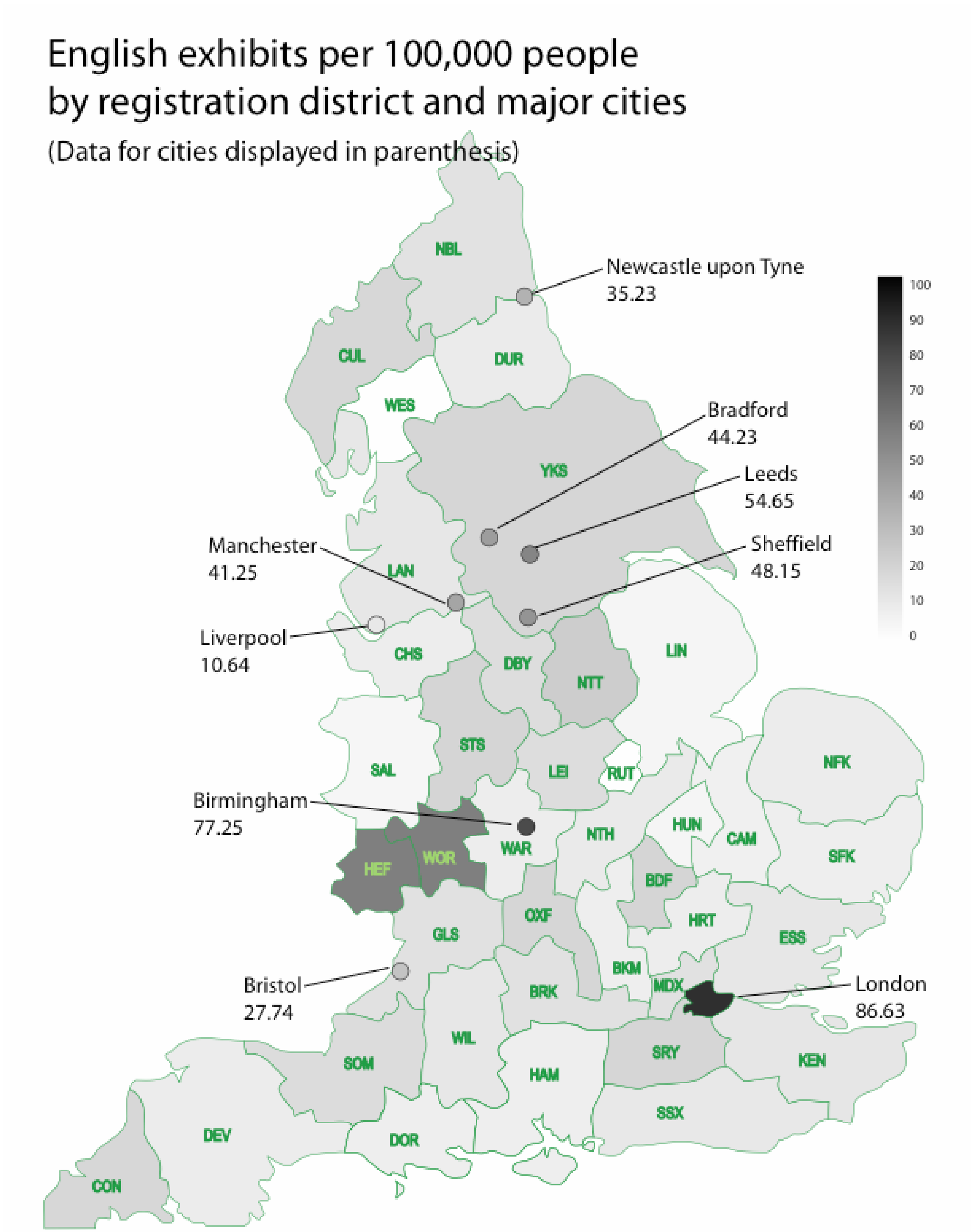
Notes: Data on the concentration of innovations were constructed by matching the home addresses of 4,074 English exhibitors at the Crystal Palace Exhibition with registration counties using 19th-century maps and the *Getty Thesaurus of Geographic Place Names*. Data on the concentration of manufacturing workers were constructed by matching counts of 16,738,695 English workers recorded in the British Census of 1851 from Lee (1979) with the exhibition data. Innovations are assigned to 16 industry classes. C3 measures the proportion of innovations or workers that occur in the three counties with the largest shares of innovations or workers in that industry.

