Education and Inventive Activity in the United States, 1890-1920.

by

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I. Introduction

The role of technological progress in economic growth has been widely recognized since Adam Smith (1776) discussed the increased labor productivity brought about by new machines in his famous example of the pin factory.[1] He pointed out that innovation can be a major factor in generating "the wealth of nations." Hence, the quest to identify the factors that affect technological progress has attracted the attention of economists. Innovation contributes not only to an increase in productivity, but also to a greater variety of products. This paper focuses on the determinants of innovative activity, especially the influence of education. The central purpose is to determine extent to which education has affected inventive activity, as reflected in patents.

This paper explores the effect of education on regional inventive activity as reflected in patents issued in the United States between 1890 and 1920. This period is sometimes referred to as "the Progressive Era." The government adopted a series of economic policies designed to limit the power of large corporations.[2] These included the Interstate Commerce Act and the Sherman Antitrust Act. In the early twentieth century, the U.S. embraced the first universal and free system of secondary education, which contributed an increase from 10% in 1910 to 50% in 1940 in the proportion graduating from high school (Goldin et al. 2009, p. 143). The transformation in the nation's educational policies at the turn of the century provides a useful opportunity to analyze the relationship between education and

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[1] As he said machines "enable one man to do the work of many" (1776, I. i.5, p. 17). Tony Aspromourgos (2012) has a study on the significance of machines in Smith's work.
[2] See Faulkner (1951).

inventive activity.

In the first part, I review the literature, including Alisher Akhmedjonov's (2010) discussion of innovation and invention, which identifies four measures of innovation. Next, I review the literature that compares the performance of Germany and the U.S. in terms of technological change, and examines the effect of education on their performance. I also discuss three papers that focus on the causal relationship between education and innovation, where the emphasis is on regional differences in innovative activity. Lastly, I review Naomi Lamoreaux and Kenneth Sokoloff's studies (Sokoloff 1988; Lamoreaux and Sokoloff 1999, 2000), which provide abundant evidence for a relation between market demand for technology and inventive activity. Specifically, they analyze the regional clustering of patenting activity in the U.S. using data from the late eighteenth and early twentieth centuries.

The second part of this paper is an empirical analysis of inventive activity in the U.S., using data from 1890 to 1920. The results show a significant and positive relationship between education and innovation, and they also support some of Lamoreaux and Sokoloff's findings. The main results are as follows: tertiary education had a significant effect on state-level innovative activity from 1900 to 1920, while the effect of high school was not significant. During this period the influence of university and technical schools increased. Furthermore, railroad mileage had a consistently strong effect on innovation. These results are consistent with those found previously, but with some features specific to the period 1900 to 1920.

The paper proceeds as follows. In the second section, I review theoretical and empirical studies of the determinants of innovation with a focus on the role of education. Section 3 describes the historical patterns of patenting activity in the U.S., and section 4 provides a geographical analysis of inventive activity in the U.S. Section 5 presents a model of the determinants of patenting and reports the empirical results. Section 6 concludes.

II. Literature Review

A. Definitions and Measures

Simon Kuznets defines "inventive" activity as "technical inventions" that involve "new combinations of existing knowledge" and are potentially useful in economic production (1962, p. 21), while the OECD (1997, p. 18) describes innovation as follows: "A technological product innovation is the implementation/commercialization of a product with improved performance characteristics such as delivering objectively new or improved services to the consumer. A technological process innovation is the implementation/adoption of new or significantly improved production or delivery methods." This definition can be seen to encompass changes in equipment, human resources working methods, and the management of a firm. Hence, innovation has a broader meaning than invention, because it includes new methods of business management in addition to new technological products. Both terms are used in the analysis of technological development, and both carry a connotation emphasizing the economic value of creative activity.

Akhmedjonov (2010) discusses four measures of innovative activity:

research and development spending, patents, bibliometric data[3], and firm surveys of innovation. Akhmedjonov argues that innovation counts from surveys are the best measure, because they directly reflect the output of a firm's innovative activity, and are based on similar collection procedures across countries. In contrast, R&D spending measures only inputs to innovation. Patents are not very useful for international comparison, since patent laws differ across countries. Finally, bibliometric data was not systematically collected until very recently, and is not capable of precisely measuring all types of innovation.

