Dense Enough To Be Brilliant: Patents, Urbanization, and Transportation in Nineteenth Century America*

Elisabeth Ruth Perlman, perlmane@bu.edu
EXTREMELY UNFINISHED AND INCOMPLETE

April 17, 2014

Abstract

This paper explores the relationship between urbanization and innovation, as measured through number of patents issued, in nineteenth-century America. The shape of this relationship is not well understood. It is clear that large, dense cities are more innovative than other places. It is also clear that such a population is not enough to induce technological improvements (Kowloon Walled City was not reputed for its great innovations). This paper maps the relationship between patents and population for all counties in the United States, 1790-1900, not just populous or innovative locations. I revisit the Sokoloff (1988) hypothesis that increasing market access, through the spread of transportation infrastructure leads to an acceleration of innovation. The alternate hypothesis that increased communication lead to increasing innovation outside of the major urban areas is examined by studying the linguistic relationship between patents with a full-text database. This textual analyses lets me explore the generation and spread of interrelated ideas across time and space.

Introduction

Innovation is not randomly distributed across space, but rather happens disproportionality in some areas. Which area, and with what attributes, has been a question of focus for some time. It is clear that large, dense cities are more innovative than other places it is also but

*Acknowledgments:I am extremely grateful to Robert Margo, Tom Nicholas, Jeremy Atack, Carola Frydman, Daniele Paserman, Claudia Olivetti, Michael Meurer, Suresh Naidu, Thomas M. Darby, Peter Sims, Matthew C. Berntsen, Henry Gross, Ross Corliss, and the volunteers at the Directory of American Tool and Machinery Patents and to seminar participants at the BU Development Reading Group, the BU Labor Reading Group, the Essex FRESH Meeting, and the Harvard Economic History Tea for their helpful advice, data, and comments. All errors are my own.

it is also clear that such a population is not sufficient to make an area innovative, and that many technological improvements come out of less populous places. This paper explores the relationship between urbanization and innovation, as measured through number of patents issued, in nineteenth-century America and the Sokoloff (1988) hypothesis that increasing market access through the spread of transportation infrastructure leads to an acceleration of innovation.

A large class of economic models has assumed that technological change is related to some the spread of ideas through combination of urban density and large populations (Romer, 1991; Glaeser et al., 1992). The idea that information transmission is costly, that this cost is related to physical distance, and that people cluster to reduce this cost goes back at least to Marshall (1890); Jacobs (1970) posited the idea the stumbling on and the spread of serendipitous innovations was easier in dense areas. Henrich (2004) suggests that a minimum population size is necessary for technological progress, noting that in particular the archaeological record from the island Tasmania has a suggests that its population was small enough that it actually had negative technological progress on net over time. Many papers have looked at the geographic distribution of innovation and productivity–at the causes and effects of urban agglomerations—from many different perspectives (mostly with modern data): measuring TFP, noting wage effects, co-location of patents that cite each other, inventor surveys.

The process of moving people, goods, and information between places underwent a tremendous reduction in difficulty in the nineteenth century as costs fell dramatically and speed increased. In 1800 the best way to transmit a message between Boston and NY was by sail and the next best way was over unpaved and in sections dubiously maintained roads; by 1900 one could simply place a telephone call or send a telegraph. If a physical package needed to be sent it could be moved overland by train or over water via steam ship. This change was more dramatic for places on the periphery of the transportation and communication network. In 1800 the best way to get to places not located on the coast or a navigable river was simply to walk; by 1900 railroad tracks densely intersected much of rural America.

The idea behind innovative agglomerations is that knowledge sharing is social, and for social connections to productively transmit knowledge, people need shared skills, including a vocabulary for discussing innovation. This paper will explore how Marshall's "information in the air" of urban agglomerations interacts with concrete, direct channels of information transmission, such as canals, railroads, and telegraphs, and how population size and density interact with infrastructural improvements in information flows over time. This paper maps the relationship between patents and population for all counties in the United States, not just populous or innovative locations. It revisit the hypothesis posed by Sokoloff (1988) that market access drives innovation. Sokoloff argued that between 1805 and 1835 in the eastern United States, counties along the newly-built canals, particularly the Erie, saw a sharp increase in patenting activity. I have constructed a dataset, including the data used in Sokoloff (1988), linking all patents issued between 1790 and 1836 to the counties in which the named inventors resided. With the greater time granularity my data provide, it appears that the increase in patenting activity happened before the arrival of the canal, which is inconsistent with the Sokoloff hypothesis. Linking the patent data created by Tom Nicholas (Akcigit et al., 2013) to Jeremy Atack's transportation data (Atack et al., 2010), it also appears that greater patenting activity preceded rather than followed the railroads. Finding the direction of causality among infrastructure, market access, and innovation is critical both for economic history and modeling innovation in an endogenous growth framework. My analysis will help disentangle these factors by establishing the temporal order followed by these processes, and measuring the magnitude and timing of their effects.

Related Literature

Noting the change in which areas of New York and Pennsylvania patented between 1790-1846, Sokoloff (1988) argues that patenting greatly increased in counties that received canals during this time. Unlike in the modern world, where transport costs are not often thought to be a large barrier to trade, before the twentieth century they were of utmost importance. Moving goods over land without mechanical power, even on the best highways, was incredibly costly. Before railroads, waterways were by far the most efficient way to transport goods, and these counties along canals previously had poor transportation links

A number of studies Pavcnik (2002); Amiti and Konings (2004); Van Biesebroeck (2005); Becker and Egger (2013); Deloecker (2007); Fernandes (2007); Foster et al. (2008); Topalova and Khandelwal (2011), using modern plant- or firm-level data, have noted that exporting firms often do become more productive after trade liberalization. A few papers have presented a model to motivate why a firm might want to invest in either product or process innovation upon being exposed to trade. Bustos (2011) and Lileeva and Trefler (2010) both consider a model that examines process innovation. Both of these studies then pair their Melitz (2003) style model with firm or plant level data to see that when exposed to a wider market, firms invest in process innovation.

In these models, firms enter a market after paying a fix cost f. Firms' productivity is drawn from a known distribution $G(\varphi)$. After this, firms in closed economies can upgrade their production abilities, and thereby lower their marginal cost, by process innovation, by paying a fixed cost f_i. In Lileeva and Trefler (2010) this means drawing from another known distribution, while in Bustos (2011) the effect of the investment is certain; firms are restricted to one product. Firms in an open economy can also choose to export if they pay a fixed cost f_x. There is an iceberg, per-unit, cost of exporting τ. Consumers in all these models have CES preferences leading to constant markups. All markets clear (full employment), and there is free entry and exit. This leads to a heterogeneous productivity effect as some firms start exporting without investing while others start exporting and invest. In autarky only, firms above a cutoff will invest in process upgrading, however firms above a lower cutoff will invest after the area is opened to trade. Thus, if applying for a patent is an important part of process innovation, this model provides motivation for looking for increased patenting activity with the introduction of transportation (note that Melitz (2003) shows that in his model reducing transport cost is very similar to lowering other cost of trade).

Modem studies have examined the relationship between density and productivity, Fallah et al. (2009) exams urban sprawl and labor productivity across industries. Even after controlling for city level amenities and observed worker characteristics, they find that less dense places are indeed less productive. Thinking that diversity improves productivity Glaeser et al. (2012) uses the location of historical mines as a plausibly exogenous source of variation for establishment size in city, and finds that places with larger establishment do, indeed, seem to experience less employment growth.

The geographic distribution of patents remained highly heterogeneous into the late nineteenth century. Lamoreaux and Sokoloff (2008), examining innovation in the glass industry 1870-1925, finds that, despite the logic production and innovation should concentrate together because of complementarities (learning by doing, etc.),the centers of production were not always centers of invention. Some areas which contain a great deal of production don't innovate much, and others that contain very little production, innovate heavily. Southern New England is noted as the latter sort of outlier. This area has the most advanced transport network of any area with any glass production at all, as great deal of innovation (it also has a great deal of trade in intellectual property).

Innovation clusters may occur because innovation seems to give rise to further innovation, as noted by Jaffe et al. (1993). They found that patents are more likely to cite other patents from the same metropolitan area than one might otherwise predict. One potential reason for this citation clustering might be that inventors move to areas of innovation. Khan and Sokoloff (2004) noted that they did migrate in the nineteenth century, perhaps to be nearer markets for intellectual property or other financing. In addition to noting that "innovation is spatially concentrated," the handbook article by Feldman and Kogler (2010) on geography and innovation lists seven other facts about the distribution of innovation in space. These included that "knowledge spillovers are geographically localized," a point Khan (2012) addresses by examining the spatial correlation of innovations displayed at a number of fairs showcasing innovation. She divided the sample into patented and non-patented (but prize winning) innovations, and finds that patented innovations seem to have much higher spatial autocorrelation, and seemed to provide spillovers to adjacent counties that prized (but non-patented) inventions did not.

There is some evidence that patents themselves may spur a different geographic distribution (Moser, 2011), since a patent produces a detailed schematic of an invention. With a schematic, it is easier for geographically disparate people to gain in-depth knowledge of the new invention, and thus build on this knowledge.

Data

Patents are a legal document that grant a limited term monopoly. The U.S. Constitution gives Congress the power "[t]o promote the progress of science and useful arts, by securing for limited times to authors and inventors the exclusive rights to their writings and discoveries." In 1790, as permitted by this clause, federal patents are introduced requiring that patentable subject matter be novel, useful and that the patent disclose the patented invention.[1]

[1]While the first patents may have been issued with an eye toward the legislative discretion that chartered the monopoly rights from the system evolved, patents were soon seen as themselves a "right" owed to any

The requirement of novelty was backed by the declaration in the 1790 Patent Act that the Patentee was supposed to be “the first and true inventor” anywhere in the world. The enablement requirement specified that a patent application disclose a claimed invention in sufficient detail for the notional person skilled in the art to carry out that claimed invention and, vitally for the use of this data, that this description of the invention be made available to the public immediately upon issue. Thus patents themselves transmit information about new technological ideas. Thought the enforcement of these requirements has greatly fluctuated, today legislation requires many of the same things: novelty, non-obviousness, (nominally) utility, and enablement.

Though patents are imperfect indicators of technological improvement, they are the most accessible and detailed written records of innovation. As such, economists and economic historians have long studied them to probe the economics of technological development. While these studies have been wide ranging, they have been constrained by the availability of data. Until very recently, difficulty of gathering a truly representative sample has necessarily focused research on narrow subsets, be they single industries or limited geographical areas. Even for the modern period, there has been little work using the textual information contained in patents, and none using this and geographic information.

This paper makes use of a geo-linked database of patents issued 1790-1900 and links together several data sources. In 1836 there was a fire in the patent office, which burned all the patents that had been issued to that date. In an attempt to recover from the damaged this caused the patent office put out a call for existent information on patents; in 1874 congress used the information the patent office had received to compile a list of patents issued 1779-1836. This 1874 congressional list has been updated by volunteers, such as Jim Shaw and the maintainers of the Directory of American Tool and Machinery Patents, who have found patents that the

new invention, regardless of government judgment on criteria besides novelty and non-obviousness.

1874 congress was not aware of. I geo-located the patents in it by merging the town and county information with a database of historical town names from the AniMap 3.0.2 County Boundary Historical Atlas and have corrected a number of errors in this database. This allows each patent to be located with latitude and longitude coordinates. The rest of the patent data comes from Tom Nicholas' dataset of patents issued from 1836-1900, which has latitude and longitude coordinates of the listed places on these patents. These geo-located patents are then merged with the National Historical Geographic Information System shape-files of U.S. county boundaries. This allows patent counts by county to be created.

This paper uses both contemporaneous county boundaries and a sample of consistent land area counties, harmonized to 1840 boundaries as suggested in Hornbeck (2010). U.S. Census Data is from Haines (2010). Transportation data comes from Atack et al. (2010), these data are linked with shape-files of U.S. county boundaries to explore the spread of railroads and canals. The textual data was scraped from Westlaw and is linked by patent number.

Figure 1 shows the total patents in each year as well as the US population from the census. Note that that number of patents per person does is not at all smooth over time, and the large increase in patenting activity that starts in the 1850s. Table 1 shows the summary statistics for each year. In this table and in most of the analysis done in this paper, the number of patents refers to those issued in a two year period: the complete named year and the complete year before the named year. Years in which there is no data for a variable are years for which it is missing in my dataset.

Figures 2, 3, and 4 are maps that show the spread of patenting across the country. They present the number of patents issued per 1000 people in five year bins after the named year as well as the spread of the canal and railroad network by county for six years, 1790, 1810, 1830 (this picture is nearly equivalent to the later period presented in Sokoloff (1988)), 1850, 1870, and 1890. One can clearly see the increasing area that is involved in patenting, as well as the increasing amount of patenting per person.

Results and Discussion

A starting point for thinking about the relationship between patents and population is to assume that each period each person has an independent probability p of producing a patent. In a county of n the number of patents would be a binomially distributed random variable with mean np. The expected value of the number of patents for any given county is np; this model would predict a linear relationship between the population in a county and the number of patent issued to residents of that county (with coefficient p).

