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Source: *The Journal of Economic History*, JUNE 2011, Vol. 71, No. 2 (JUNE 2011), pp. 363-382

Published by: Cambridge University Press on behalf of the Economic History Association

Stable URL: https://www.jstor.org/stable/23018303

Do Patents Weaken the Localization of Innovations? Evidence from World's Fairs

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This article takes advantage of an exogenous shift towards patenting in chemicals to test whether patents contribute to the geographic diffusion of innovations. Data on U.S. innovations that were exhibited at four world fairs between 1851 and 1915 suggest that innovative activity became less localized after patenting rates increased. These changes cannot be explained by changes in the localization of chemical production or economy-wide changes in the localization of innovations.

Patent laws are created to fulfill two functions: to strengthen the incentives for innovation and to encourage the diffusion of new ideas.[1] Previous studies have focused on incentives and paid little attention to the diffusion effects of patenting. Diffusion effects may, however, be equally important if they facilitate knowledge spillovers and cumulative innovation.[2]

In the absence of intellectual property rights, inventors have fiercely guarded new ideas from spreading to outsiders. Silk weavers in seventeenth-century Bologna hanged Ugolino Menzani for sharing the knowledge of a new silk twisting machine with Venetian weavers.[3] Mechanics in New England's nineteenth-century cotton industry relied on family relations to exchange technical knowledge.[4] Today, farmers in developing countries share information about new crops and improvements in agricultural technologies primarily within local

The Journal of Economic History, Vol. 71, No. 2 (June 2011). doi: 10.1017/S0022050711001562.

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I wish to thank Avner Greif, Bronwyn Hall, Rebecca Henderson, Eric Hilt, Zorina Khan, Naomi Lamoreaux, David Mowery, Christina Romer, and the late Ken Sokoloff, as well as seminar participants at Brown, Davis, Clio, and the NBER for helpful comments. Kamran Bilir, Marina Kutyavina, Frédéric Panier, Irina Talis, Alessandra Voena, and Anne Yeung provided excellent research assistance.

[1] E.g., Nordhaus, "Economic Theory"; Khan, *Democratization of Invention*; and Mokyr, *British Industrial Revolution*, p. 43.

[2] See Mokyr, *Gifts of Athena*, p. 295, and Scotchmer, "Standing," for discussions of cumulative innovation and Romer, "Increasing Returns" and "Endogenous Technological Change," for the role of knowledge spillovers in encouraging economic growth.

[3] Belfanti, "Circulation," p. 581; and Epstein, "Property Rights."

[4] Meyer, *Networked Machinists*; and Wallace, *Rockdale*, pp. 211–43. Within such networks, inventors may exchange information freely, as, for example within a system of collective invention; see Allen, "Collective Invention"; and Nuvolari, "Collective Invention."

social networks.[5] To the extent that knowledge flows through local social networks, knowledge spillovers, and the boost that they provide to cumulative innovation, may be localized as well. Systematic analyses of patent citations confirm this for twentieth-century data.[6]

This article examines whether patenting helps to weaken the localization of innovations. As a first order effect, patents require the disclosure of new ideas in exchange for the grant of temporary monopoly rights. However, by creating property rights in ideas, patents may also encourage inventors to advertise new ideas outside of their local social networks. In their case study of the U.S. glass industry, Naomi Lamoreaux and Kenneth Sokoloff argue that a lively trade in patented inventions in the late nineteenth century encouraged the geographic concentration of inventions in New England.[7] The emergence of journals in the mid-nineteenth-century, such as the *Scientific American*, the *American Artisan*, the *American Inventor*, and the *Patent Right Gazette*, which advertised patented inventions, facilitated such trades on a national scale. If patent rights, supported by specialized patent agents and journals, enabled trades in patented inventions across distant locations, they may have encouraged the geographic diffusion, rather than concentration, of innovations.

Anecdotal evidence from inventors' biographies suggests that inventors who held patent rights were more likely to publicize knowledge of their inventions beyond their local networks. In England, the Norwich iron founder Robert Ransome advertised his ploughshares to all ironmongers in Norwich and fifty outlets in East Anglia after he obtained a patent grant.[8] In the nineteenth-century United States, a patent on the lathe encouraged Massachusetts inventor Thomas Blanchard to advertise it widely, so that knowledge of the lathe diffused to Missouri and Arkansas.[9] Similarly, knowledge of the Fourdrinier papermaking machine began to diffuse quickly only after it had been patented.[10] In

[5] Conley and Udry, "Social Networks in Ghana."