This study focuses on inventive activity in the U.S. between 1890 and 1920, using patents, a measure that only accounts for technical creation. There are several reasons for using patents: first, the other three measures are limited in terms of the historical data available. Second, the examination of U.S. patent applications not only focuses on the originality of an invention, but also judges it by its economic value, or "usefulness." Also indicated by Akhmedjonov (2010, p. 7), all four measures of innovation tend to produce consistent results on most issues once the researcher controls for obvious biases.

B. Case Studies

The purpose of this section is to study the effect of a series changes in the German and the American education policies in the nineteenth century and early twentieth century on their technological performance. In ***Technological Innovation***

[3] Coined by Alan Pritchard in "Statistical Bibliograph or Bibliometrics" (1969), it is defined as "the application of mathematics and statistical methods to books and other media of communication", which are usually in the form of publications and citations or innovation announcements.

and Economic Performance (Steil et al. 2002), nine advanced industrialized countries[4] are studied to compare their performance in technological innovation, and to analyze the factors affecting that performance. Contributors to this edited volume, Robert Gordon, Horst Siebert, and Michael Stolpe, agree that education is a critical factor. An effective education system is shown to be crucial to a country's technological development. Among these countries, Germany and the U.S. are especially representative in terms of the role of education in technological change.

Germany dominated the chemical industry from the 1870s to the 1920s. This success was due mainly to the earlier establishment of engineering schools, or polytechniques. Although it was not the first country to open an engineering school, Germany experienced rapid proliferation of polytechniques during the 1820s and '30s. With the belief that "a school of applied science is an effective means of countering the British lead in industrial affairs (Edelstein 2009, p. 188)," Germany was the first to copy the French École Polytechnique education model. About thirty years later Germany converted to the *technische Hochschulen*, with curricula shifting from civil, military, and mining engineering towards more general applied science. An abundant supply of qualified engineers supported Germany's leadership in high-tech industries up until the early twentieth century.[5]

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[4] The chapter "Country Studies" includes the United States, Japan, Germany, France, the United Kingdom, and four Nordic countries, which are Denmark, Finland, Norway, and Sweden.

[5] Germany also became a leader in the production of automobiles, machinery, electrical engineering, and pharmaceuticals. Horst Siebert and Michael Stolpe studied policies, capital markets, and labor markets that supported its success in these industries in the chapter "Germany" in Steil's (2002) book. Horst Siebert and Michael Stolpe (2002) also point out the problem in the Germany university system, which is lack of competition. State governments controlled university budgets and the future direction of research and teaching. This led to the nation's main limitation in continued development in technological innovation.

While Germany was perhaps the first country to recognize the role of education in technological progress, the United States implemented policies achieving universal secondary education between 1910 and 1940, and had the highest participation rate in college after World War II. The U.S. education system was a critical factor in the nation's high standing in technological innovation. Robert J. Gordon (2002) studies two features of the U.S. education system, the first being its "mixed system of government and privately-funded research universities (p. 72)." U.S. government agencies provided funding based on a criterion of peer review, which stimulated competition among universities. Moreover, private funding from the industrial sector transformed university research, making it more practical and applicable. The other main feature studied by Gordon is America's early expansion of the graduate school of business, starting by Harvard Business School building world's first master program of business administration in 1908. The expansion helped prepare finance and general management strategies for the rise of the venture capital industry and Internet companies in the 1990s. Thus, adequate funding and healthy competition among U.S. universities allowed for a steady supply of high-quality creative workers.

In the late nineteenth century and early twentieth century the U.S. established a large number of new engineering programs, subsequent to its introduction of the Morrill Land Grant Act (Edelstein 2009, p. 189). The Act granted each state 20,000 acres of federal public lands and provided funds for the founding of state colleges. Ninety-two engineering schools described as, "of acceptable quality", were opened by 1889, and by 1931 this number had risen to 144.[6] From1910 to 1940, the stock of engineering graduates in New York State grew by 6.5% as compared to 2.9% for Germany, although at the end of the period the proportion of engineers in the labour force was similar (0.05, see Edelstein 2009, p.212). Policy changes enhancing the effectiveness of the American university system, especially the expansion of engineering education between 1880 and 1940, played a major role in supporting technological change in the U.S.