TABLE 3 – PATENTING RATES AND GEOGRAPHIC CONCENTRATION WITHIN TEXTILES

	Patenting rates	HHI
Silk	2.6%	34.90
Paper	3.1%	56.91
Wool	6.0%	40.75
Dyed fabrics	7.1%	40.82
Embroidery	8.8%	23.37
Cotton	11.4%	25.21
Clothing	12.4%	33.29
Flax and hemp	15.6%	26.52
Correlation		**-0.6753**
Textiles (w/o paper)	**8.6%**	**20.20**
Correlation		**-0.5680**

Notes: Patenting rates are calculated by dividing the number of references to patents by the number of exhibits in each industry. HHI reports a Herfindahl Hirschman index of concentration, where market shares are replaced by the share of each of England's 42 registration counties of the total number of English exhibits in that industry. Raw data are drawn from *Official Catalogue…* (1851) and cities are matched to registration counties through contemporary maps and the *Getty Thesaurus of Geographic Names.*

FIGURE 1



English exhibits per 100,000 people
by registration district and major cities
(Data for cities displayed in parenthesis)
Newcastle upon Tyne
35.23
Bradford
44.23
Leeds
54.65
Sheffield
48.15
Manchester
41.25
Liverpool
10.64
Birmingham
77.25
Bristol
27.74
London
86.63
NBL
CUL
DUR
WES
YKS
LAN
CHS
DBY
NTT
LIN
SAL
STS
LEI
RUT
NFK
HEF
WOR
WAR
NTH
HUN
CAM
SFK
BDF
GLS
OXF
HRT
ESS
BKM
MDX
BRK
WIL
SOM
SRY
KEN
HAM
SSX
DEV
DOR
CON
100
90
80
70
60
50
40
30
20
10
0