Figure 7 shows the relationship between number of patents and total population for 1870, though some things about this relationship do change over time the basic shape of it does not– it always looks remarkably linear, with the most populous counties producing more patents than a linear relationship would predict, and a substantial number of zeros, often where the fit would predict a positive relationship. Over the years, the slope of this predicted linear relationship does change; figure 5 shows the relationship between patenting and population for two years, 1840 and 1870. While the population has increased substantially in that time, it is also notable how much the slope of the relationship between population and number of patents has changed between the two years. Figure 8 shows the coefficients on total population when number of patents is regressed on it for the years in my sample. Note the slow increase until 1850, and then the large change with much steeper slopes thereafter. (Also presented, in figure 9, is the relationship between the number of patents and the number of people employed in manufacturing over time.) To further explore this change Figure 6 presents a histogram of the number of patents per 10,000 people by county, weighted by population, in both 1840 and 1870. The distribution has spread out considerably, with many fewer zeros and many more large numbers. Figure 10, give more sense of how the consternation of patenting has changed over time. The Herfindahl index falls substantially over the nineteenth century, reading a low in 1870, and being close to flat between 1880 and 1900.

Total population explains more of the variation in number of patents than anything else, other parametric relationships between the number of patents and populations are not meaningfully better fits. However, there are many more observed zeros than a linear model predicts, variation that suggests the naive model is wrong.

A simple way of refining the thoughts in the naive model above is to assume that there are two types of people, rural people and urban people. Each period each person has an independent probability p_r or p_u of producing a patent depending on their type. In a county of n, with n_r rural people and n_u urban people the number of patents would be the sum of two binomially distributed random variables with means $n_r p_r$ and $n_u p_u$. The expected value of the number of patents for any given county is $n_r p_r + n_u p_u$; this model would predict an increasing relationship between the population in a county and the number of patent issued to residents of that county. At low populations one would expect very few urban people, so a near linear relationship with coefficient p_r, at middle populations one would expect a coefficient that was convex combination or the two probabilities $\frac{n_r p_r + n_u p_u}{n_r + n_u}$, and at the largest populations one would expect a linear relationship with p_u.

Table 2 examines the relationship between patents and different types of population and the patents per 10,000 people and the number of patents (the series on the number of patents seems to have a unit root). In all regressions urban population seems to be more important than rural population, however for most counties the rural population is much larger than the urban populations, so both the average elasticity and the elasticity at means are larger for rural population than for urban population.

Sokoloff (1988) argued that increased market access, gained by reviving a canal, increases the level of innovation and thus patenting in a county. Figure 11 examines the number of patents per 10,000 people in counties over time by the year that these counties received the railroad. Note that the counties that received the railroad the earliest also had the highest level of patenting per capita (and also over all, as they tended to have larger populations). Figure 12 shows the mean patenting per 10,000 people by the number of years until the railroad arrived, where the presence of the railroad is measured at ten-year intervals. If the railroad arrived in a county in 1854, it would be measured as not present in 1850 and present in 1860, and 1850 would be coded at ten years until railroad arrives, despite the fact that in reality it was only four years until arrival, and 1860 would be coded as the date of arrival, zero years, despite the fact that in reality it was six years ago. One can see in figure 11 an increase in patents per 10,000 people once the railroad arrives in a county. Table 3 show the results of a regression of patents per 10,000 people on a dummy for the presence of a railroad in a county, the increase seen in figure 11 is reflected here.

As noted above, the presence of people in a county seems to be highly correlated with not only number of patents, but also with patents per capita; figure 14 shows the relationship between the average population in a county and the number of years until a railroad arrives in the same way that figure 11 shows this relationship for patents. As noted in Atack et al. (2010) total population does seem to increase, but urban population increases much faster. Thus, table 6 controls for both total population and urban population. The presence of a railroad seems to be positive on patents per 10,000 people, but negative on the change in the number of patents.

Table 3 also re-examines the setting examined Sokoloff (1988) of the building of canals across the north-eastern United States. The arrival of a canal in a county is positively associated with more patenting activity. Figure 16 shows this relationship in the same way that figure 11 shows it for railroads. Figure 16 has yearly data, and so is not subject to the same mismeasurement as the data that were measured every ten years. However, population values have been exponentially interpolated between census years. Figure 15 and table 7 show results for the railroad in the Midwest at a yearly frequency, subject to the same inter-census interpolation.

Table 4 examines the interaction between urban population and presence of the railroad. Note that after 1840 there is no city larger than 25,000 in this sample that does not have a railroad. It is clear that the presence of a railroad does not diminish the relationship between patents and population; the elasticities suggest that the most correlated population with patents is that in smaller urban areas.

Figure 13 shows the average number of classes in a county per patent by year to the railroad, in the same way figure 12 presents this; table 5 presents a regression of this same thing. A railroad has a positive relationship with the number of classes patented in a county.Table 8 looks at the similarity between the bag of words representation of the text of a patent and the bag of words representation of all patents issued in that year (the inverse document frequency is commuted using all patents issued in the last ten years) averaged by county; figure 17 shows these averages on a map for 1840. Figure 18 is a population cartogram of 1830 showing patents per 1000 people in five year bins. This makes the population centers that are small in land area, such as Manhattan and Philadelphia, more viable.

Conclusion

The most important determinant of patenting in the nineteenth century US was population. However, it is clear that raw numbers of people were not enough to encourage patenting, particularly as the relationship between the population and patents shifted over time. Access to transpiration was an important correlate of patenting activity, leading to larger number of patents, patents in a wider verity of patent classes, and patents that are more similar to the typical patent of the year.

Extensions include examining: the relationship between patents, manufacturing and education more deeply; patent that are particularly innovative, by being an early patent on a classification (see figure 19); the effect of the 1812 war and the trade changes therein; the change in similarity scores over time; and the effect of an increase in a network size change a central and dense places patenting. Railroad data and urban data can both be instrumented for.

References

Akcigit, U., Kerr, W. R., and Nicholas, T. (2013). The Mechanics of Endogenous Innovation and Growth: Evidence from Historical U.S. Patents.

Amiti, M. and Konings, J. (2004). Trade Liberalization , Intermediate Inputs , and Productivity : Evidence from Indonesia. *American Economic Review*.

Atack, J., Bateman, F., Haines, M., and Margo, R. A. (2010). Did Railroads Induce or Follow Economic Growth?: Urbanization and Population Growth in the American Midwest, 1850-1860. *Social Science History*, 34(2):171–197.

Becker, S. O. and Egger, P. H. (2013). Endogenous product versus process innovation and a firm's propensity to export. *Empirical Economics*, pages 1–26.

Bustos, P. (2011). Trade liberalization, exports, and technology upgrading: Evidence on the impact of mercosur on argentinian firms. *The American Economic Review*, 101(February):304–340.

Deloecker, J. (2007). Do exports generate higher productivity? Evidence from Slovenia. *Journal of International Economics*, 73(1):69–98.

Fallah, B. N., Partridge, M. D., and Olfert, M. R. (2009). Urban Sprawl and Productivity.

Feldman, M. P. and Kogler, D. F. (2010). Stylized Facts in the Geography of Innovation. *Handbook of the Economics of Innovation*, 01(10):381–410.

Fernandes, A. M. (2007). Trade policy, trade volumes and plant-level productivity in Colombian manufacturing industries. *Journal of International Economics*, 71(1):52–71.

Foster, L., Haltiwanger, J., and Syverson, C. (2008). Reallocation, firm turnover, and efficiency: Selection on productivity or profitability? *American Economic Review*, 98(1):394–425.

Glaeser, E. L., Kallal, H. D., Scheinkman, J. A., and Shleifer, A. (1992). Growth in Cities. *Journal of Political Economy*, 100(6):1126–52.

Glaeser, E. L., Kerr, S. P., and Kerr, W. R. (2012). Entrepreneurship and Urban Growth: An Empirical Assessment with Historical Mines.

Haines, M. R. (2010). Historical, Demographic, Economic, and Social Data: The United States, 1790-2002 [Computer file].

Henrich, J. (2004). Demography and cultural evolution: How adaptive cultural processes can produce maladaptive losses-The Tasmanian case. *American Antiquity*, 69(2):197–214.

Hornbeck, R. (2010). Barbed Wire: Property Rights and Agricultural Development. *The Quarterly Journal of Economics*, 125(2):767–810.

Jacobs, J. (1970). *The Economy of Cities*. Vintage Books, New York.

Jaffe, A. B., Trajtenberg, M., and Henderson, R. (1993). Geographic localization of knowledge spillovers as evidenced by patent citations. *The Quarterly Journal of Economics*, 108(3):577–98.

Khan, B. Z. (2012). Of Time and Space: A Spatial Analysis of Technological Spillovers among Patents and Unpatented Innovations in the Nineteenth Century.

Khan, B. Z. and Sokoloff, K. L. (2004). Institutions and Democratic Invention in 19th-Century America: Evidence from "Great Inventors," 1790–1930. *American Economic Review*, 94(2):395–401.

Lamoreaux, N. R. and Sokoloff, K. L. (2008). The Geography of Invention in the American Glass Industry, 1870-1925. *The Journal of Economic History*, 60(03):700–729.

Lileeva, A. and Trefler, D. (2010). Improved access to foreign markets raises plant-level productivity. . . for some plants. *The Quarterly Journal of Economics*, 125(3):1051–1099.

Marshall, A. (1890). *Principles of Economics*. Macmillan and Co., New York.

Melitz, M. J. (2003). The impact of trade on intra-industry reallocations and aggregate industry productivity. *Econometrica*, 71(6):1695–1725.

Moser, P. (2011). Do Patents Weaken the Localization of Innovations? Evidence from World's Fairs, 1851-1915. *The Journal of Economic History*, 64(2):548–552.

Pavcnik, N. (2002). Trade liberalization, exit, and productivity improvements: Evidence from Chilean plants. *The Review of Economics Studies*, 69.

Romer, P. (1991). Endogenous Technological Change. (3210).

Sokoloff, K. L. (1988). Inventive Activity in Early Industrial America: Evidence From Patent Records, 1790–1846. *The Journal of Economic History*, 48(04):813–850.

Topalova, P. and Khandelwal, A. (2011). Trade liberalization and firm productivity: The case of india. *Review of Economics and Statistics*, 93(3):995–1009.

Van Biesebroeck, J. (2005). Exporting raises productivity in sub-Saharan African manufacturing firms. *Journal of International Economics*, 67(2):373–391.