C. Education and Innovation: Three Studies.

This section discusses three papers that analyze the effect of education on technological innovation. Otto Toivanen and Lotta Vaananen (2011) utilize data on Finnish inventors taken from the U.S. Patent and Trademark Office (USPTO) in the 1960s in order to study the relationship between education and an individual's propensity to patent. Akhmedjonov (2010) builds a model to analyze the impact of firm, industry and national characteristics on innovation, with an emphasis on employee education levels. Wei Chi and Xiaoye Qian (2010) study the role of education on Chinese provincial inventive activity. All three studies find that education has a significant, positive, effect on innovative activity.

Toivanen and Vaananen match U.S. patent data with the Finnish Linked Employer-Employee data Series (FLEED) to establish the education level and labor market status of Finnish inventors in the period 1988-1996. They consider a 5% random sample from the FLEED, assigning a weight of 20 for each of the control

[6] See Wellington, 1892-93, and U.S. Department of Interior. Office of Education (1931).

observations. In comparison to the random sample population, the majority of the inventors were male (92.1%) and were highly educated; specifically, 33% of the inventors had masters or doctorate degrees, while only 2.2% of the workers from the random sample held these degrees. An ordinary least squares regression (OLS), with 46 dummies for the level and field of education, shows that only an engineering education has a significant and positive coefficient with a magnitude that increases with education level (bachelor 0.026, masters 0.093, doctorate 0.291).

The instrumental variable (IV) estimates are a particularly important aspect of their empirical work, since the OLS estimates may have a selection bias. The error term in the OLS estimates may correlate with the schooling and patent measures. For example, individuals with greater ability at invention may have a lower propensity to obtain formal education from a technical university or vice versa. Hence, the authors use distance to the nearest technical university as an instrument, under the hypothesis that individuals select their educational institution in part according to cost. They obtained statistics regarding student intake in engineering programs from 1950 to 1981, and "inter-municipality driving distances" to the universities for each inventor.[7] The instrument would affect individual choice in education by increasing the cost of obtaining a university engineering degree. In the first stage, the results show that the distance inversely correlates with an individual's educational choice. The first column in Table 1 shows the results without the control variable, father's education, and second column shows the results with the control variable. The coefficients on the distance, in 100km, are -

[7] The data were from the Finnish Educational Establishment Statistics and the Finnish Road Administration.

0.0026 without father's education and -0.0016 with father's education, meaning that if distance decreases by 100km, there is about a 10% increase in the probability of choosing engineering education compared to the average probability of 0.022.[8]

Table 1
IV Estimates, First Stage.

	No Family Background	+Father's Education
University eng.	-0.262***	-0.161***
Engineering	-0.452***	-0.461***
University	-1.08***	-0.378**
nobs	60, 234	33, 645

Notes and Source: From Table 5 in Toivanen and Vaananen's(2011) paper. *** and ** indicate significance at 1% and 5% level respectively. Coefficients have been multiplied by a factor of 100. The instrument is distance to nearest technical university when the dependent variable is either the indicator for a university engineering degree or an engineering degree, and distance to nearest university when the dependent variable is a university degree. In all specifications, the control variables include gender, nationality, native tongue, and cohort dummies. Father's education is included as 45 dummies representing educational field-level combinations.

Finnish education policies during the 1960s and 1970s, which resulted in the geographic widening of university engineering offerings, clearly represented a move to shorten distances to engineering schools. The newly offered engineering programs at the University of Oulu in 1959, Tampere in 1965, and Lappeenranta in 1969 significantly decreased the distance to the nearest technical university for Finnish residents. This contributed to a surge in the number of engineering students.

The linear estimating equation they use in the second stage is as follows:

$Y_i = \alpha + \beta X_i + \theta ENG_i + \varepsilon$,

where Y_i is a 0/1 indicator of a patent being issued to an inventor; X_i is a vector of control variables including gender, cohort dummies, and native tongue; ENG_i is a

[8] The average of the coefficients, 0.0021 is 10% of the probability of choosing an engineering degree.

dummy variable in which 1 is for an individual with an engineering degree by the year 1988. The estimated coefficients are 2 to 2.5 times the values of those in the OLS estimates (see Table 2). The instrument is able to capture those individuals on the margin whose choice of education is affected by the cost of obtaining an engineering degree, which in this model directly correlates with proximity to a university.

Table 2
IV Estimates, Second Stage.