[6] Marshall, *Principles of Economics*, was first to identify localized knowledge spillovers as a potential source for the localization of economic activity. Jaffe, Trajtenberg, and Henderson, "Geographic Localization," Jaffe, "Technological Opportunity," and Audretsch and Feldmann, "R&D Spillovers," use patent citations to show that knowledge spillovers tend to be localized. See Breschi and Lissoni, "Knowledge Spillovers," and Feldman, "New Economic Geography," for surveys of the literature on knowledge spillovers and geographic localization.

[7] Lamoreaux and Sokoloff, "Geography of Invention." Dutton, *Patent System*, pp. 122–50, describes a significant trade in patented inventions in early-nineteenth-century England.

[8] MacLeod, *Inventing*, p. 100, also see pp. 93–95.

[9] Cooper, *Invention*, pp. 170–95. Also see MacLeod, *Inventing*, pp. 93–100.

[10] Thomson, *Paper Industry*, pp. 158–59.

contrast, tight secrecy slowed the diffusion of innovations in the coke-smelting process.[11]

This article takes advantage of an exogenous shift towards patenting to examine the effects of intellectual property rights on the geographic diffusion of innovations. Until the mid-nineteenth century, chemical innovations were difficult to reverse-engineer and rarely patented because inventors could rely on secrecy. As a result, less than 5 percent of British exhibits of chemicals at the Crystal Palace Exhibition in 1851 were patented, and not a single U.S. exhibit of chemicals was patented in 1851. After 1851 a series of scientific breakthroughs, including the publication of the periodic table in 1869, weakened the effectiveness of secrecy. As a result of this change, which was exogenous to the localization of innovations, the share of chemical exhibits that were patented increased to nearly 20 percent in 1893 and 1915.

A geographic analysis of exhibition data suggests that this shift towards patenting was followed by a weakening of localization. This decline in geographic concentration cannot be explained by changes in the location of production. Data from decennial census records for 1840 to 1920 indicate that the localization of chemical production remained relatively stable after 1876.

Difference-in-differences comparisons of changes in the localization of exhibits of chemicals and manufacturing machinery after 1876 confirm these results. Measuring localization by a geographic Herfindahl-Hirschmann index (HHI), and using 1876 as a baseline for both industries, geographic concentrations decreased by more than 70 percent for chemicals after 1876, compared with roughly 25 percent for manufacturing machinery. Difference-in-differences regressions that estimate the effect of a 1 percent increase in the share of patented innovations on geographic concentration imply that a 1 percent increase in patenting rates was associated with a 1.3 percent decrease in localization.

THE DATA

Exhibition data are drawn from the records of four world's fairs: the Crystal Palace Exhibition in London in 1851, the American Centennial Exhibition in Philadelphia in 1876, the World's Columbian Exhibition in Chicago in 1893, and the Panama-Pacific International Exposition in San

[11] Mokyr, *Economics*, p. 26.

TABLE 1
STATISTICS ON THE WORLD'S FAIRS OF 1851, 1876, 1893, AND 1915

Exhibition	Crystal Palace	Centennial	World's Columbian	Panama-Pacific
Location	London	Philadelphia	Chicago	San Francisco
Year	1851	1876	1893	1915
Countries	40	35	45	32
Exhibitors	17,062	30,864	70,000	30,000
Visitors	6,039,195	9,892,625	27,500,000	19,000,000
Area (in acres)	25.7 for exhibition buildings	71.4 for buildings and grounds	717 for grounds 49 for buildings	635 for buildings and grounds
Prominent exhibits	MacCormick's grain reaper, Colt's revolving handgun, steam engines, typewriter	Corliss steam engine, telephone, Edison's quadruplex telegraph	Electric escalator, electric elevated railway, floodlights, Ferris wheel	Two-color photography, Ford's conveyer belt, a phone line from San Francisco to New York

Notes: Data from Royal Commission, *Official Catalogue*; *Bericht*; Kretschmer, *Geschichte der Weltaustellungen*; Department of Publicity and Promotion, *World's Columbian Exposition Chicago*; and the Division of Exhibits, *Panama-Pacific International Exposition San Francisco*.

Francisco in 1915 (Table 1). Exhibits ranged from early sewing machines in 1851 (U.S. exhibit 551 in 1851, exhibited by S. C. Blodgett) and power-loom lathes for the machine shops at Lowell (U.S. exhibit 447 in 1851) to Ford's conveyer belt in 1915. In 1851 Cyrus McCormick displayed his "Virginia grain reaper" (U.S. exhibit 73) and Samuel Colt showed his "revolving cylinder handgun" (U.S. exhibit 321). In 1876 exhibits included the steam engine, the telephone, and Edison's quadruplex telegraph. In 1893 exhibits showcased applications of electricity, including an electric elevator and an elevated electric railway. In 1915 the San Francisco exhibition introduced two-color photography and the first phone line to New York.