FIGURE 2

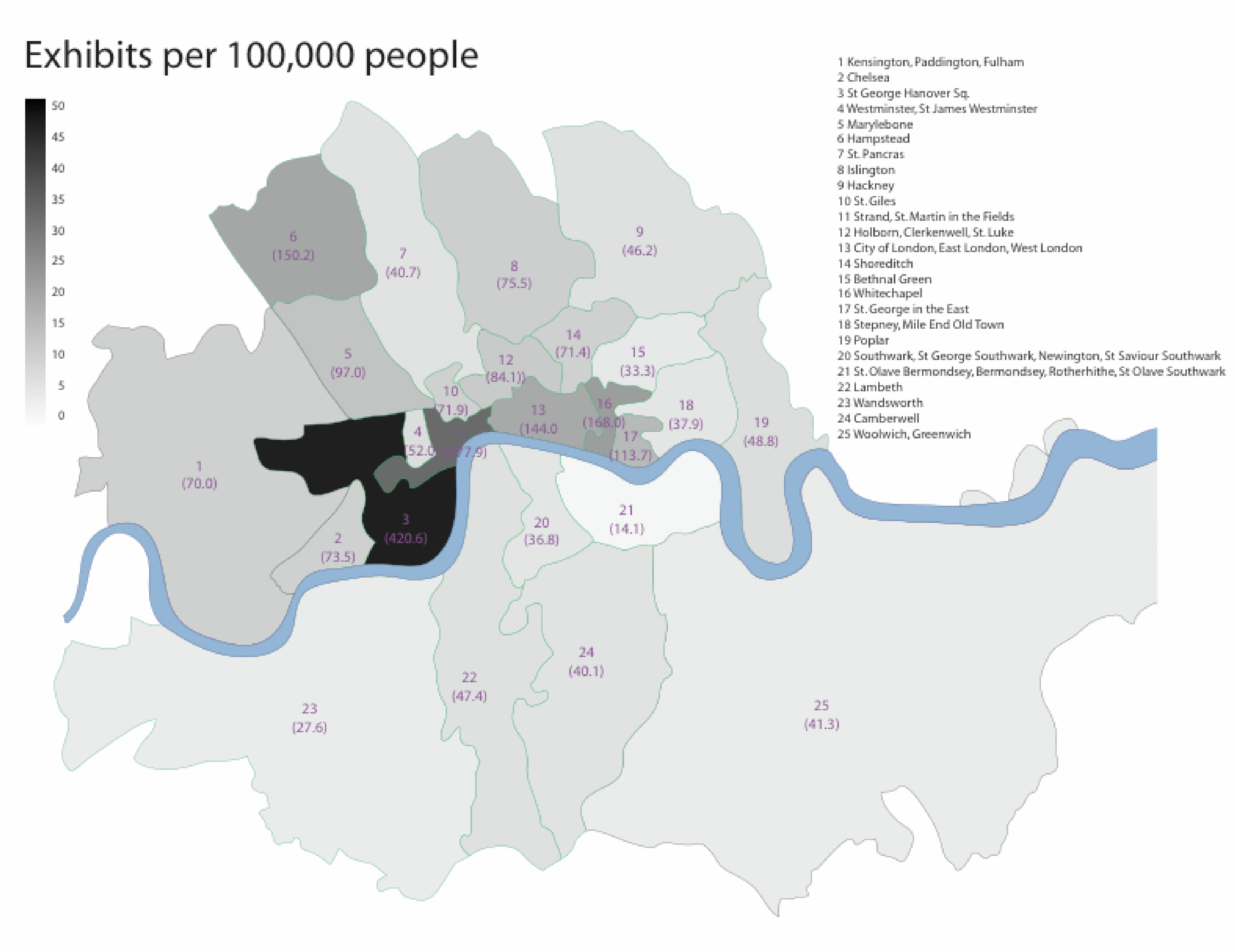
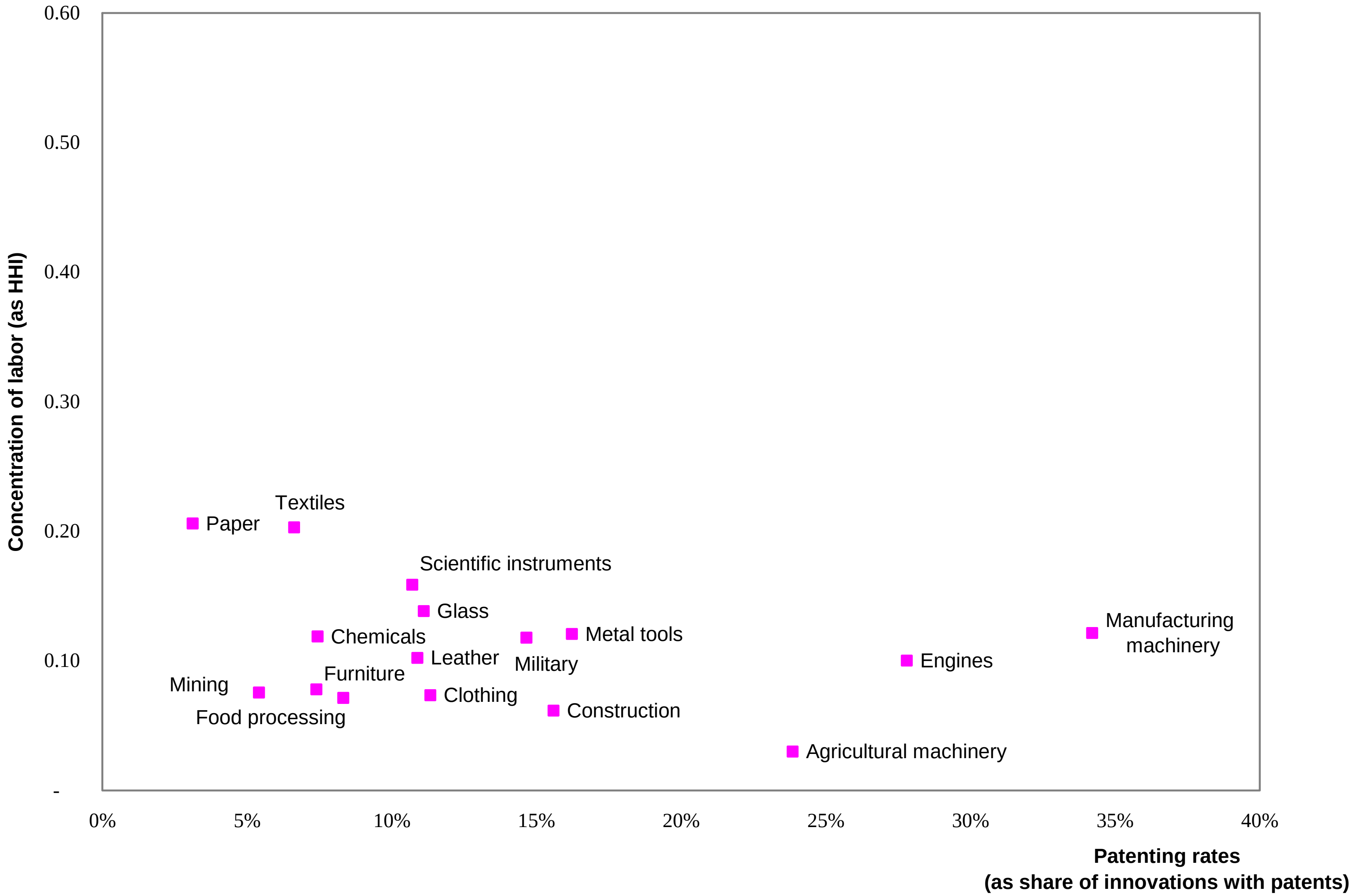