Dependent Variable: Patent Count		
	NoFamily Background	+Father's Education
University Eng.	0.234*** (0.110***)	0.302** (0.118***)
Engineering	0.136*** (0.059***)	0.106***(0.063***)
University	0.067*** (0.032***)	0.202** (0.035***)
Nobs	60234	33645

Notes: The Table shows the estimated coefficient, and part of the results from Table 4 (Toivanen and Vaananen, 2011). *** and ** indicate significance at 1% and 5% level respectively. The corresponding OLS results are in the parentheses. Coefficients have been multiplied by a factor of 100. In all specifications, the control variables include gender, nationality, native tongue, and cohort dummies. Father's education is included as 45 dummies representing educational field-level combinations.

As shown in Table 2, the results confirm the significant effect of education on an individual's propensity to obtain a patent, with the factor most strongly linked to this being the propensity to complete an engineering degree. Toivanen and Vaananen also conduct a counterfactual analysis, which suggests that without the establishment of the three new engineering programs in 1959, 1965, 1969, there would have been a roughly 20% decrease in individual inventive activity.

Akhmedjonov (2010) studies the impact of higher education and workforce training on innovation at the firm level. He examines the determinants of innovation in transition countries of Eastern Europe and the former Soviet Union. In these countries, education levels are as high or even higher than in many high-income countries, but gross domestic product (GDP) per capita is on par with middle-income countries.

In Akhmedjonov's model, firms are risk neutral, profit-maximizers, and innovation leads to reduced costs of production and thus increased profits. The economy is defined as a continuum of differentiated goods, where firms compete through improvements in product quality through innovation. Suppose a firm produces *n* goods, and profit for each good is π, $0 < \pi < 1$. If the firm succeeds in an innovation the firm will increase its market to $n + 1$ goods at a profit of $\pi + x$ per unit, but if a competitor succeeds at innovating over another good, its market will remain at n. Even if the firm's market does not increase, innovation can increase profits by reducing costs on all goods.

The model can explain how the characteristics of a firm and the sector affect its decision-making process in regards to innovation. A central hypothesis proposed by Akhmedjonov is that human capital development is complementary to technological change.[9] More specifically, he assumes that education and on-the-job training lower the cost of innovation, and thus has a positive effect on a firm's innovative activity. The more competition in the sector, however, the fewer firms tend to innovate, because competition increases the chance of another firm taking over the market for a product. The third factor affecting the decision to innovate is

[9] For two reasons: 1. Scientists and engineers are the main carriers of innovation, because they can better capture information for innovation from markets and production processes (Jacobson et al. 1996). 2. Employees with higher-level education and technical training are more receptive to innovation (Friesen and Miller 1984).

size; as the size of a firm increases, so will the number of goods it produces (n), which means innovation will reduce the cost of producing more goods.

Akhmedjonov constructs an empirical model based on a data set from the Business Environment and Enterprise Performance Surveys (BEEPS) database. The dependent variable is a 0/1 (No/Yes) indicator of the following survey question: "Developed a major new product line/service, Upgraded an existing product line/service, Obtained a new product licensing agreement and Obtained a new quality accreditation." (Akhmedjonov 2010, p. 15) The following table shows some significant factors from the results of the regression equation:

$$\text{Firm Innovation} = \alpha + \beta_1 \text{ Firm Size Dummies} + \beta_2 \text{ Industry Dummies} + \beta_3 \text{ Country-Level Variables} + \beta_4 X + \varepsilon,$$

where X is a vector of variables based on human capital development, financing, and competitive environment. Country-level variables include the unemployment rate, foreign direct investment, and population. Results are shown in Table 3.

Table 3
Determinants of Firm Innovation

Dependent Variables:	Developed a new product line/service		Upgraded existing product line/service	
	Estimate	Marginal Effect	Estimate	Marginal Effect
Some university education or higher	0.918*** (0.136)	0.21	0.520*** (0.191)	0.13
Skilled worker training	0.674*** (0.149)	0.157	0.651*** (0.177)	0.16
Fraction of exports in revenues	0.096 (0.264)	0.022	0.433** (0.268)	0.108
Access to external financing	0.368*** (0.086)	0.085	0.349*** (0.111)	0.087
Small firm	-0.359*** (0.122)	-0.084	-0.511*** (0.125)	-0.126
Foreign direct investment	-1.367 (0.075)	-0.314	-1.141 (2.718)	-0.285
GDP per capita	-0.218 (0.141)	-0.05	-0.068 (0.180)	-0.017
Population	0.064 (0.075)	0.015	-0.043 (0.102)	0.011
Constant	-0.810 (1.396)		0.300 (1.629)	
Observations	2797		2793	
Pscudo R-squared	0.0978		0.0935	