Catalogues that guided visitors through the fairs list the name of each exhibitor, his location, and a brief description of the innovation. For example, the competing grain reapers of Oded Hussey and Cyrus MacCormick were recorded as:

> 65 Hussey, O. Baltimore, Maryland. – Reaping and mowing machine. and
>
> 73 M^{c}Cormick, C.H. Chicago, Illinois. – Virginia grain reaper.

To be included in a fair, inventors submitted a written application to their local commission, which specified "what is novel and important about the product, how its production shows special skillfulness and proves an original approach."[12] A comprehensive system of evaluation and prizes helped to enforce these criteria.[13] Thus, William Felkin, mayor of Nottingham and a member of the city's local selection committee, warned applicants that, "Articles notable only for their singularity will not be admitted."[14]

Patented innovations are identified by matching exhibits with patents in the Annual Reports of the United States Patent Office.[15] For example,

> "United States Patent No. 4387; Otis, Benjamin H.; Dedham, Mass.; Mortising Machine; granted Feb. 20, 1846" from the *Annual Report for 1846* and
>
> "United States Exhibit 23; Otis, B.H.; Cincinnati, Ohio; Boring and Mortising Machine" from the Royal Commission, *Official Catalogue*

constitute a match.

Most exhibits were not patented. In 1851, 15 percent of U.S. exhibits were protected by patents.[16] Exhibits that won a prize for being exceptionally innovative were only slightly more likely to be patented.[17]

By far, the most significant variation in patenting was linked to variation in the effectiveness of secrecy. In industries where innovations were easy to reverse-engineer, such as manufacturing machinery, nearly half of all exhibits were patented; 42 percent of U.S. exhibits of manufacturing machinery were patented in 1851, 44 percent in 1876, 49 percent in 1876, and 47 percent in 1915. In comparison, less than 5 percent of U.S. exhibits of chemicals were patented in 1851 and 1876. After scientific breakthroughs lowered the effectiveness of secrecy, patenting rates increased to nearly 20 percent in 1893 and 1915 (Table 3).

[12] Ibid., pp. 50 and 117.

[13] Moser, "Innovation Without Patents."

[14] Leapman, *World for a Shilling*, p. 37.

[15] Exhibits are matched with patents that were issued up to twenty years prior and one year after the exhibition. For example, exhibits at the U.S. Centennial Fair in 1876 were matched with U.S. patent grants between 1856 and 1877. The median age of a patent at the exhibition is two years.

[16] These figures exclude exhibits of art, which were generally not patentable.

[17] In a data set of 6,377 British exhibits, 15.6 percent of prize-winning exhibits are patented, compared with 11.1 percent of average quality exhibits (Moser, "Innovation Without Patents," pp. 20–21).

Changes in Geographic Localization

To measure changes in geographic localization, exhibits are matched with data from the National Association of Counties. Counties of origins can be identified for 99.6 percent of exhibits between 1851 and 1915 (Table 2). Concentration ratios C2 and C3, measure the share of exhibits that originate from the two and three counties with the largest number of exhibits. Herfindahl-Hirschman indices (HHI) measure localization as the square of each county's share of the total number of exhibits, summing across counties, and multiplying by 100. A value of 100 indicates complete concentration.

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

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

Bias in the World Fair's Data

Anecdotal evidence suggests that exhibition data are more likely to capture the high-value end of the distribution of innovations because inventors used the fairs as a way to advertise their best ideas.[18] The German firm Bayer, for example, won silver, bronze, and gold medals for the dye intermediaries that it exhibited.[19] "To win these prizes, Bayer had to remain innovative; firms displayed their dyes only when they had a reasonable chance of receiving favorable press at the exhibition."[20]

Exhibitors may also have been reluctant to display innovations that were protected by secrecy, because displaying them would have increased the risk of imitation. As a result, the data miss many innovations that were protected by secrecy and overstate the share of innovations that were protected by patents.[21]

[18] Murmann, *Knowledge*, p. 113.
[19] Bayer, *Beiträge zur Hundertjährigen*, p. 20.
[20] Murmann, *Knowledge*, p. 114.
[21] See Moser, "Innovation Without Patents," for a more detailed discussion of bias and measurement error in the world's fair data.