Tables and Figures

Figure 1: Number of Patents and Population over Time

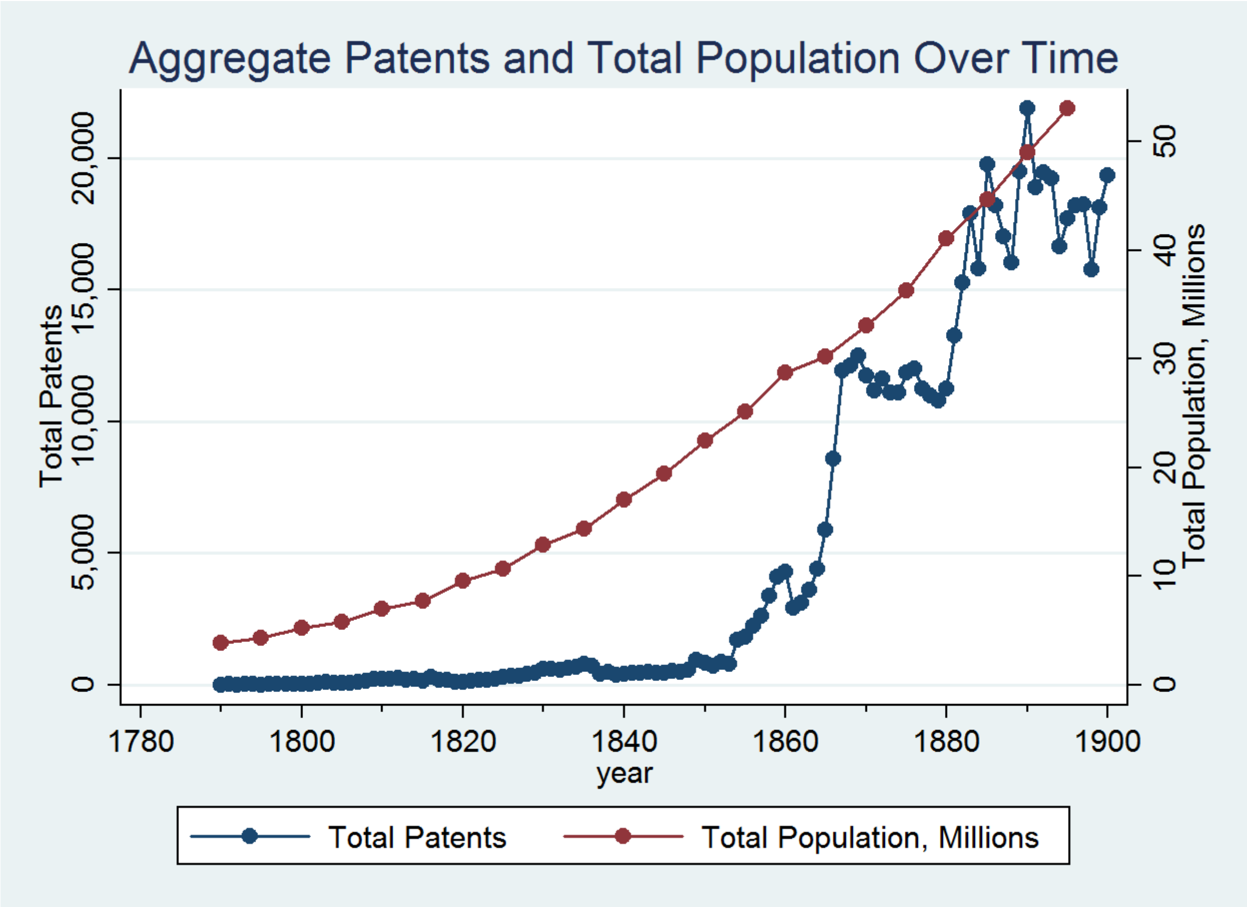
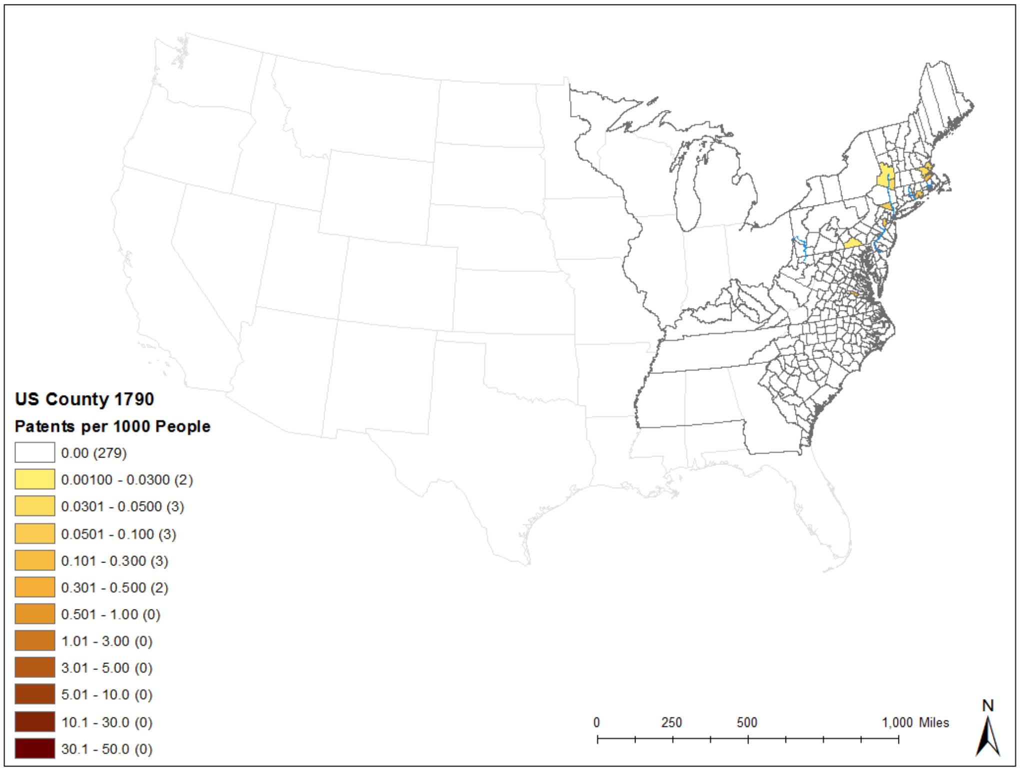


Figure 2: Patent per 1000 People with Transport, 1790 and 1810
Patent counted in five year increments.



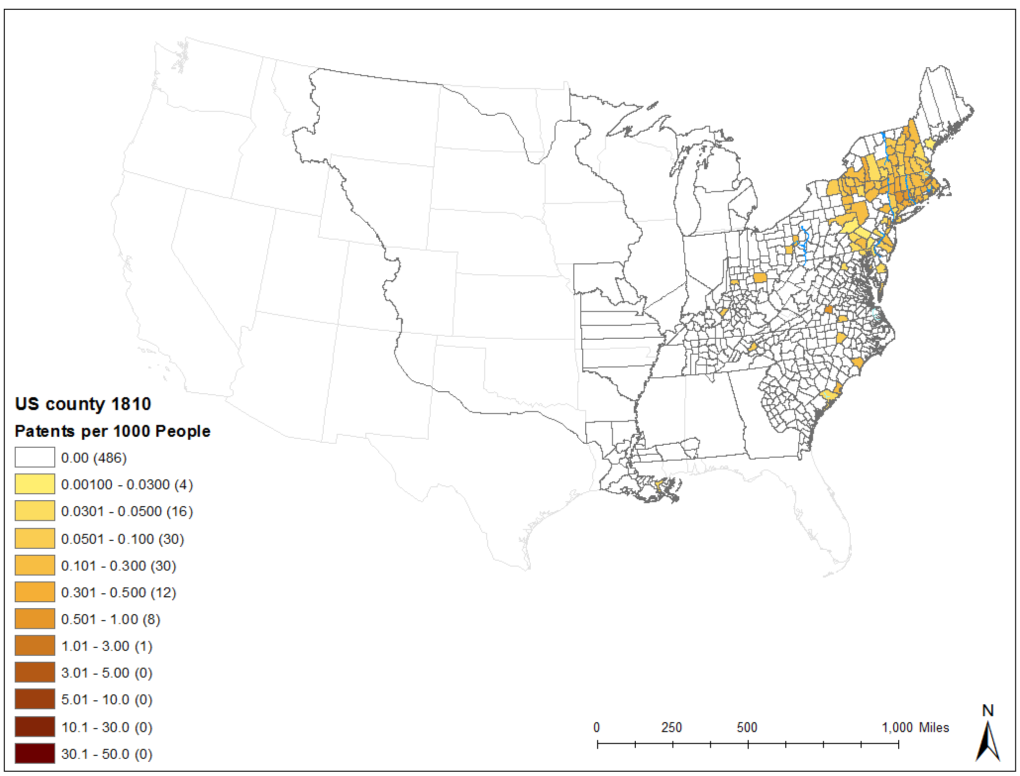
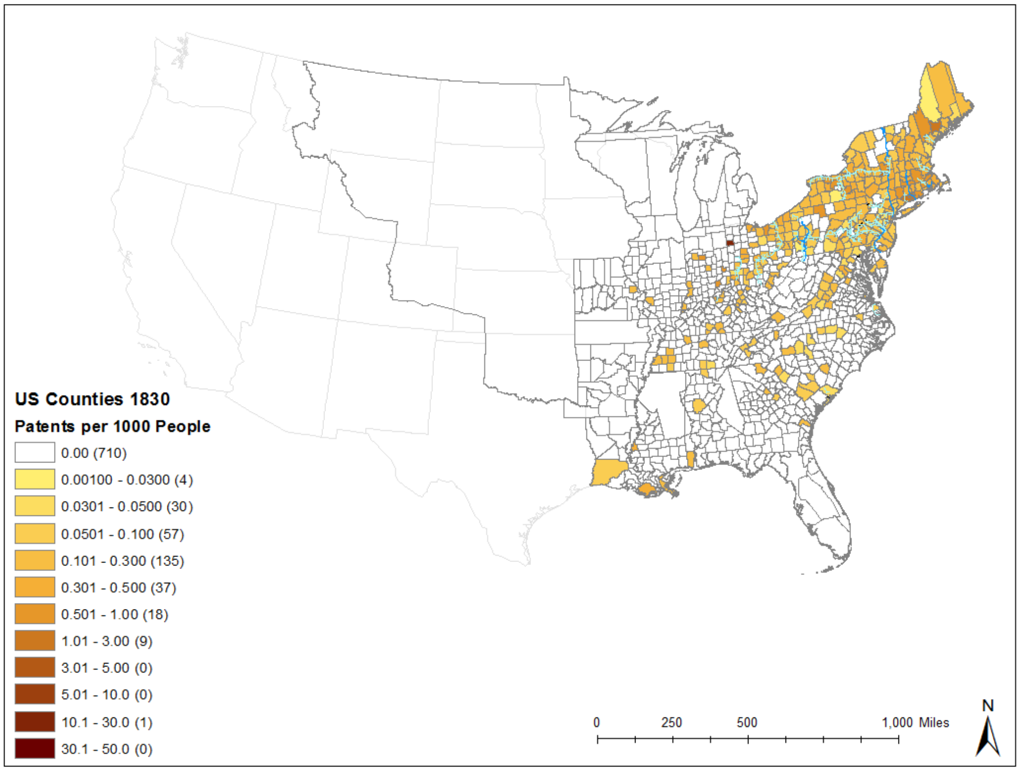


Figure 3: Patent per 1000 People with Transport, 1830 and 1850
Patent counted in five year increments.



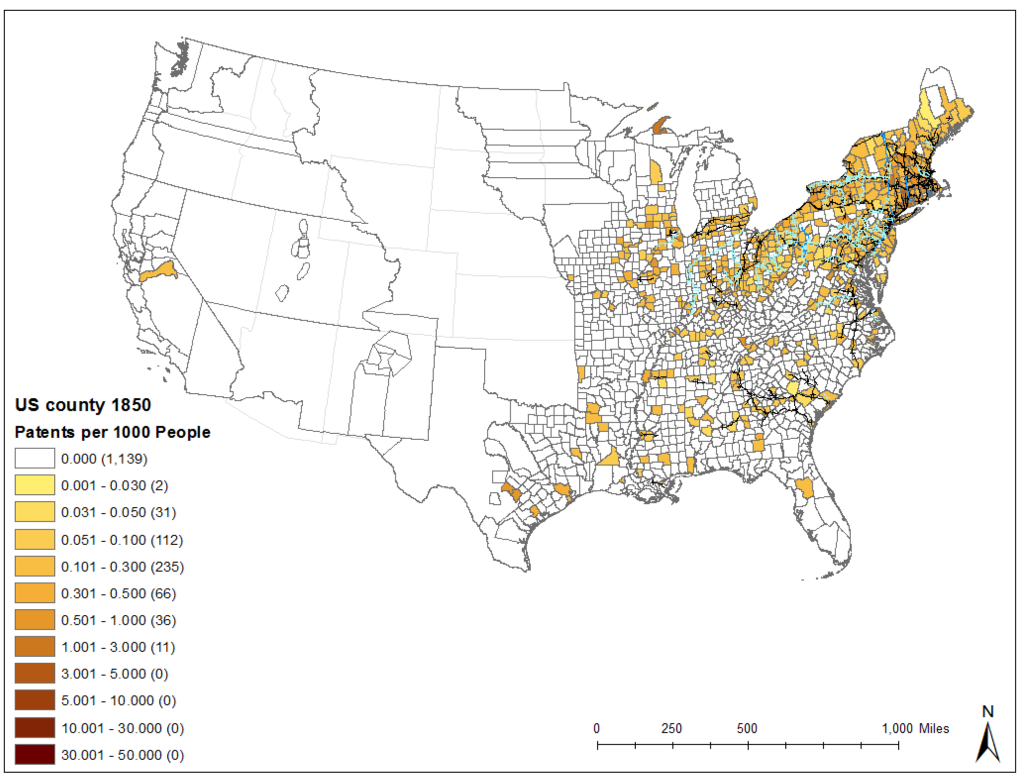
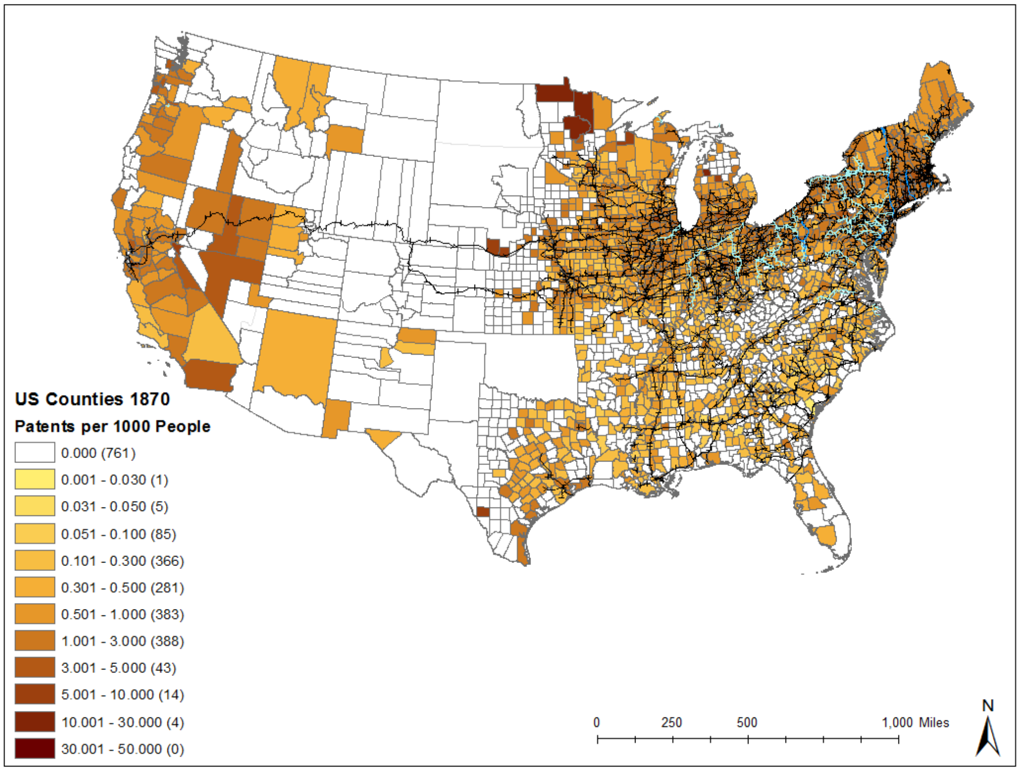


Figure 4: Patent per 1000 People with Transport, 1870 and 1890
Patent counted in five year increments.