Note and Source: From Table 13 (Akhmedjonov 2010). ***, **, * represent significant level at 1%, 5%, and 10% respectively. Standard errors are in parentheses. Formal education is measured by the fraction of workers with some university education or higher. The skilled worker training is a dummy variable showing “if the firm offered formal training to its skilled workers in the last 12 months.” (Akhmedjonov 2010, p. 21) Access to external financing is also a dummy variable. Small firm is defined to have 1-49 employees, while medium firm has 50-249 employees, and large firm over 250. The foreign direct investment is as a percentage of GDP. GDP per capita, measured in 2005 internal dollars, is in logs.

Akhmedjonov uses the data from 1400 firms in 27 transition countries in his study of the factors that influence innovation at the firm level.[10] The results suggest that formal post-secondary education and employee training are both significant factors in increasing a firm's level of innovation. The coefficient on university education indicates that evaluated at the mean of the data, an increase in the fraction of workers with formal post-secondary education is associated with an increase in the probability of developing a new product line by 21%. Similarly, a program offering skilled worker training will increase the probability by 15.7%. Besides these factors, the results show that export intensity, access to external financing and firm size also have a positive and statistically significant relationship with innovation. The results depict a negative relationship between GDP per capita and innovation, which indicates the presence of a convergence effect, with lower income countries experiencing a higher rate of innovation.[11]

The results reveal that the percentage of a firm's employees with formal post-secondary education, and the amount of training it provides, both have a significant, positive, effect on its innovative activities. Akhmedjonov argues that the causality is in both directions, because firms with new technologies are able to attract highly educated employees and are obliged to train their employees to equip them with the appropriate industry knowledge; still, employees with higher levels of education and

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[10] These are Albania, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Estonia, Georgia, Hungary, Kazakhstan, Kyrgyz Republic, Latvia, Lithuania, Macedonia, Moldova, Poland, Romania, Russia, Serbia, Slovak Republic, Slovenia, Tajikistan, Turkey, Ukraine, and Uzbekistan.

[11] Akhmedjonov also includes the effect of the sector. Although the results show that manufacturing firms are the most likely to develop a new production line, there may be some selection bias, because the majority of interviewees are in manufacturing sector.

training impart to firms a greater capacity to absorb new knowledge and technology.

Chi and Qian (2010) study the spatial correlation of provincial innovative activities in China, which suggest the presence of two clusters in Beijing and Shanghai and their surrounding areas. More importantly, the Moran I statistics, which are estimates of spatial autocorrelation, provide evidence of the increased spatial autocorrelation of innovative activities from 0.082 in 1997 to 0.218 in 2006. The authors then develop empirical models to analyze the effects of educational attainment on provincial innovative activity. Chi and Qian construct a data set that includes provincial GDP, population, size of the labor force, educational attainment of workers, fixed capital investment (FCI), and patent applications from *China Statistical Yearbooks* and *China Labor Statistical Yearbooks* over the years 1997-2006, as well as workers' educational levels from 1996. Educational attainment is measured by the percentage of workers with tertiary, secondary, or primary education and average number of years of schooling in these categories. In terms of the measure of innovation, Chi and Qian use patent applications in order to avoid the lag caused by the application process, which usually takes two to four years. Their OLS estimating equation is:

$\text{Ln patent} = \beta_1 + \beta_2 \text{ HC} + \beta_3 \ln \text{FCI} + \beta_4 \ln \text{employee} + \varepsilon$,

where patent is the number of patent applications per 10,000 people; HC (human capital) is a vector of the variables including high school, secondary school, and primary school, and average years of schooling. FCI is fixed capital investment, and employee is the labor force. The authors then estimated a spatial error model (SEM) and a spatial autoregressive model (SAR), which are defined as follows:

SEM: $\ln \text{patent} = \beta_1 + \beta_2 \text{HC} + \beta_3 \ln \text{FCI} + \beta_4 \ln \text{employee} + \varepsilon$

with $\varepsilon = \lambda W \varepsilon + \mu$ and $\mu \sim N(0, \sigma^2)$,

SAR: $\ln \text{patent} = \rho W \ln \text{patent} + \beta_1 + \beta_2 \text{HC} + \beta_3 \ln \text{FCI} + \beta_4 \ln \text{employee} + \varepsilon$

with $\varepsilon \sim N(0, \sigma^2)$,

where W is the n × n spatial weight matrix. λ is the parameter for the spatial error term; and ρ is the degree of spatial dependence between observations.