TABLE 2
SHARE OF U.S. EXHIBITS WITH GEOGRAPHIC DATA

	All Exhibits	Total	Share Matched with County Data (in %)
Chemicals	324	322	99.4
1851	32	31	96.9
1876	139	138	99.3
1893	63	63	100.0
1915	90	90	100.0
Manufacturing machinery	892	889	99.7
1851	32	31	96.9
1876	469	467	99.6
1893	357	357	100.0
1915	34	34	100.0
Total	1,216	1,211	99.6

Notes: Locations are identified using nineteenth-century maps and gazetteers, such as Bartholomew, *Gazetteer of the British Isles*, and the *Getty Thesaurus of Geographic Names* (http://www.getty.edu/research/tools/vocabularies/tgn/index.html).

TABLE 3
PATENTING AND LOCALIZATION, U.S. EXHIBITS, 1851 TO 1915

	1851	1876	1893	1915
Chemicals				
Patenting rates (%)	0.0	3.6	19.0	19.1
HHI	14.9	31.6	18.7	9.3
Concentration ratio C2 (%)	48.4	73.7	55.6	37.1
Concentration ratio C3 (%)	61.3	76.8	69.8	46.0
Manufacturing machinery				
Patenting rates (%)	41.9	43.9	49.3	47.1
HHI	13.8	8.7	5.1	6.4
Concentration ratio C2 (%)	41.9	35.6	26.3	23.5
Concentration ratio C3 (%)	48.4	41.8	33.6	29.4

Notes: Data from Royal Commission, *Official Catalogue London*; United States Centennial Commission, *Official Catalogue*; Department of Publicity and Promotion, *World's Columbian Exposition Chicago*; and the Division of Exhibits, *Panama-Pacific International Exposition*. U.S. exhibits are assigned to counties in the records of the National Association of Counties (www.naco.org). Patenting rates measure the share of exhibits with patents. The Herfindahl-Hirschman index (HHI) is calculated by squaring each county's share of the total number of innovations in an industry, summing across counties, and multiplying by 100. The concentration ratio C3 measures the combined share of the three counties with the largest share of exhibits in an industry.

The data may also overestimate the share of innovations that originated from a host city, especially if exhibits were large or difficult to transport. This bias may be mitigated; however, by the fact that exhibitors were only required to pay for transportation cost to the nearest collection point.[22] To test for such host city bias, I compare the locations of British exhibits at the London fair of 1851 and the Philadelphia fair of 1876 (4,677 and 835 exhibits, respectively). If transportation costs bias the data towards the host city, London's share of exhibits should be smaller in 1876 when the costs of transporting exhibits to London were negligible relative to the total transportation costs. London's share was, however, nearly identical in 1851 (40.7 percent) and 1876 (39.1 percent). Nevertheless, to be conservative the analysis is carried out with and without the host city data.

AN EXOGENOUS INCREASE IN PATENTING

An exogenous increase in patenting rates creates a unique opportunity to evaluate the effects of patenting on the localization of innovations. Until the 1850s, "processes (of making chemicals and dyes) were simple and crude; exact knowledge was circumscribed and operations proceeded empirically."[23] As a result, chemical innovations such as textile dyes were nearly impossible to reverse-engineer and therefore rarely patented. After 1851 advances in analytic tools, which were exogenous to the localization of innovations, increased inventors' tendency to patent chemicals.[24] In 1869 the Russian scientist Dmitri Mendeleev recognized that properties such as valence recur periodically if elements are organized by their atomic weights. He used this insight to publish the periodic table, which facilitated systematic chemical analyses.[25] In 1865 the German chemist August Kekulé had described the chemical structure of the benzene ring (as a six-member ring of carbon atoms with alternating single and double bonds).[26] By the 1880s Kekulé's model became widely used; it greatly influenced the theory of organic chemistry, and coal tars in particular.[27]

[22] Berichterstattungs-Kommission der Deutschen Zollvereins-Regierungen, *Amtlicher Bericht*, pp. 40 and 64.

[23] Haber, *Chemical Industry*, p. 83.

[24] For a detailed analysis of this shift, see Moser, "Innovation Without Patents."

[25] Asimov, *Biographical Encyclopedia*, p. 410; and Maher, "Prediction," p. 274.

[26] In 1865 Kekulé published a French version; in 1866 he followed up with a longer paper in German (Kekulé "Sur la constitution" and "Untersuchungen").

[27] Haber, *Chemical Industry*, p. 81.