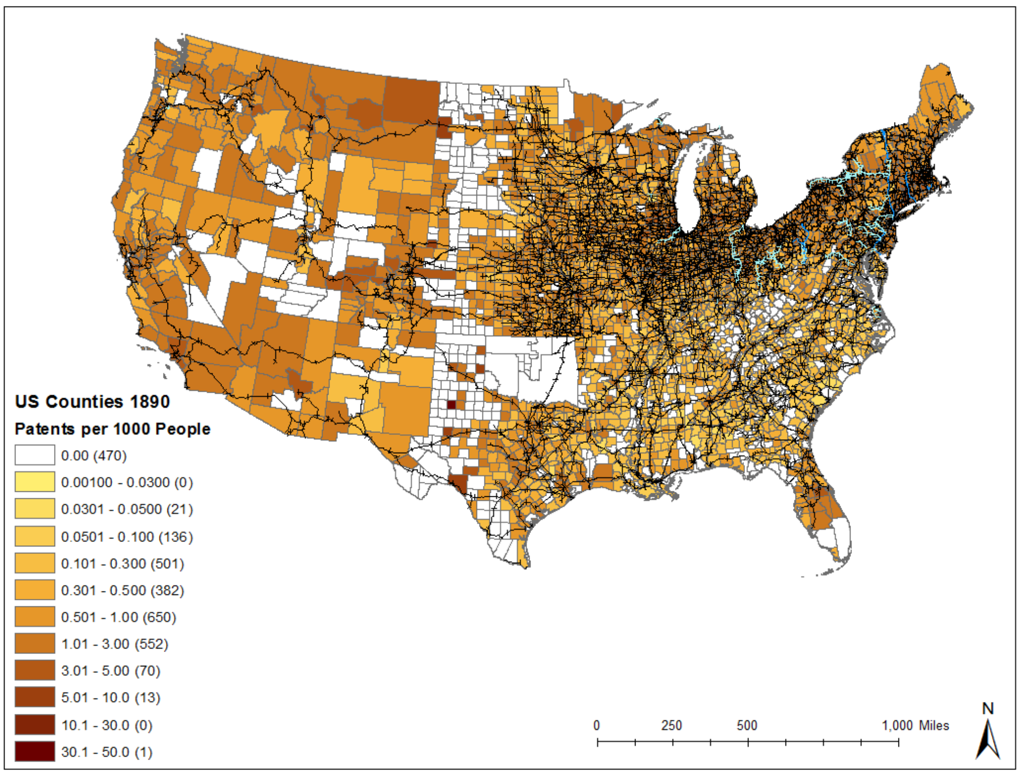


Figure 5: Number of Patents vs. Total Population in 1840 and 1870

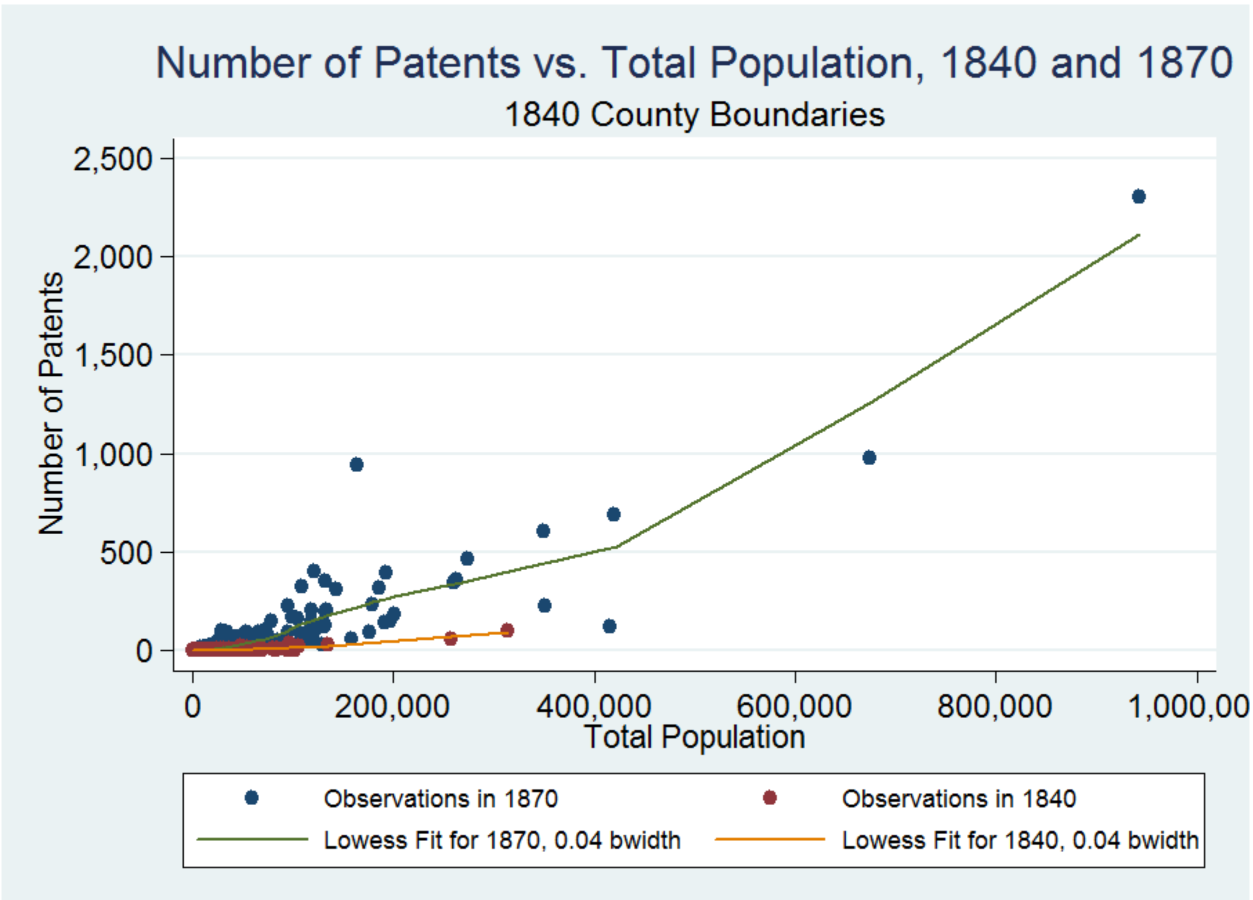


Figure 6: Histogram of Patents per 10,000 People by County, Weighted by Population.

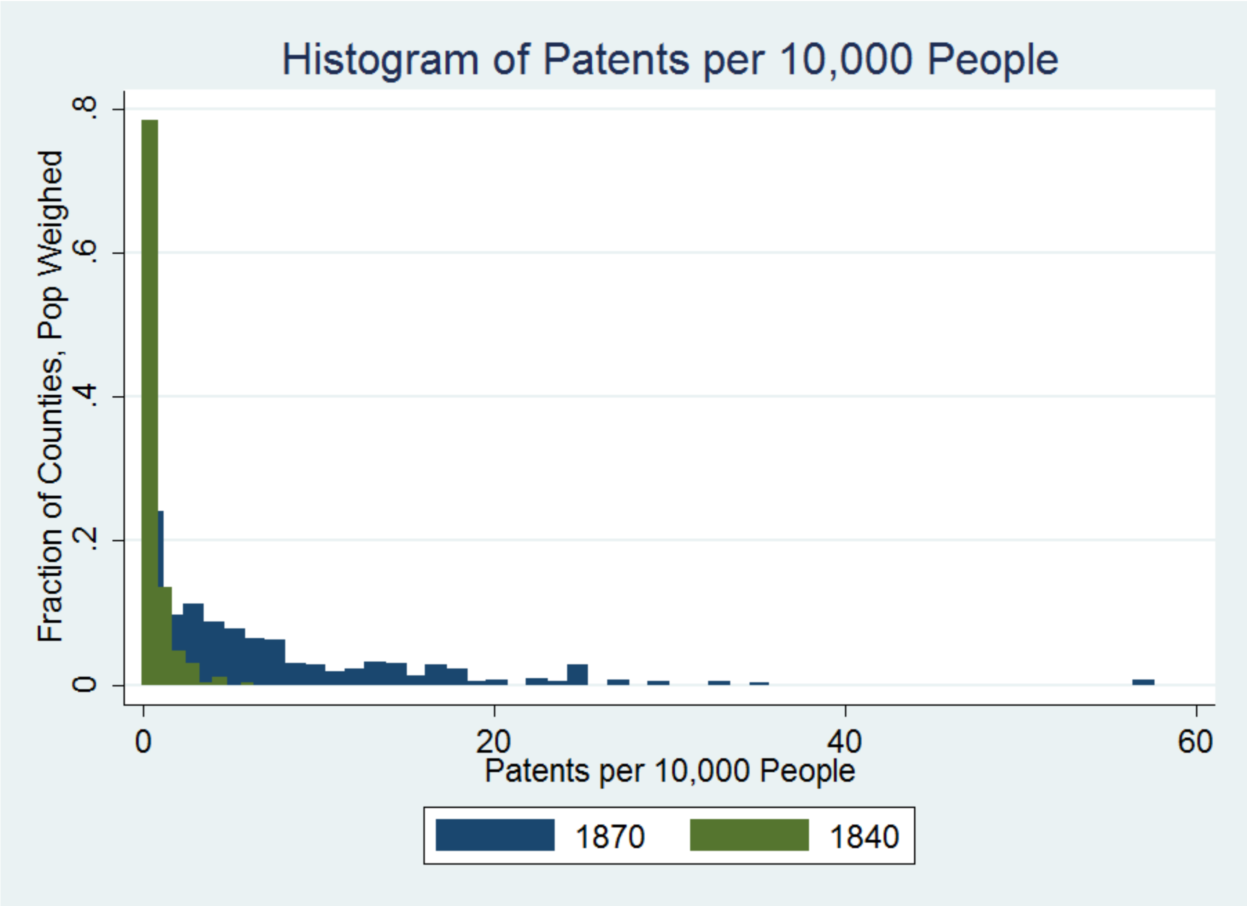


Figure 7: Number of Patents vs. Total Population in 1870

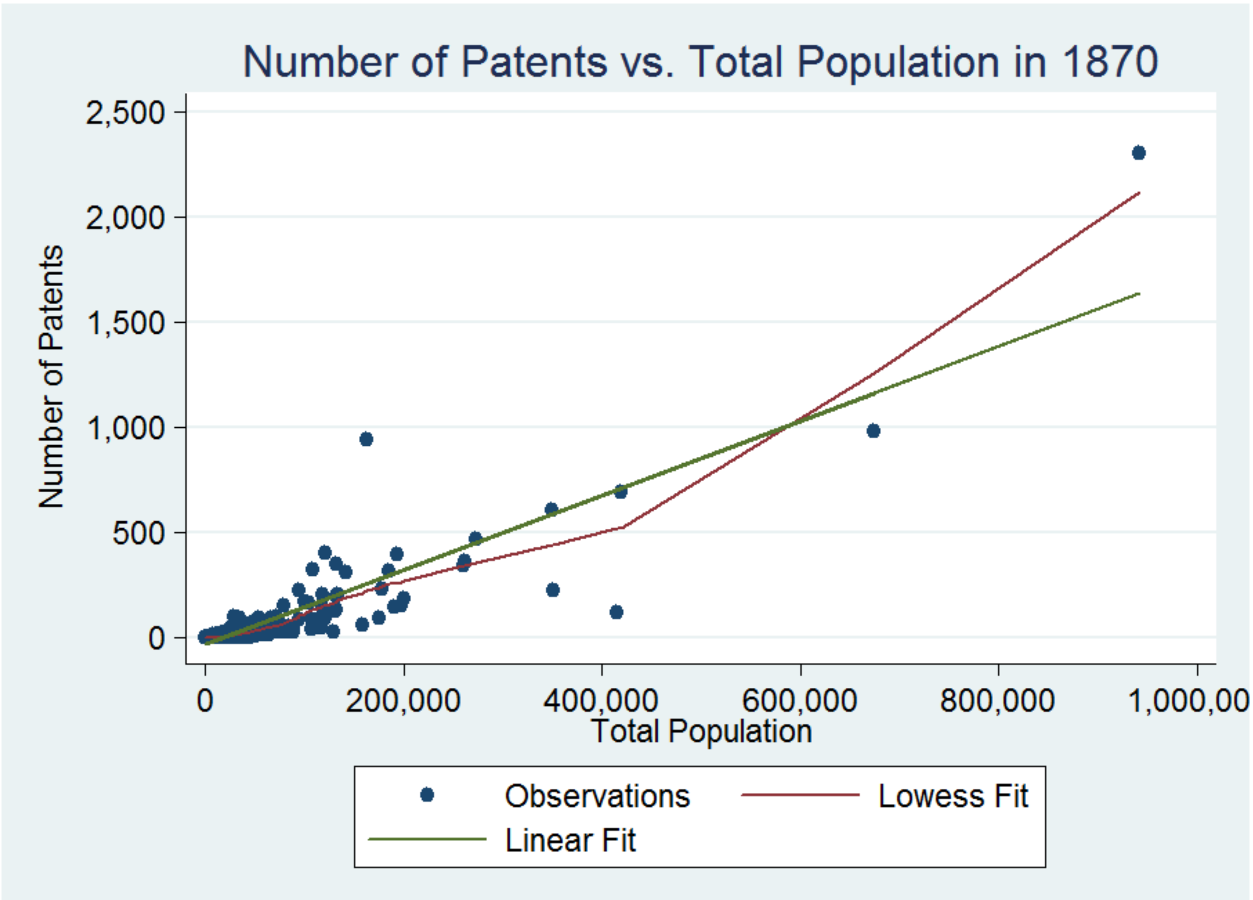


Figure 8: The Coefficient on Total Population in a Regression of Number of Patents on Total Population