Table 4

The impact of education on regional innovation activity, 1997–2006

	OLS	SEM	SAR
1997			
high	0.21***	0.207***	0.201***
secondary	0.039***	0.037***	0.04***
primary	-0.036***	-0.035***	-0.036***
2001			
high	0.134***	0.115***	0.131***
secondary	0.031***	0.032***	0.034***
primary	-0.029***	-0.03***	-0.032***
2003			
high	0.13***	0.134***	0.123***
secondary	0.024***	0.044***	0.039***
primary	-0.026***	-0.038***	-0.036***
2006			
high	0.088***	0.088***	0.083***
secondary	0.008	0.008	0.001
primary	-0.023***	-0.023	-0.19*

Note and Source: The table shows part of the results from Table 2 (Chi and Qian 2010). The dependent variable is the logarithm of the number of patent applications per 10,000 people. ***, **, * represent significant level at 1%, 5%, and 10% respectively. Standard errors are in parentheses.

These results indicate that workers' formal education has a significant effect on innovation, and also shows that the higher the education level, the greater the effect. For example, the OLS results in 1997 show that a percentage point increase in the fraction of employees with tertiary education imply an increase in patent applications of 21%, while one percentage point increase in secondary education corresponds to an increase in patent applications of only 3.9%. The effect of education appears to be declining with time. The coefficient of higher-level education decreases from 0.21 in 1991 to 0.088 in 2006. The results are robust across the different research approaches. Chi and Qian conclude that Chinese employees' education level has a strong relationship with regional innovative activity, especially in regard to tertiary education. However, the study shows that the effect of education declined during the 10 years from 1997 to 2006. They suggest that there may be an overall decline in the marginal benefit of education in stimulating innovation.

These three papers use different models and different measures of innovation and education, but lead to similar results. Education and innovation are shown to be positively correlated, with post-secondary education displaying the most significant benefits in terms of increasing innovative activity.

D. The Geographic Spread of Invention in the United States

At least three reasons have been put forward to explain the geographic concentration of invention. First, technological inventions are closely related to production processes. This means that people involved in an industry are likely to have a higher propensity to invent than outsiders, and this leads to a correspondence between the geographic distribution of inventive activity and the labour force. A second explanation is related to the theory of "learning by doing". Kenneth Arrow (1962) and Armen Alchian (1963) argue that technological knowledge is a byproduct of production, and is related to a given firm's position on the "learning curve." The theory suggests that invention will concentrate in the areas "where capacity is expanding and producers are shifting down the steeper segments of their learning curves." (Lamoreaux and Sokoloff 2000, p. 701) Third, there is an explanation first proposed by Kenneth Sokoloff (1988) that invention is associated with proximity to the market. According to this theory, areas close to an extensive market may be where inventors cluster in order to realize greater returns. Naomi Lamoreaux and Kenneth Sokoloff have several research papers on this topic, studying the relationship between patenting and proximity to navigable waterways (Sokoloff 1988), patent records and extensive trade in the rights to technological knowledge (Lamoreaux and Sokoloff 1999), and inventive activity in the glass industry from the late nineteenth to the early twentieth century (Lamoreaux and Sokoloff 2000). They conclude that inventive activity has a strong association with market demand, but less of a close relationship with clusters in production.

Lamoreaux and Sokoloff (2000) analyze inventive activity in the U.S. glass industry over the period 1870 to 1925. They use patent data finding that the variation of new technology in the glass industry did not increase where production expanded most rapidly. Results suggest that inventors tended to assemble in areas where there was enough institutional support to market their inventions, even if the distance of those areas from production centres precluded inventors from acquiring production experience.