As a result of such advances in scientific methods, chemical innovations that had been protected by secrecy became vulnerable to imitation. Innovations in dyes were particularly affected by the "dramatically increased ability of chemists to determine the composition of dyes," which "made it more difficult for individual firms to keep dye recipes secret and prevent competitors from imitating them quickly."[28] Methods to produce madder red, for example, had been kept secret for thousands of years.[29] In 1869, however, the German chemists Carl Graebe and Carl Lieberman announced:

> "We have produced from anthracine artificial alizarine. The properties of the product obtained by us as well as the colors which we have produced with the same on mordanted cotton exhibit perfectly the identity of the artificial alizarine with that obtained from madder root."[30]

By 1876 Charles Strobel and Heinrich Caro had synthesized alizarine orange and in 1878 Rudolf Nietzki was able to match the scarlet shades of madder red.[31]

As secrecy became less effective, larger shares of chemicals were patented. At the Crystal Palace Fair in 1851, none of the 32 chemical exhibits from the United States had been patented. At the American Centennial Exhibition in 1876, 3.6 percent of U.S. chemical exhibits were patented. The most significant increase in patenting rates, however, occurred after 1876. In 1893, 19 percent of U.S. chemical exhibits were patented; in 1915, 19.1 percent were patented. At the same time, patenting rates for manufacturing machinery, which had always been relatively easy to reverse-engineer, remained stable around 45 percent (42 percent in 1851, 44 in 1876, 49 in 1893, and 47 in 1915, Table 3).[32]

CHEMICAL INNOVATIONS BECAME LESS LOCALIZED AFTER 1876

This shift towards patenting was followed by a weakening of geographic localization. In the third quarter of the nineteenth century, chemical innovation and production had become more localized, as young chemists moved to Philadelphia as a "center of chemistry" to acquire formal training. Benjamin Silliman, for example, went there to attend lectures by Rush, Morton, and Wistor and work in the laboratory

[28] Murmann, *Knowledge*, p. 121.
[29] Chenciner, *Madder Red*, p. 193.
[30] Graebe and Lieberman patented their discovery in Britain, Prussia, and the United States (U.S. Supreme Court, *Supreme Court Reports*, p. 437).
[31] Brunello, *Art of Dyeing*, p. 301.
[32] Moser, "Innovation Without Patents," pp. 29–30.

of Robert Hare.[33] In the 1850s and 1860s "the best opportunity for real laboratory work a young chemist could find was in the analytical laboratories of consulting chemists in Philadelphia and New York."[34] Reflecting this concentration of research activity, the HHI of geographic concentration increased from 15 in 1851 to 32 in 1876. Concentration ratios C2 and C3 similarly increase from 48 and 61 percent in 1851 to 74 and 77 percent in 1876.

After 1876 chemical exhibits became less localized. By the time of the Chicago fair in 1893, the HHI had declined to 19. By the San Francisco exhibition in 1915, it had declined even further, to a level of 9. Concentration ratios C2 and C3 confirm the decline in concentration, with a reduction to 56 and 70 percent in 1893, and a further decline to 36 and 44 percent in 1915.

A caveat to these results is that Philadelphia's large share of chemical exhibits in 1876 may be due to host city bias, in addition to the city's role as a center of innovation. Thus the increase in localization after 1851 is weaker when data for host cities are dropped (with an HHI of 15 in 1851 and 22 in 1876, Figure 1). Philadelphia was, however, also the county with the largest number of chemical exhibits at the London fair in 1851, and it was the county with the third largest number of chemical exhibits at the Chicago fair in 1893, confirming its importance as a center of chemical innovation.[35] Moreover, the main result of a decline in localization after 1893 remains substantially unchanged (with an HHI of 22 in 1893 and 9 in 1915).

The Localization of Production Remained More Stable

To control for unobservable factors that may have contributed to the decline in geographic concentration, alternative tests compare changes in the localization of exhibits with changes in the localization of production. Innovations may be more likely to occur in centers of production where opportunities for learning-by-doing and production bottlenecks stimulate innovation.[36] Then, a potential decline in the importance of geographic factors that encourage the concentration of production, including access to waterways, natural resources, or skilled labor, may have caused the observed decline in the localization of exhibits, independent of patenting. Census data, however, indicate

[33] Haynes, *American Chemical Industry*, p. 328.
[34] Ibid., p. 330.
[35] Ibid., pp. 328–30.
[36] Arrow, "Economic Implications"; and Rosenberg, *Exploring*, pp. 259–60.