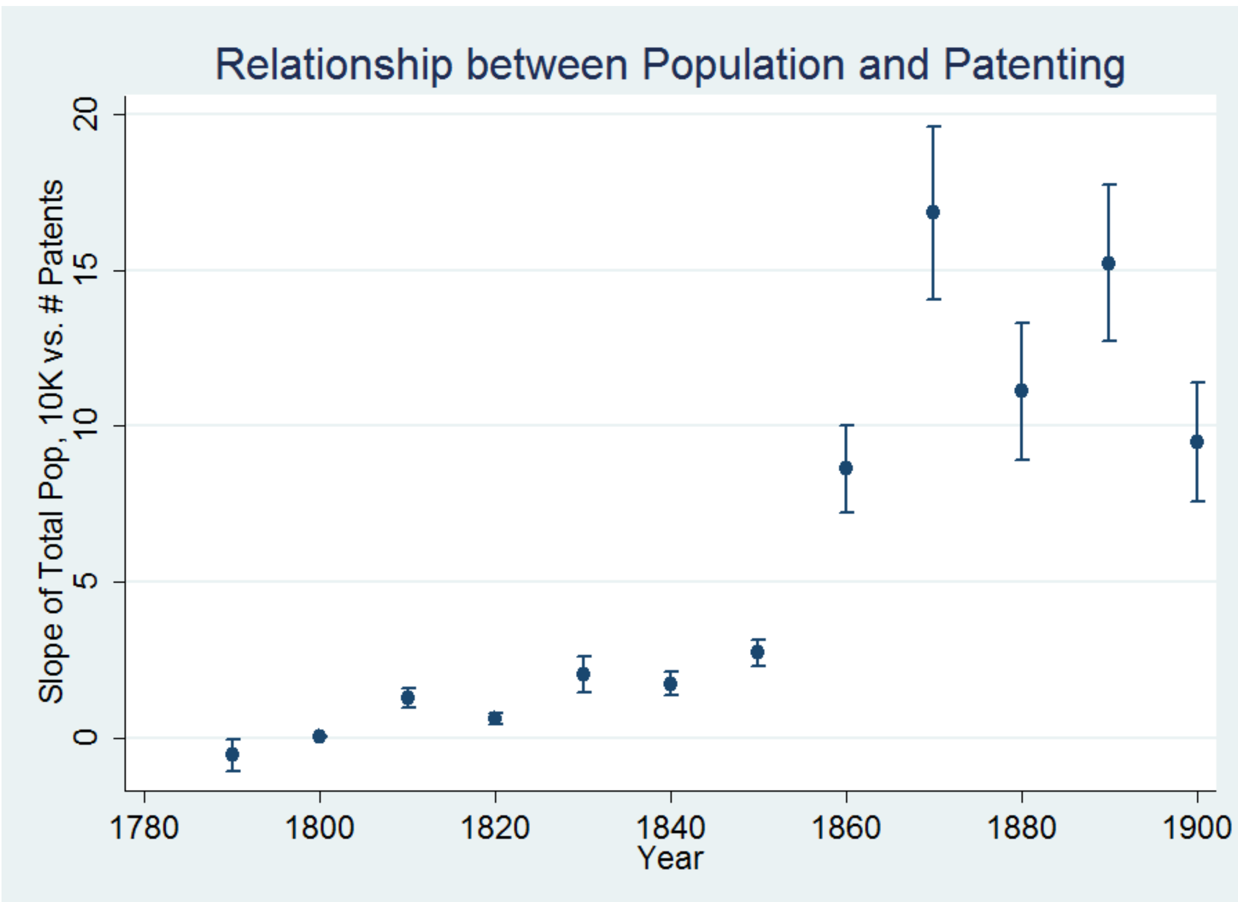


Figure 9: The Coefficient on Manufacturing Employment in a Regression of Number of Patents on Manufacturing Employment