Exhibits per 100,000 people
50
45
40
35
30
25
20
15
10
5
0
1 Kensington, Paddington, Fulham
2 Chelsea
3 St George Hanover Sq.
4 Westminster, St James Westminster
5 Marylebone
6 Hampstead
7 St. Pancras
8 Islington
9 Hackney
10 St. Giles
11 Strand, St. Martin in the Fields
12 Holborn, Clerkenwell, St. Luke
13 City of London, East London, West London
14 Shoreditch
15 Bethnal Green
16 Whitechapel
17 St. George in the East
18 Stepney, Mile End Old Town
19 Poplar
20 Southwark, St George Southwark, Newington, St Saviour Southwark
21 St. Olave Bermondsey, Bermondsey, Rotherhithe, St Olave Southwark
22 Lambeth
23 Wandsworth
24 Camberwell
25 Woolwich, Greenwich
6 (150.2)
7 (40.7)
8 (75.5)
9 (46.2)
5 (97.0)
14 (71.4)
15 (33.3)
12 (84.1)
10 (71.9)
13 (144.0)
16 (168.0)
18 (37.9)
19 (48.8)
17 (113.7)
1 (70.0)
4 (52.0)
3 (420.6)
2 (73.5)
20 (36.8)
21 (14.1)
24 (40.1)
22 (47.4)
23 (27.6)
25 (41.3)

FIGURE 3 – PATENTING AND THE GEOGRAPHIC CONCENTRATION OF WORKERS BY INDUSTRY IN 1851



Notes: Patenting rates are calculated by dividing the number of references to patents by the number of exhibits in each industry. HHI reports a Herfindahl Hirschman index of concentration, where market shares are replaced by the share of each of England's 42 registration counties of the total number of English exhibits in that industry. Raw data are drawn from *Official Catalogue…* (1851) and cities are matched to registration counties through contemporary maps and the *Getty Thesaurus of Geographic Names.*

FIGURE 4 – GEOGRAPHIC CONCENTRATION OF ENGLAND'S WORKERS IN CHEMICALS, MANUFACTURING MACHINERY, AND INSTRUMENTS, 1841 - 1901