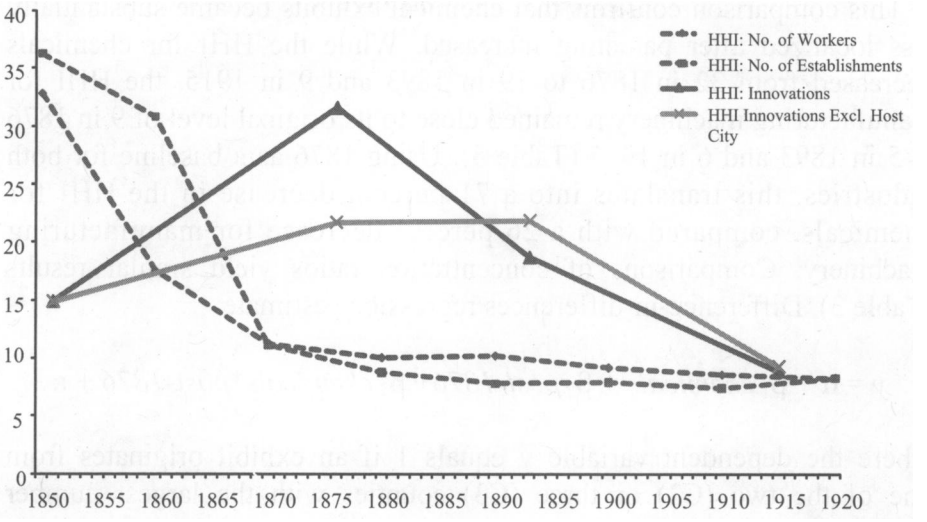

FIGURE 1
CHANGES IN THE LOCALIZATION OF U.S. CHEMICAL INNOVATIONS AND CHEMICAL PRODUCTION, 1850 TO 1920

Notes: Data from the Royal Commission, *Official Catalogue* (1851) and from the U.S. Bureau of the Census, *Report on Manufacturing*, 1850–1920. The Herfindahl-Hirschman index (HHI) is calculated by squaring each county's share of the total number of innovations, workers, or firms, summing across counties, and multiplying by 100. The series HHI Innovations excluding Host calculates the HHI excluding data for Philadelphia in 1876, Chicago in 1893, and San Francisco in 1915. Census data for chemicals in 1850 are based on counts of salt manufacturers only; other branches of chemicals, including bleaching, dyeing, drugs, and paint are added between 1860 and 1870.

that the localization of chemical production remained relatively stable after 1870, with HHIs around 10 for chemical workers and firms between 1870 and 1920 (Figure 1).[37]

Changes in the Localization of Manufacturing Machinery as a Control

A difference-in-differences test compares changes in the localization of chemical exhibits with manufacturing machinery as a control. Innovations in both industries were affected by declining costs of transportation and communication, which helped to diffuse the concentration of inventive activity more generally, but only chemicals experienced a shift towards patenting.

[37] The drop in localization from 1850 and 1860 to 1870 is likely to be an artifact of the data. Census data for chemicals in 1850 are based on counts of salt manufacturers only; other branches of chemicals, including bleaching, dyeing, drugs, and paint, are added between 1860 and 1870.

This comparison confirms that chemical exhibits became substantially less localized after patenting increased. While the HHI for chemicals decreased from 32 in 1876 to 19 in 1893 and 9 in 1915, the HHI for manufacturing machinery remained close to its original level of 9 in 1876 at 5 in 1893 and 6 in 1915 (Table 3). Using 1876 as a baseline for both industries, this translates into a 71 percent decrease in the HHI for chemicals, compared with a 26 percent decrease for manufacturing machinery. Comparisons of concentration ratios yield similar results (Table 3). Difference-in-differences regressions estimate:

$$y = \alpha + \beta_1 \, chemicals + \beta_2 \, post\text{-}1876 + \beta_3 \, chemicals*post\text{-}1876 + \varepsilon$$

where the dependent variable y equals 1 if an exhibit originates from one of the two (C2) or three (C3) counties with the largest number of exhibits in a given year and industry.[38] *Chemicals* distinguishes innovations in chemicals from innovations in manufacturing machinery, *post-1876* distinguishes innovations in 1893 and 1915. Alternative specifications separate the post-1876 period into 1893 and 1915 to measure the timing of effects.

Results of such regressions confirm that chemicals became less localized after 1876. A parameter estimate of –0.140 for *chemicals*post-1876* (significant at 5 percent, Table 4, column 1) implies that the probability that an exhibit originated in one of the two counties with the largest number of exhibits decreased by 14 percent more for chemicals than for manufacturing machinery after patenting increased. Similarly, an estimate of –0.191 for *chemicals*1915* (significant at 10 percent, Table 4, column 2) suggests that the probability that an exhibit originated from the top two counties decreased by 19 percent more for chemicals than for manufacturing machinery in 1915 compared with 1851 and 1876. Estimates for *chemicals*1893* are not significant, suggesting that the effect became stronger over time. Parameter estimates increase in regressions that use 1876 as a control (Table 4, columns 3–4). Coefficients remain negative when concentration is measured as C3, but estimates are smaller and not significant. The estimate for *chemicals *post-1876* is –0.091 (Table 4, column 5), and the estimate for *chemicals*1915* is –0.159 (columns 6).