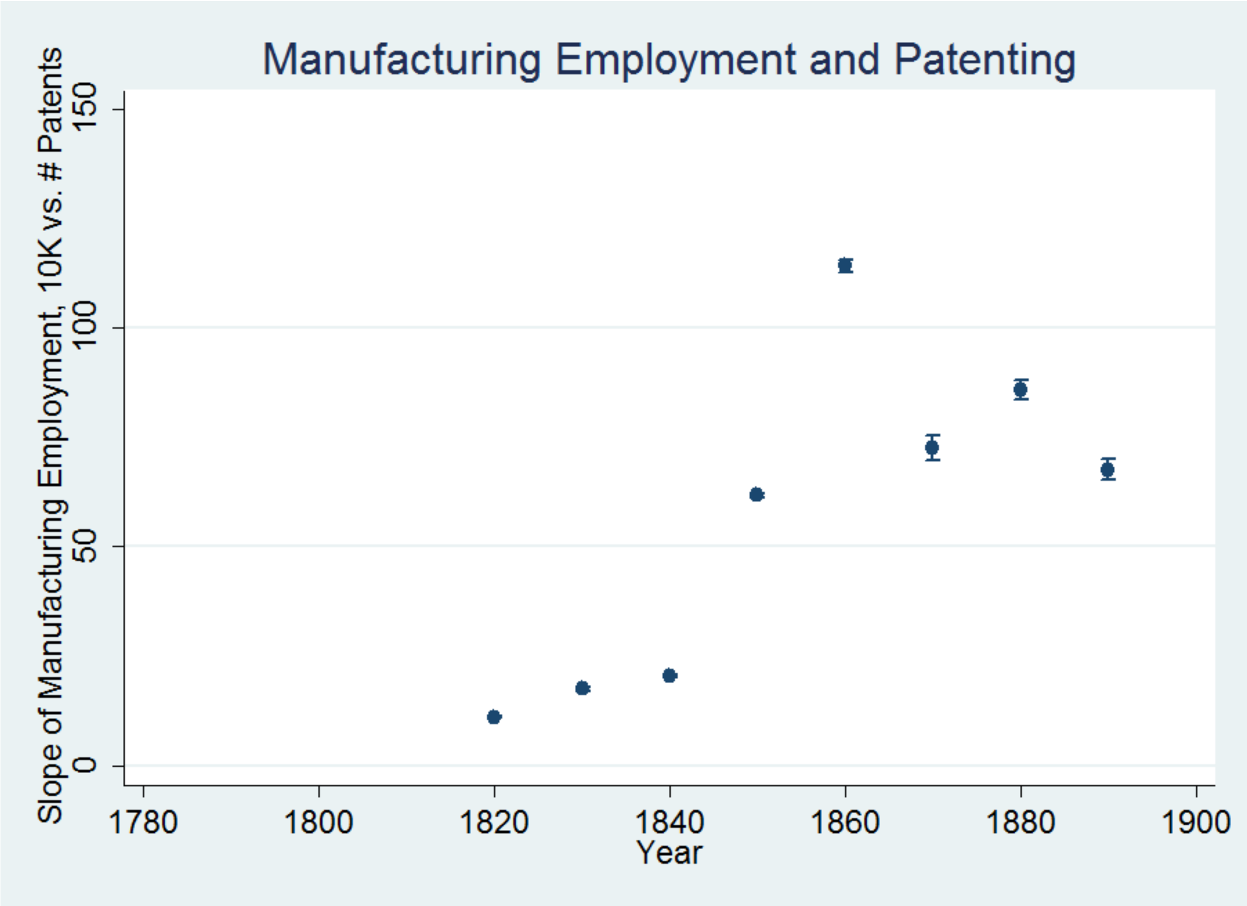


Figure 10: Concentration of Patents in Counties by Year, Herfindahl Index

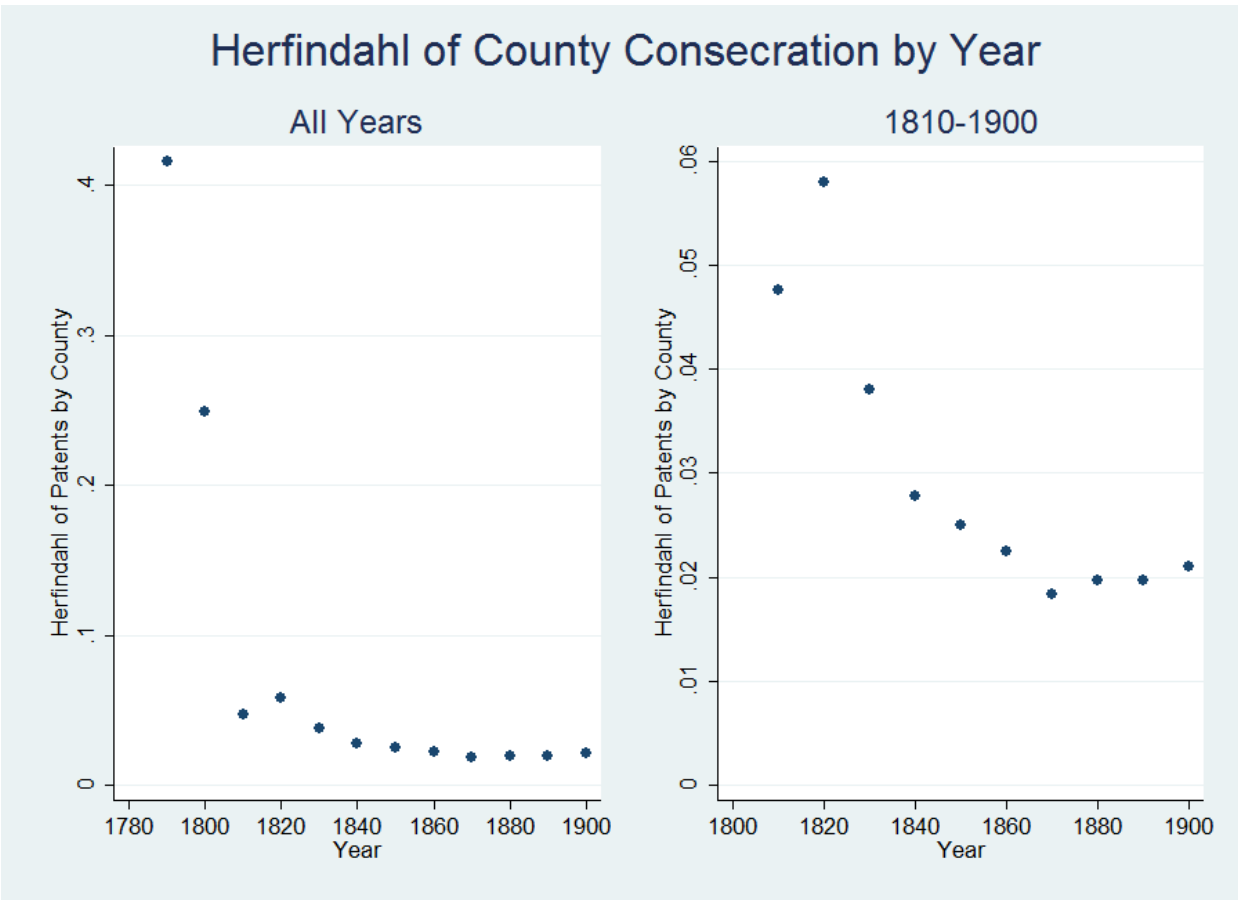


Figure 11: The Mean Patents per 10,000 People by the Year of Railroad Arrival

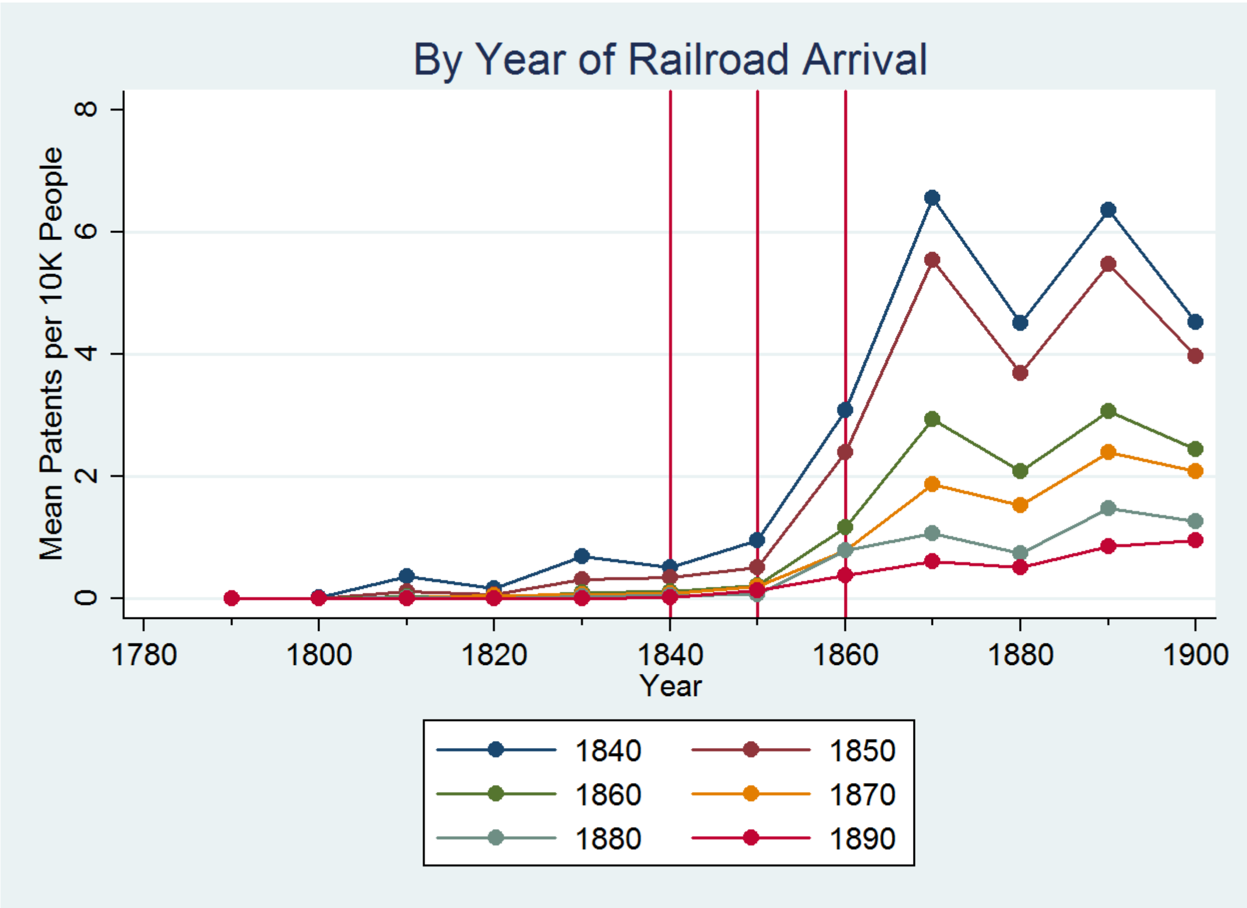


Figure 12: The Mean Patents per 10,000 People by the Years to Railroad Arrival

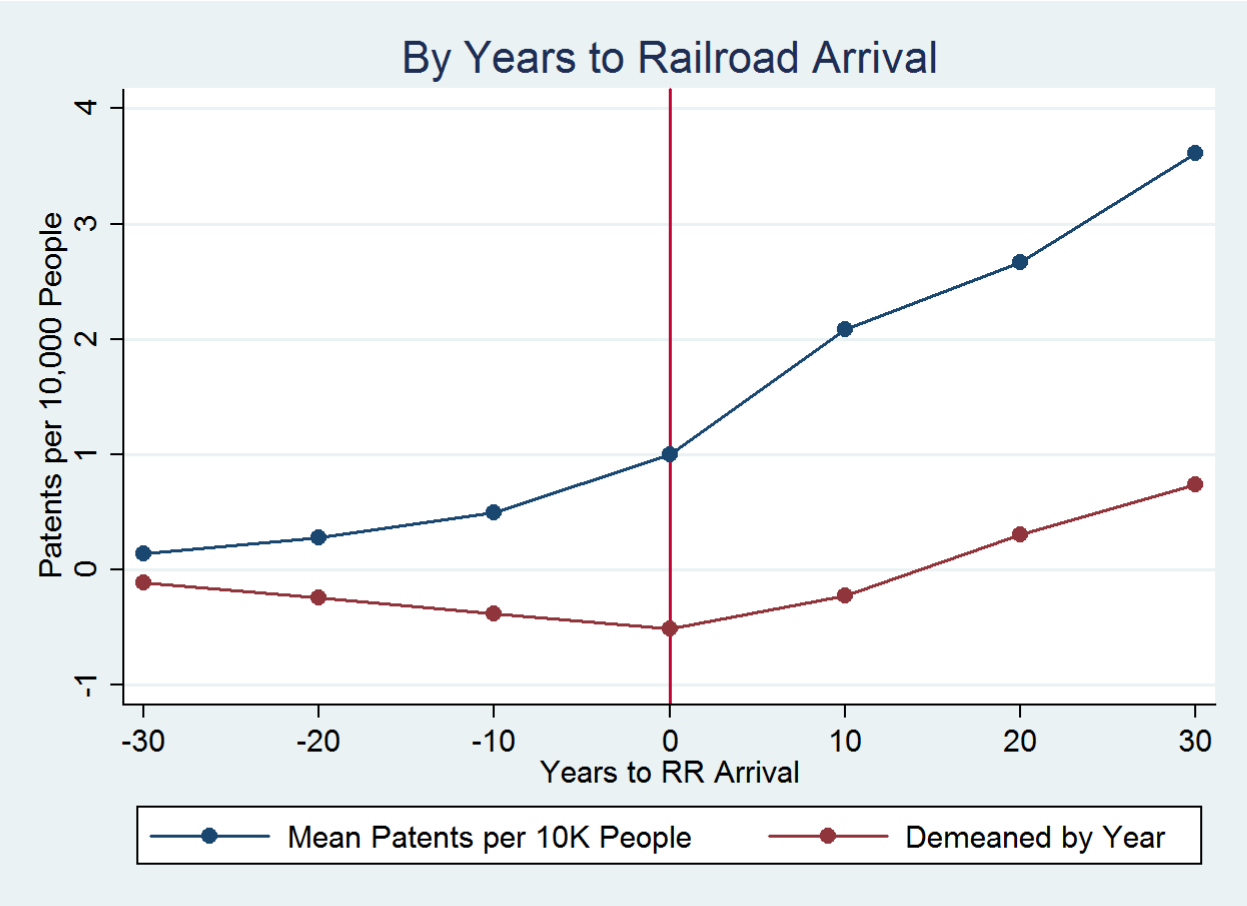


Figure 13: Mean Number of Classes per Patent Issued by the Years to Railroad Arrival

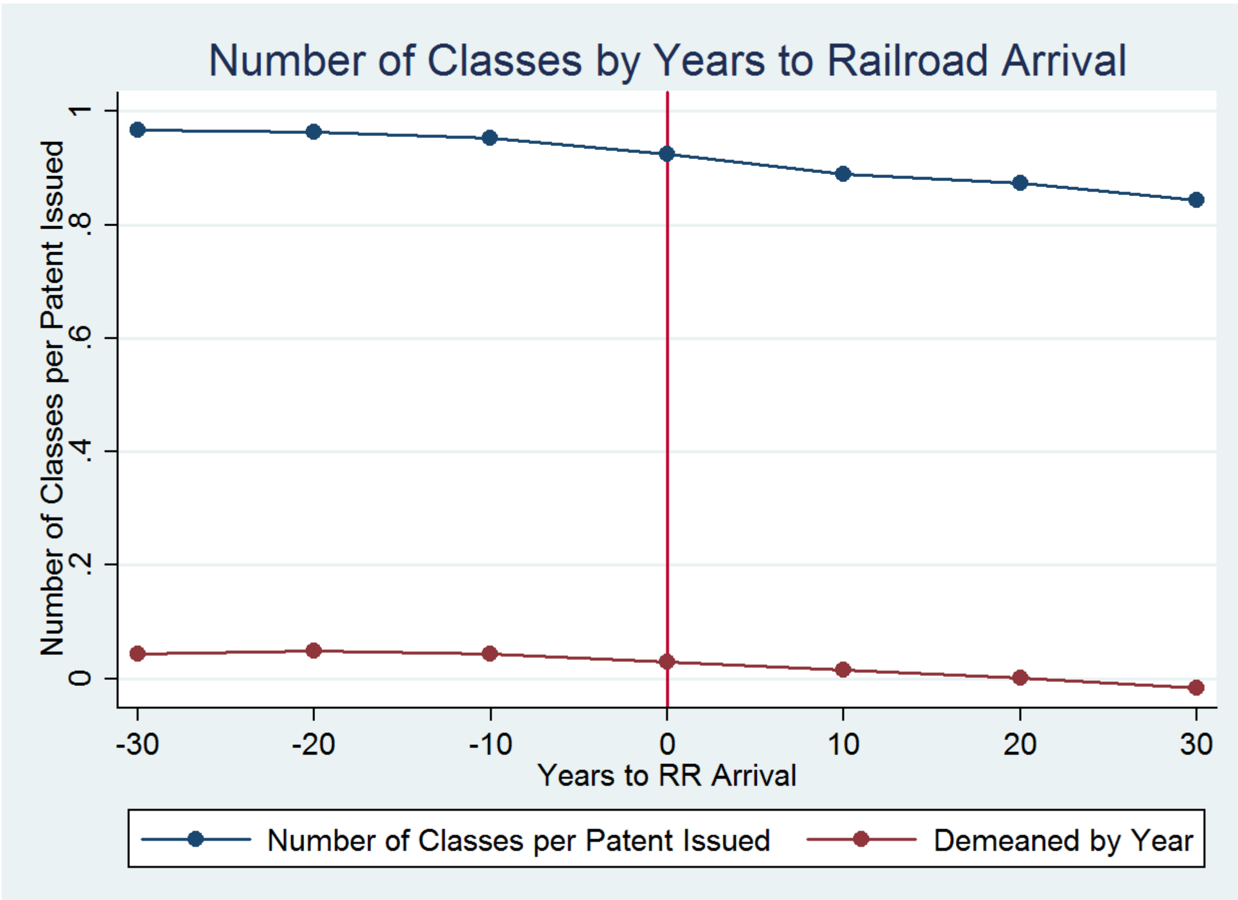


Figure 14: Mean Population by the Years to Railroad Arrival

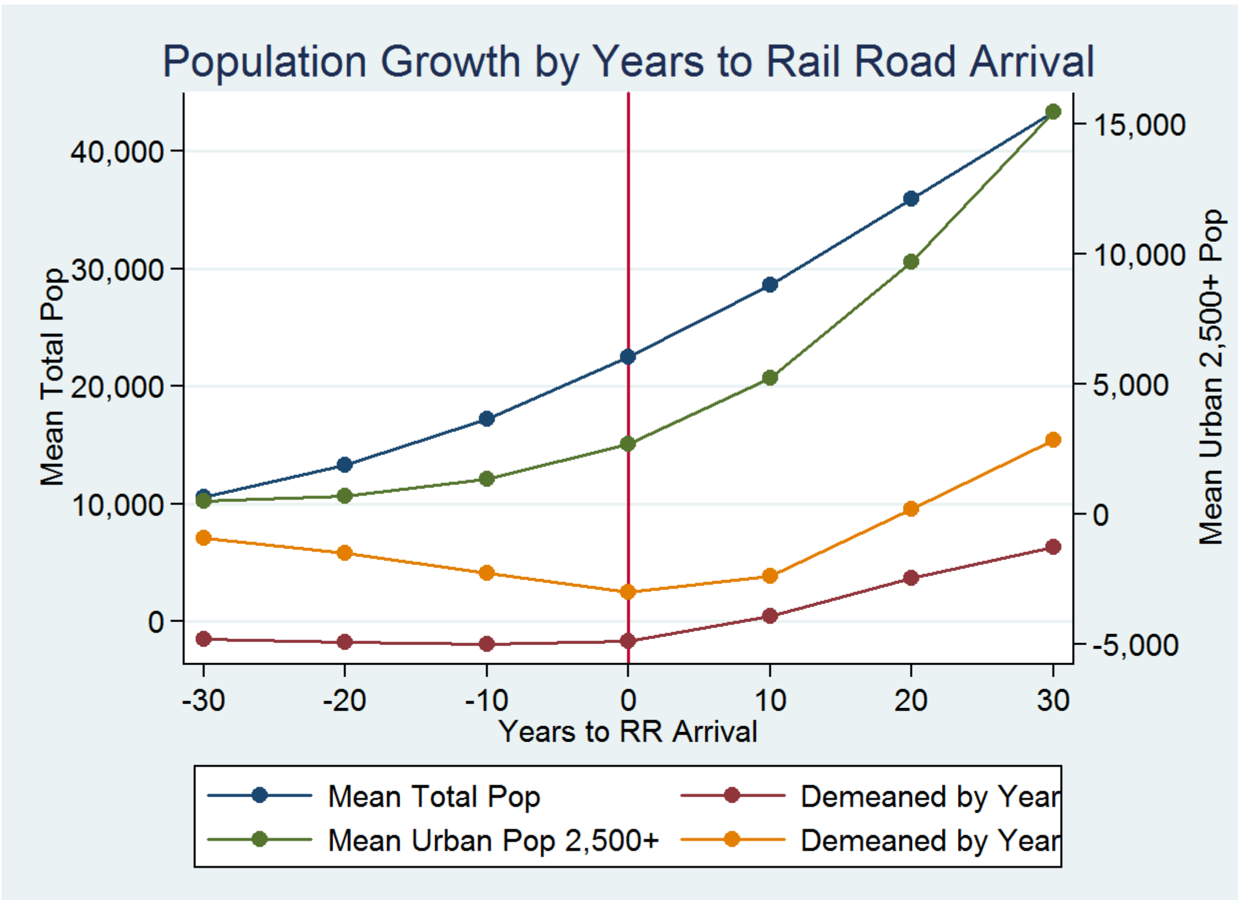


Figure 15: The Mean Patents per 10,000 People by the Years to Railroad Arrival, Yearly Population exponentially interpolated between census years.