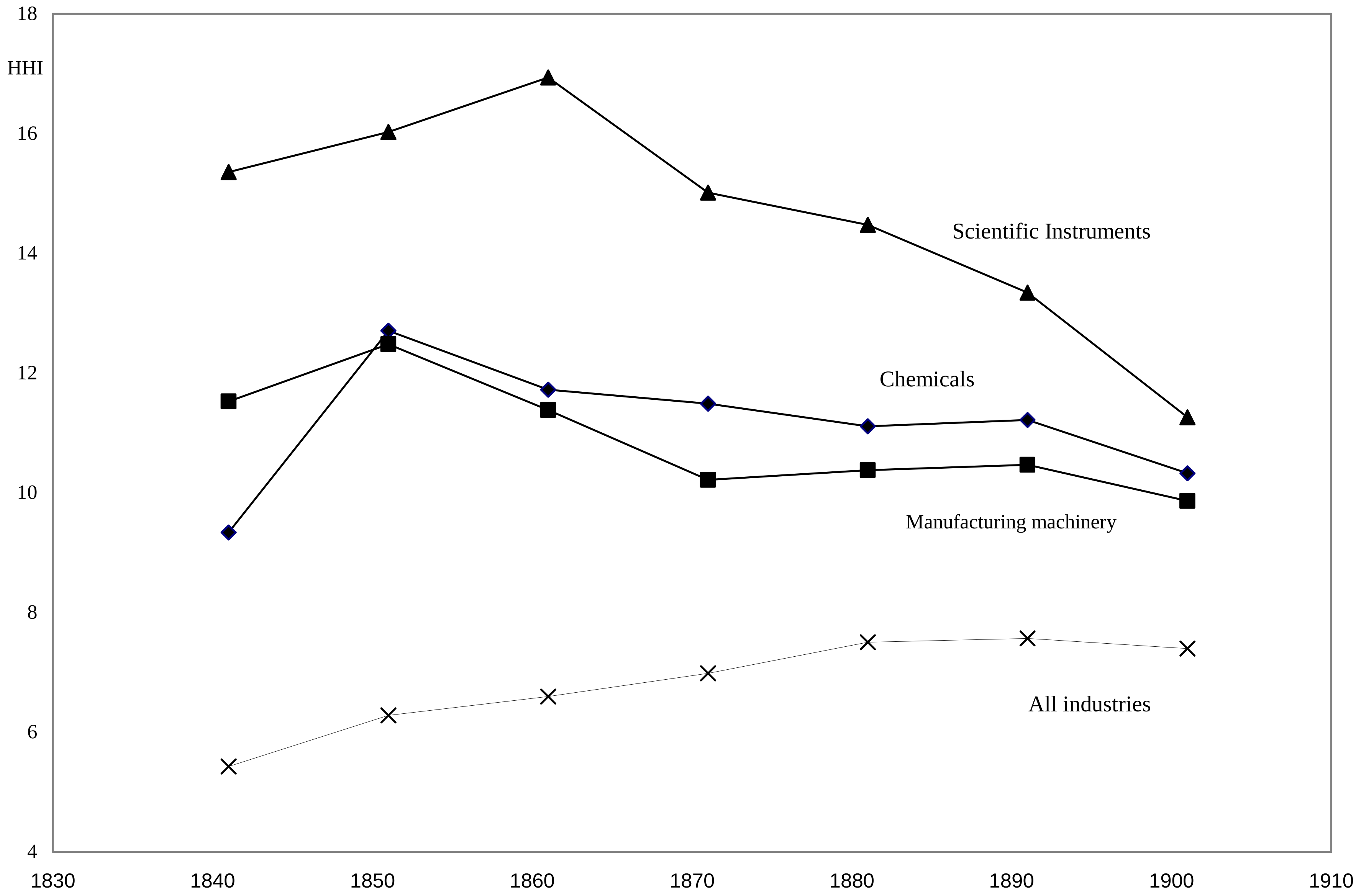
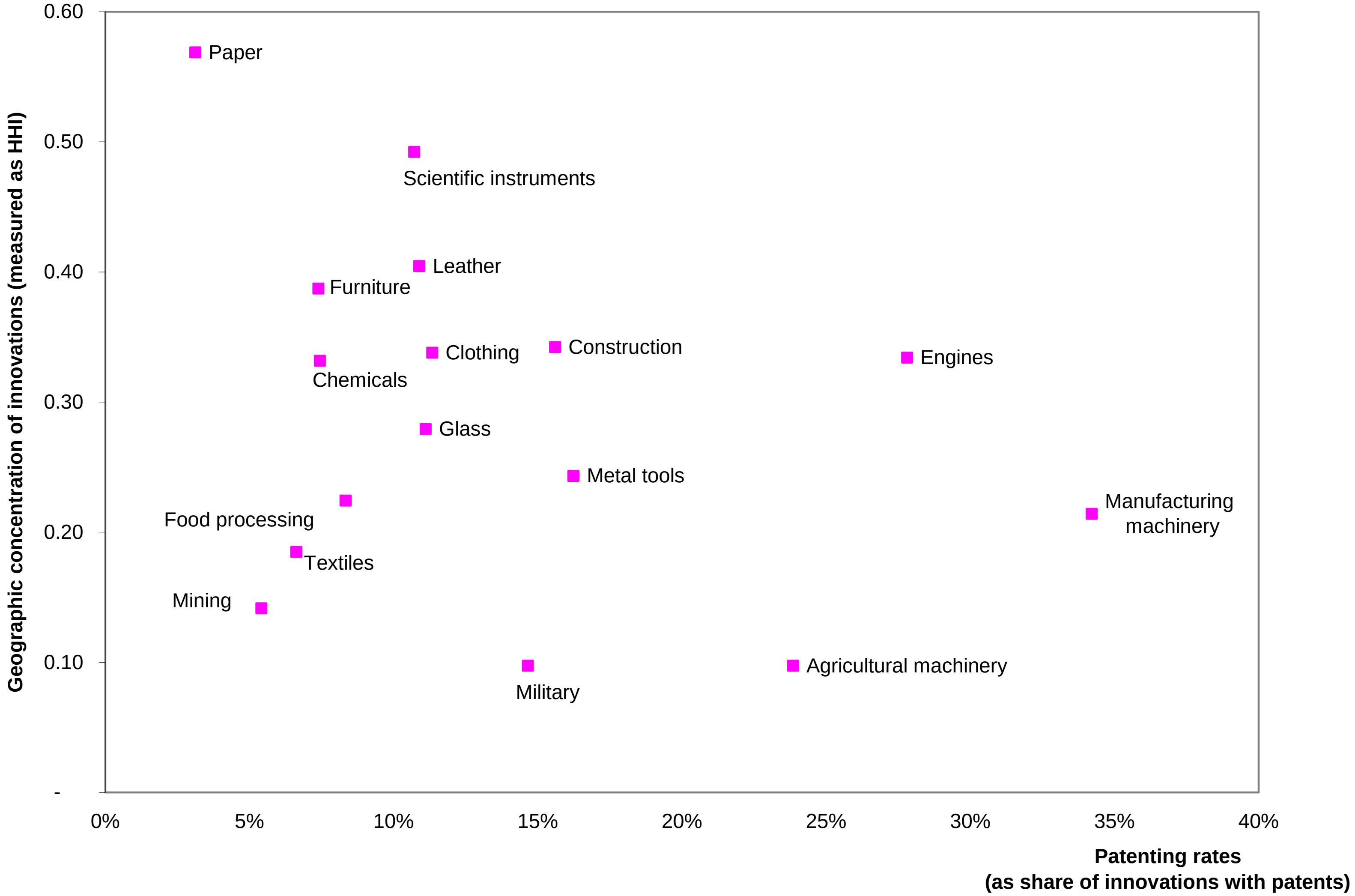


FIGURE 5 – PATENTING AND THE GEOGRAPHIC CONCENTRATION OF INNOVATIONS IN 1851



Notes: Patenting rates are calculated by dividing the number of references to patents by the number of exhibits in each industry. HHI reports a Herfindahl Hirschman index of concentration, where market shares are replaced by the share of each of England's 42 registration counties of the total number of English exhibits in that industry. Raw data are drawn from *Official Catalogue…* (1851) ; cities are matched to registration counties through contemporary maps and the *Getty Thesaurus of Geographic Names.*