[38] The identifying assumption of the difference-in-differences test is less restrictive than assumptions for a regression with industry controls: If changes in patenting rates were the same for both industries, changes in the geographic localization of the two industries would have been roughly comparable. Unobservable factors, such as differences in research intensity or in the age and size distribution of firms, are accounted for by industry-fixed effects.

TABLE 4
DIFFERENCE-IN-DIFFERENCES ESTIMATES OF CHANGES IN LOCALIZATION AFTER 1876: C2 AND C3

	Concentration Ratio C2			
	(1)	(2)	(3)	(4)
Chemicals	0.327***	0.327***	0.376***	0.376***
	(0.042)	(0.042)	(0.044)	(0.044)
Post-1876	–0.099***		0.095***	
	(0.031)		(0.031)	
Chemicals*post-1876	–0.140**		–0.190***	
	(0.062)		(0.064)	
Fair of 1893		–0.096***		0.092***
		(0.032)		(0.032)
Fair of 1915		–0.124		–0.120
		(0.076)		(0.076)
Chemicals*1893		–0.035		–0.084
		(0.079)		(0.080)
Chemicals*1915		–0.191*		–0.241**
		(0.098)		(0.099)
Control	Pre-1876	Pre-1876	1876	1876
N	1,210	1,210	1,148	1,148
	Concentration Ratio C3		C2 Excl. Host City	
	(5)	(6)	(7)	(8)
Chemicals	0.318***	0.318***	0.277***	0.277***
	(0.040)	(0.040)	(0.055)	(0.055)
Post-1876	–0.089***		–0.00272	
	(0.033)		(0.032)	
Chemicals*post-1876	–0.091		–0.0612	
	(0.062)		(0.075)	
Fair of 1893		–0.086**		–0.005
		(0.033)		(0.032)
Fair of 1915		–0.128		0.017
		(0.081)		(0.080)
Chemicals*1893		0.044		0.090
		(0.075)		(0.094)
Chemicals*1915		–0.151		–0.176
		(0.103)		(0.110)
Control	Pre-1876	Pre-1876	Pre-1876	Pre-1876
N	1,210	1,210	936	936

* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

Notes: Robust standard errors are in parentheses. Estimates compare changes after 1876 in the localization of innovations, measured at the county level, in chemicals and manufacturing machinery. The dependent variable equals 1 if an exhibit originates from one of the two (C2) or three (C3) counties with the largest number of exhibits in a given year and industry. The indicator variable *post-1876* distinguishes exhibits in 1893 and 1915 from exhibits in 1851 and 1876. The treatment effect of higher patenting rates is estimated by the interaction between *Chemicals* and *post-1876*. Indicator variables for 1893 and 1915 distinguish exhibits in 1893 and 1915 respectively from exhibits in 1851 and 1876. Localization is measured at the county level using the records of the National Association of Counties.

In regressions that drop exhibits from host cities, coefficients are no longer significant but they remain negative. The estimate for *chemicals*post-1876* is –0.061 (Table 4, columns 7, not significant), and the estimate for *chemicals*post-1893* is –0.176 (Table 4, column 8, not significant).

This loss of statistical significance may be explained by host city bias. But it may also be due to the fact that dropping chemical exhibits from Philadelphia leads to an underestimate of geographic concentration in 1876. Both the history of U.S. chemical innovations and Philadelphia's prominent representation at the London and Chicago fairs suggest that Philadelphia was an important center of chemical innovation, so that omitting it creates an underestimate of localization in 1876, and therefore the decline in localization after 1876. Dropping exhibits from host cities also leads to a significant loss of data. In 1876 a total of 191 exhibits (32 percent) originate from Philadelphia, including 71 exhibits of chemicals and 120 exhibits of manufacturing machinery; in 1893 a total of 66 exhibits (16 percent) originate from Chicago, including 16 exhibits of chemicals and 50 exhibits of manufacturing machinery; in 1915 a total of 17 exhibits (14 percent) originate from San Francisco, including 15 exhibits of chemicals and 2 exhibits of manufacturing machinery.

Effects of a One Percent Increase in Patenting Rates

An alternative test directly measures the effects of a 1 percent increase in patenting rates on geographic concentration. It implements a two-stage least square regression:

$$y = \alpha + \beta_1 \textit{ share of exhibits with patents} + \beta_2 \textit{post-1876} + \beta_3 \textit{chemicals} + \varepsilon$$

The coefficient β_1 measures the difference-in-differences estimator in Table 4 rescaled by the difference in differences in patenting rates for chemicals and manufacturing machinery before and after 1876, where the dependent variable y equals 1 if an exhibit originates from one of the two (C2) or three (C3) counties with the largest number of exhibits in a given year and industry, and the share of exhibits with patents is instrumented by *chemicals*post-1876*.[39]