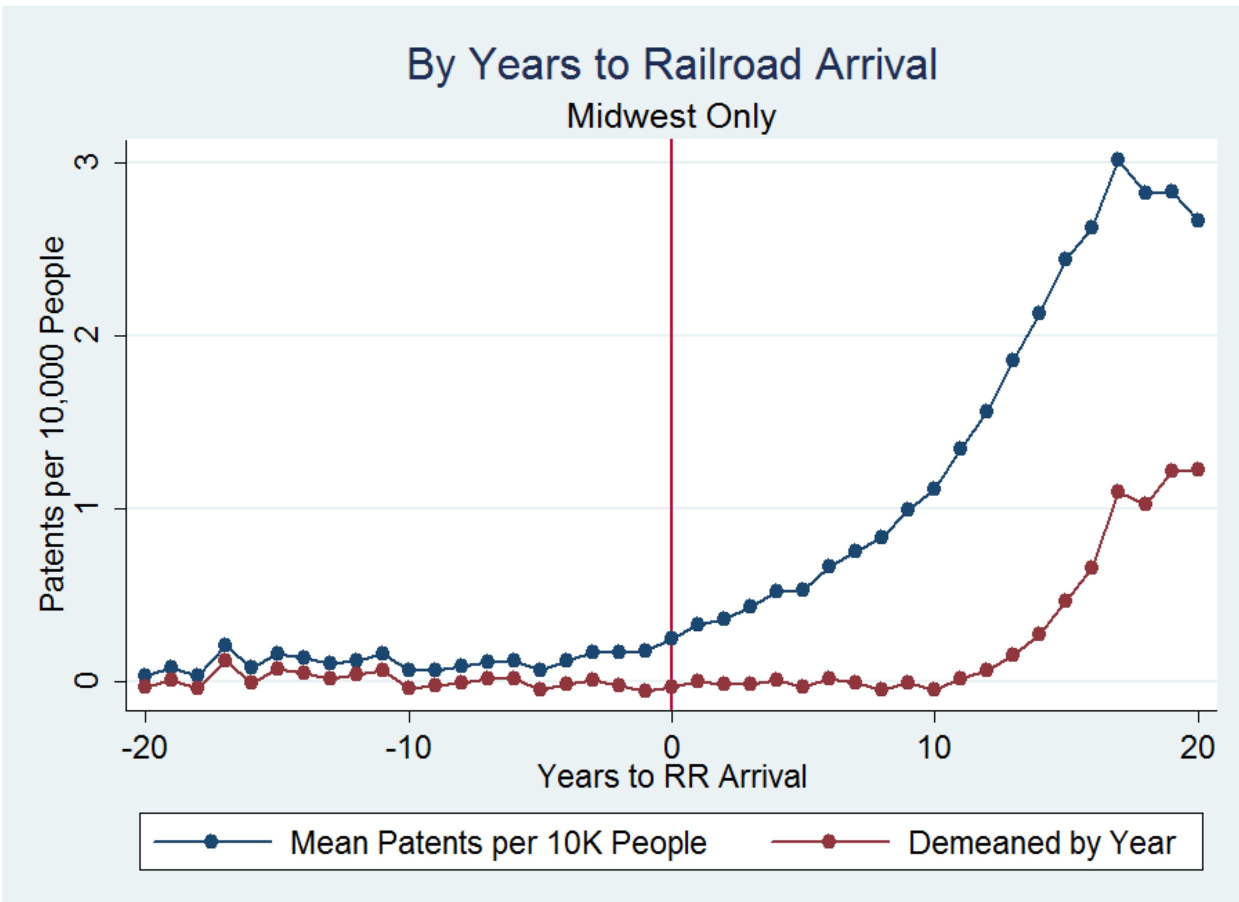


Figure 16: The Mean Patents per 10,000 People by the Years to Canal Arrival, Yearly Population exponentially interpolated between census years.

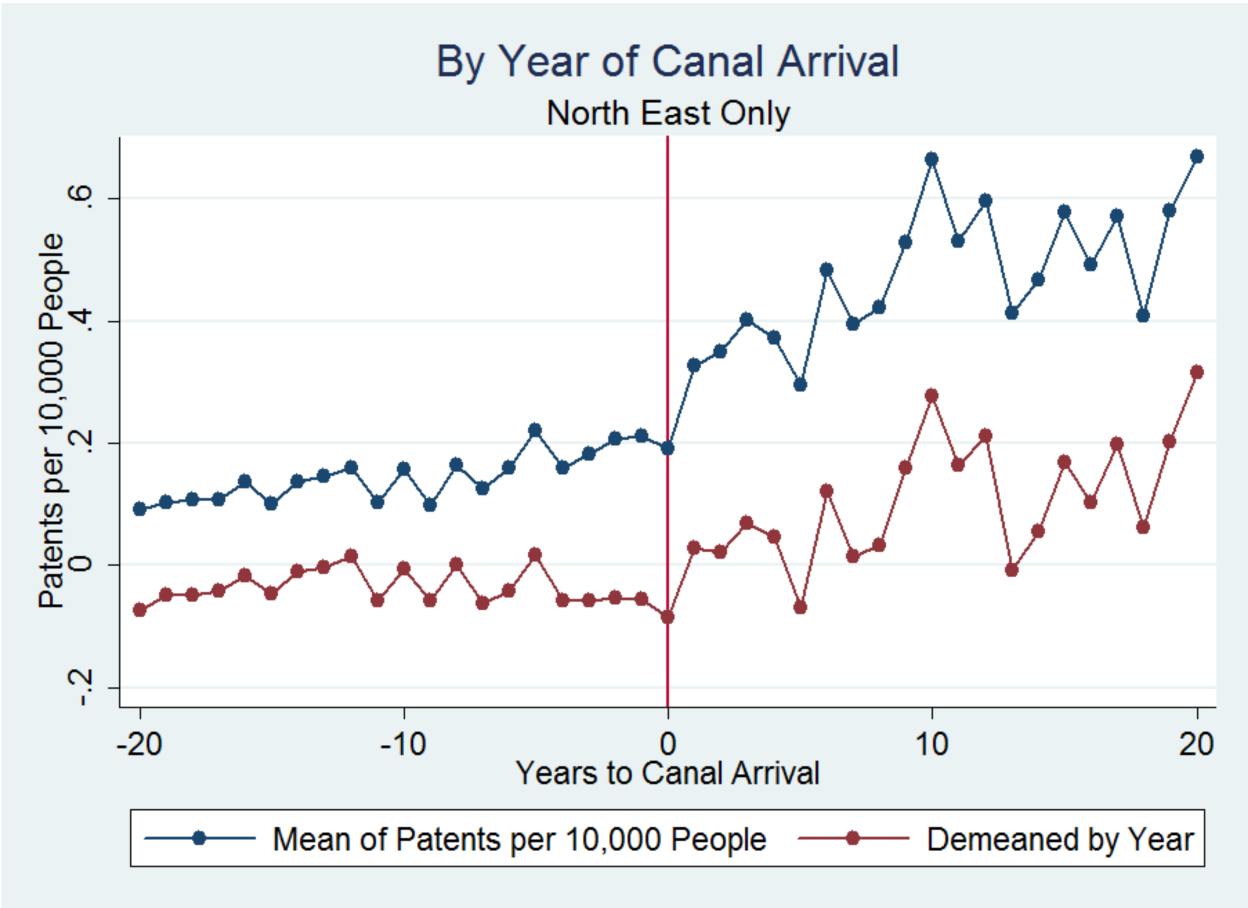


Figure 17: The Average Textual Similarity to the Years Patents in a County in 1840

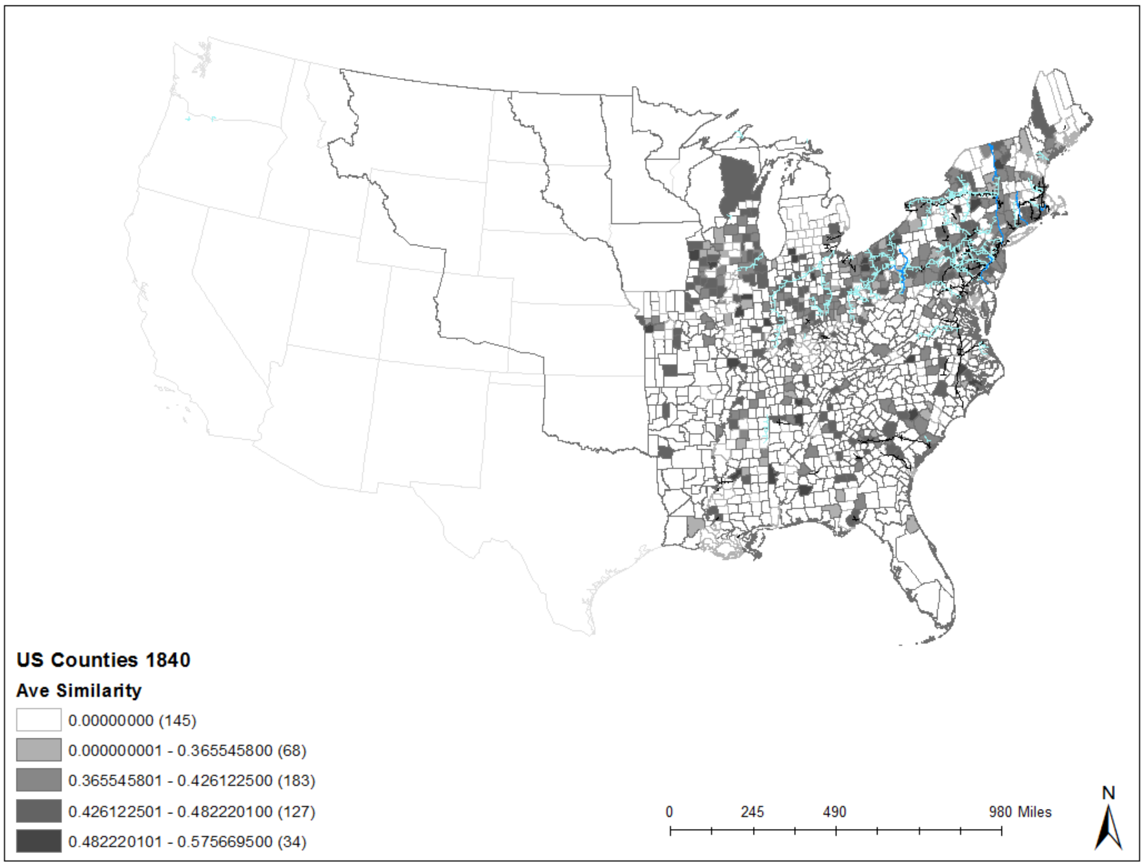


Figure 18: Patent per 1000 People in 1830, Population Catogram
Patent counted in five year increments.

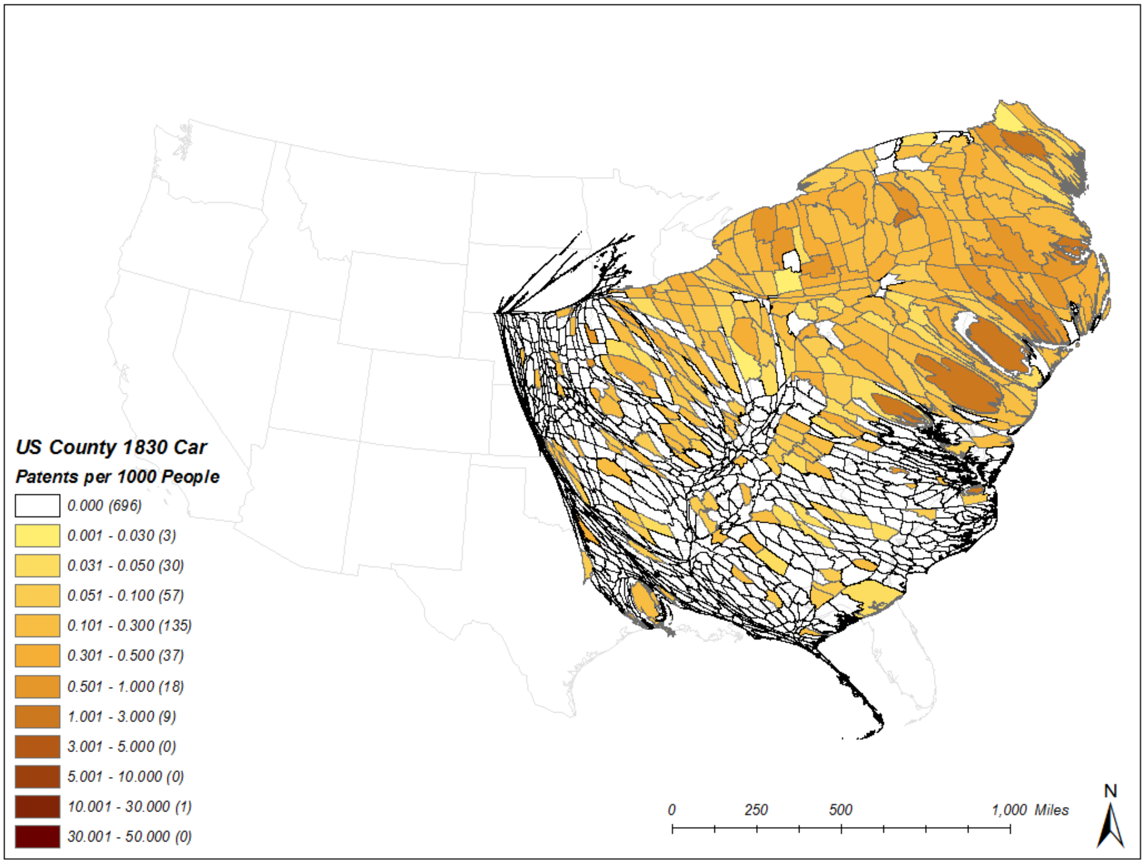


Figure 19: Location of Patents that are the First in there Classification in 1840 by County
Patent counted in five year increments.

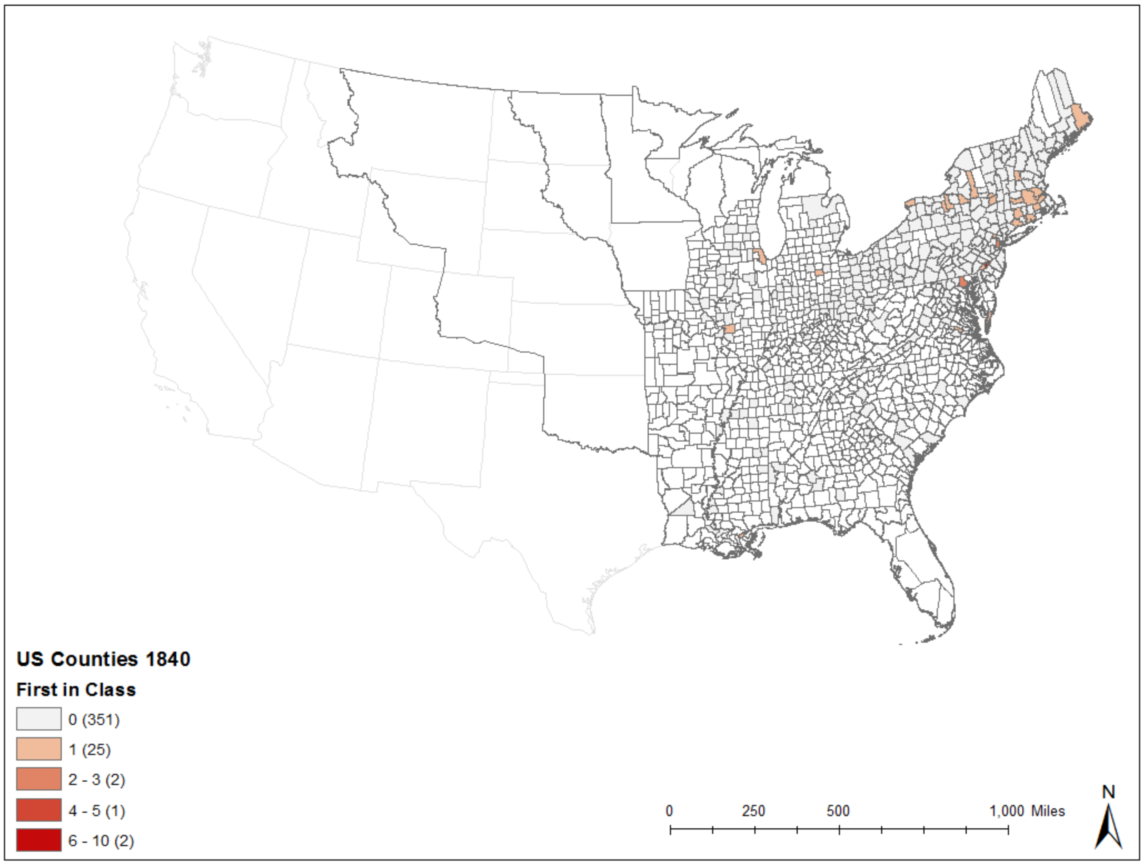


Table 1: Means by Year

	(1) 1790	(2) 1800	(3) 1810	(4) 1820	(5) 1830	(6) 1840	(7) 1850
Number of Patents	0.0187	0.00313	0.232	0.128	0.580	0.640	1.407
Patents per 10,000 People	2.967	0.00248	0.0893	0.0420	0.183	0.173	0.311
Number of Classes						3.067	4.272
Rail Dummy					0.00703	0.132	0.253
Canal Dummy	0	0.000781	0.00391	0.00781	0.0539	0.109	0.129
Total Population	664.5	7,636	7,266	8,688	10,569	13,341	17,773
Urban Pop 2500+	4.842	465.4	515.7	600.5	903.6	1,416	2,752
Urban Pop 25K+	0.178	185.3	232.1	290.1	435.9	737.1	1,618
Employed in Manufacturing				313.7		638.9	737.5
White Illiterate						431.0	717.7
Born Out of State							3,135
Foreign Born							1,718
Acres Improved							87,856
Acres Unimproved							129,761
Farm Value							2.548e+06
Number of Colleges						0.134	0.181

	(1) 1860	(2) 1870	(3) 1880	(4) 1890	(5) 1900
Number of Patents	6.396	18.07	15.88	28.96	25.34
Patents per 10,000 People	1.452	3.051	2.171	3.213	2.487
Number of Classes	6.949	13.59	11.37	15.26	14.20
Rail Dummy	0.627	0.739	0.853	0.914	
Canal Dummy	0.147	0.138	0.0898	0.0875	0
Total Population	23,282	27,499	34,482	41,311	49,240
Urban Pop 2500+	4,759	7,200	10,284	15,411	20,969
Urban Pop 25K+	2,905	4,252	6,478	10,002	14,138
Employed in Manufacturing	978.7	1,524	2,060	3,517	3,884
White Illiterate		1,369			
Born Out of State		4,862	5,414		
Foreign Born	3,022	3,825	4,402	5,880	6,640
Acres Improved	120,967	131,199	168,667	190,978	211,193
Acres Unimproved	159,395	141,655	145,935	143,749	149,413
Farm Value	5.006e+06	6.716e+06	6.781e+06	7.825e+06	6.888e+06

Table 2: Number of Patent and Urban or Rural Population

	(1)	(2)	(3)
VARIABLES	Patents per 10K People	First Differences Number of Patents	Number of Patents
Urban Pop 25K+, 10K	-0.241	3.144**	13.957**
	(0.315)	(0.827)	(2.713)
Urban Pop 2500-25K, 10K	0.643*	0.297	8.414*
	(0.279)	(1.209)	(3.952)
Rural Pop, 10K	0.019+	0.136**	0.092
	(0.012)	(0.043)	(0.146)
County Dummies	Yes	No	Yes
Year Dummies	Yes	Yes	Yes
Counties	1191	1191	1191
Observations	12,831	12,282	12,833
R-squared	0.141	0.216	0.778

Robust standard errors in parentheses. Standard errors clustered by county.
** $p<0.01$, * $p<0.05$, + $p<0.1$

Table 3: Number of Patents vs. the Presence of a Railroad or Canal

VARIABLES	(1) Patents per 10,000 People	(2) First Differences Number of Patents	(3) NE Only Patents per 10,000 People	(4) NE Only First Differences Number of Patents
Rail Dummy	0.200+	6.242**		
	(0.111)	(0.941)		
Waterway Dummy			2.702	0.570*
			(2.250)	(0.286)
Elasticity–Full Sample	0.20	6.242	2.702	0.570
County Dummies	Yes	No	Yes	No
Year Dummies	Yes	Yes	Yes	Yes
Years	1830-1880	1830-1880	1790-1840	1790-1840
Counties	1191	1191	198	198
Observations	7,136	8,337	1,183	990
R-squared	0.486	0.028	0.177	0.075

Robust standard errors in parentheses. Standard errors clustered by county.
** p<0.01, * p<0.05, + p<0.1

Table 4: Number of Patents vs. Population Interacted with Presence of the Railroad

VARIABLES	(1) Patents per 10K People	(2) First Differences Number of Patents	(3) Number of Patents
Rail and Urban Pop 25K+, 10K	0.221**	7.001**	18.815**
	(0.056)	(0.975)	(3.234)
No Rail and Urban Pop 25K+, 10K	0.123	3.054**	9.700
	(0.271)	(0.626)	(9.501)
Rail and Urban Pop 2500-25K, 10K	1.149**	3.499**	13.418**
	(0.187)	(1.263)	(4.373)
No Rail and Urban Pop 2500-25K, 10K	0.303	1.235**	29.449
	(0.495)	(0.392)	(18.657)
Rail and Rural Pop, 10K	-0.005	0.101*	-0.012
	(0.007)	(0.041)	(0.187)
No Rail and Rural Pop, 10K	-0.021**	0.076**	-0.048
	(0.008)	(0.025)	(0.213)
Constant		-0.500*	3.447
		(0.234)	(2.594)
County Dummies	Yes	No	Yes
Year Dummies	Yes	Yes	Yes
Years	1830-1890	1830-1890	1830-1890
Counties	1191	1191	1191
Observations	8,327	8,327	8,327
R-squared	0.581	0.560	0.841

Robust standard errors in parentheses. Standard errors clustered by county.
** $p<0.01$, * $p<0.05$, + $p<0.1$

Table 5: Number of Patent Classes vs. the Presence of a Railroad

VARIABLES	(1) Classes per Patent	(2) First Differences Number of Patent Cllasses
Rail Dummy	0.040**	5.401**
	(0.012)	(0.532)
Elasticity–Full Sample	0.04	
Elasticity–At Means		5.401
County Dummies	Yes	No
Year Dummies	Yes	Yes
Years	1840-1880	1840-1880
Counties	1108	883
Observations	3,921	2,555
R-squared	0.570	0.150

Robust standard errors in parentheses. Standard errors clustered by county.
** $p<0.01$, * $p<0.05$, + $p<0.1$

Table 6: Number of Patents vs. the Presence of a Railroad and Population

VARIABLES	(1) Patents per 10,000 People	(2) Patents per 10,000 People	(3) First Differences Number of Patents	(4) First Differences Number of Patents
Rail Dummy	0.155	0.194+	-6.401**	-0.628
	(0.108)	(0.102)	(1.701)	(0.696)
Total Pop, 10K	0.030**	0.001	0.594**	0.102**
	(0.005)	(0.008)	(0.086)	(0.039)
Urban Pop 2500+, 10K		1.452**		2.432+
		(0.240)		(1.422)
Urban Pop 25K+, 10K		-1.175**		3.524*
		(0.186)		(1.651)
Elasticity–Full Sample	0.155	0.194		
Elasticity–At Means			-6.401	-0.628
County Dummies	Yes	Yes	No	No
Year Dummies	Yes	Yes	Yes	Yes
Counties	1191	1191	1191	1191
Observations	7,136	7,136	8,327	8,327
R-squared	0.518	0.536	0.512	0.559

Robust standard errors in parentheses. Standard errors clustered by county.
** p<0.01, * p<0.05, + p<0.1

Table 7: Number of Patents vs. the Presence of a Railroad, at a Yearly Frequency

VARIABLES	(1) Midwest Only Patents per 10,000 People	(2) Midwest Only First Differences Number of Patents	(3) NE Only Patents per 10,000 People	(4) NE Only First Differences Number of Patents
Rail Dummy	0.299**	0.352**		
	(0.056)	(0.063)		
Canal Dummy			0.469+	0.037+
			(0.271)	(0.020)
Elasticity–Full Sample	0.299		0.469	
Elasticity–At Means		0.352		0.037
County Dummies	Yes	No	Yes	No
Year Dummies	Yes	Yes	Yes	Yes
Years	1830-1880	1830-1880	1790-1840	1790-1840
Counties	387	388	199	201
Observations	15,614	15,520	10,048	10,050
R-squared	0.458	0.069	0.066	0.019

Robust standard errors in parentheses. Standard errors clustered by county.
** $p<0.01$, * $p<0.05$, + $p<0.1$

Table 8: Similarity Scores vs. Presence of a Railroad and Population

VARIABLES	(1) Ave Similarity	(2) Ave Similarity	(3) Ave Similarity
Rail Dummy	0.063**	0.063**	0.058**
	(0.012)	(0.012)	(0.012)
Total Pop, 10K		0.000	0.003**
		(0.000)	(0.001)
Urban Pop 25K+, 10K			-0.035*
			(0.014)
Urban Pop 2500+, 10K			-0.000
			(0.019)
Mean	0.097	0.097	0.097
SD	0.176	0.176	0.176
Mean of Non-zero	0.407	0.407	0.407
SD of Non-zero	0.058	0.058	0.058
Elasticity–Full Sample	0.063	0.063	0.058
County Dummies	Yes	Yes	Yes
Year Dummies	Yes	Yes	Yes
Years	1840-1860	1840-1860	1840-1860
Counties	1191	1191	1191
Observations	3,573	3,572	3,572
R-squared	0.620	0.621	0.626

Robust standard errors in parentheses. Standard errors clustered by county.
** p<0.01, * p<0.05, + p<0.1