[39] This test requires the additional assumption that the effects of patenting on localization are at least locally linear. The identifying assumption is that, without the increase in patenting in chemicals, changes in localization and patenting rates would have followed the same trend in chemicals and manufacturing machinery. Under these assumptions, the marginal effect of a 1 percent increase in patenting can be measured by the ratio of the decline in localization (estimated in the previous section) and the difference-

TABLE 5
DIFFERENCE-IN-DIFFERENCES ESTIMATES OF MARGINAL EFFECTS OF CHANGES IN PATENTING RATES ON LOCALIZATION USING TWO-STAGE LEAST SQUARES

	C2		C3		C2 Excl. Host
	(1)	(2)	(3)	(4)	(5)
Share of exhibits with patents	−1.302**	−1.853***	−0.845	−1.208*	−0.489
	(0.577)	(0.620)	(0.573)	(0.617)	(0.598)
Post-1876	−0.029	0.002	−0.044	−0.022	0.035
	(0.053)	(0.055)	(0.055)	(0.057)	(0.066)
Chemicals	−0.204	−0.370*	−0.027	−0.136	0.070
	(0.210)	(0.222)	(0.210)	(0.222)	(0.217)
Control	Pre-1876	1876	Pre-1876	1876	Pre-1876
N	1,210	1,210	1,148	1,148	936

* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.
Notes: Robust standard errors are in parentheses. The dependent variable equals 1 if an exhibit originates from one of the two or three counties with the largest number of exhibits in a given year and industry. The coefficient estimate for *share of innovations with patents* measures the marginal effect of a 1 percent increase in the *share of innovations that are patented* on geographic localization. The *share of exhibits with patents* is instrumented by *post-1876 * Chemicals*. The indicator variable *post-1876* distinguishes exhibits in 1893 and 1915 from exhibits in 1851 and 1876.

A point estimate of −1.302 (Table 5, column 1) indicates that a 1 percent increase in the share of exhibits with patents is associated with a 1.3 percent decrease in geographic concentration, measured as the probability that an exhibit originated in one of the two counties with the largest number of exhibits. Using 1876 as control increases the size of the estimates (Table 5, column 2), while estimates for the C3 concentration ratio are smaller and only marginally significant (Table 5, columns 3–4).[40] Dropping exhibits from host cities, also substantially reduces the size of estimated coefficients (Table 5, column 5). As noted above, this could be due to host city bias or Philadelphia's prominent

in-differences estimate of the increase in patenting rates for chemicals relative to manufacturing machinery and post-1876.

[40] Since both the concentration measure and patenting rates are bounded between zero and one, the marginal effect of an increase in patenting rates on geographic concentration must be strictly smaller than one for at least a subset of possible values of patenting rates. Estimates above 1 suggest that the effects of changes in patenting rates on the localization of innovation may be nonlinear.

position as an early center of chemical innovation, so that dropping exhibits from Philadelphia in 1876 leads to an underestimate of the decline in localization.

CONCLUSIONS

The architects of the U.S. patent system intended it to encourage the creation and diffusion of innovations. This article has taken advantage of an exogenous increase in patenting rates for chemicals to examine the effects of patenting on the diffusion of innovations.

Geographic data on the location of U.S. innovations exhibited at four world fairs between 1851 and 1915 confirm that chemical innovations became less localized after patenting rates increased. This decline in geographic concentration cannot be explained by changes in the localization of production, which stayed relatively constant after 1876, and is robust to difference-in-differences comparisons with manufacturing machinery, where patenting rates remained unchanged. Difference-in-difference estimates indicate that a 1 percent increase in the use of patents was associated with a 1.3 percent decrease in geographic localization.

These results suggest that patents may encourage the geographic diffusion of innovations. In the nineteenth-century United States, diffusion was encouraged by a unique system of complementary institutions: Independent magazines such as *The Journal of the Franklin Institute* (beginning in the 1820s) and the *Scientific American* (beginning in the 1840s) published patent specifications and regularly described important patents.[41] In the late nineteenth century, the profession of specialized patent agents emerged to further facilitate trade in patented inventions.[42] Patent agents and magazines are likely to have strengthened the effectiveness of patents as a means to diffuse new technical knowledge and weaken the localization of innovations.

[41] In 1853 another publication, the *American Polytechnic Journal*, began to publish illustrations in addition to short descriptions and lists of patent claims. It stopped publication in 1854, when the patent office began to publish fuller, illustrated descriptions of its patents in the annual report (Thomson, *Structures of Change*, pp. 192–96.)

[42] Lamoreaux and Sokoloff, "Geography of Invention" and "Inventors."

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