Lamoreaux and Sokoloff (2000) argue that inventors clustered where the market for technology trade was more fully developed. Using a probit analysis based on “whether or not a glass patent was assigned”, they find that inventions were more likely to be assigned in southern New England, Ohio, and other Mid-West states. The results indicate that the probability of assignment was associated with the number of patents previously issued, and with the concentration of patentees in a given area.[12]

Sokoloff (1988) obtains similar results for the early nineteenth century (see Table 5). By analyzing the location of patenting activity in the Northeast from 1805 to 1836, he finds higher patenting rates in metropolitan centers and in areas close to a navigable waterway. This pattern is supported by cross-sectional regressions of patents per capita using county characteristics. The coefficient on Metropolitan shows that, in the period 1805 to 1811, being located in a metropolitan area increased annual patents per million residents by 9 ($e^{2.2}$) as compared to non-urban area (control). However, the effect declined overtime, from 2.205 to 1.183. The coefficients of the transportation dummy reveal a significant, positive, relationship between inventive activity and lower-cost access to output markets. Sokoloff concludes that there is a direct association between market demand and inventive activity.

[12] See Table 7 in Lamoreaux and Sokoloff (2000).

Table 5.

The Effects of County Characteristics on Patenting: 1805-1811, 1823--1829, and 1830-1836.

Dependent Variable: Log (Annual Patents Per Million Residents)			
	1805-1811	1823-1829	1830-1836
$\text{Log}(\frac{\text{Manufacturing Labor Force}}{\text{Agricultural Labor Force}})$	0.173 (1.21)	0.093 (0.79)	0.18 (1.58)
Urban	-0.252 (-0.74)	-0.198 (-0.74)	-0.096 (-0.38)
Metropolitan	2.205 (3.51)	1.831 (3.65)	1.183 (2.49)
Located on Navigable River or Canal	0.725 (2.26)	0.573 (2.18)	0.873 (3.13)

Note and Source: This table reports some of the results from Sokoloff's (1988) cross-sectional regressions. The coefficients are reported with t-statistics in parentheses. The observations are weighted by the populations estimated for the midpoints of the periods. Urban counties contained a city of at least 10,000 residents or were adjacent to a metropolitan county in 1840. Metropolitan counties contained a city of 50,000 or greater.

A similar perspective is provided by Lamoreaux and Sokoloff (1999) in their analysis of patent assignments. They study the regional distribution of patents and patent attorneys, and include statistics on the careers of patentees. Data from 1883 shows that patent attorneys clustered in New England and the Middle Atlantic, where patenting rates were much higher than elsewhere. They then regress patents per patentee on regional and sectoral dummies (see Table 6), and also consider whether the patentee exploited the patents themselves or sold them to companies. The results indicate that patentees who assigned their patents tended to receive more patents. A disproportionate number of patentees resided in New England and the Middle Atlantic, where there was a more developed market for technology. Patents per patentee tended to be higher in the energy and manufacturing sectors.

The patentee statistics also reveal that those who assigned their patents tended to have longer careers. Lamoreaux and Sokoloff conclude that there is "a self-reinforcing process" (1999, p. 6). Without intermediaries, such as managers and patent attorneys, a patentee faces a very high cost of marketing his patents, which then reduces his productivity and specialization in inventive activity. High patenting rates in an area tended to attract more specialized support, which helped reduce these costs.

Table 6.

Determinants of Patenting Rates per Patentee, 1870-1911.

	Dependent Variable: Log (Patents Awarded to the Patentee)		
	1870-71	1890-91	1910-11
Region of Patentee:			
New England	0.114 (0.05)	0.165 (0.049)	0.180 (0.04)
Mid Atlantic	0.116 (0.04)	0.133 (0.04)	0.117 (0.03)
West North Central	-0.079 (0.08)	0.011 (0.05)	-0.039 (0.04)
South	0.027 (0.06)	0.037 (0.05)	0.029 (0.04)
West	-0.138 (0.11)	-0.175 (0.06)	-0.089 (0.04)
Sector:			
Energy	0.086 (0.05)	0.184 (0.05)	0.160 (0.05)
Manufacturing	0.089 (0.04)	0.017 (0.05)	0.109 (0.04)
Transportation	0.019 (0.06)	0.147 (0.05)	0.144 (0.05)
Construction	-0.022 (0.06)	0.018 (0.06)	0.104 (0.06)
Patent Assigned:			
Assigned to Companies	0.784 (0.09)	0.304 (0.06)	0.293 (0.05)
Assigned out of State	0.608 (0.10)	0.161 (0.10)	0.015 (0.15)

Note and Source: This table reports some of the results from Lamoreaux and Sokoloff's regressions (1999, Table 7). The standard errors are in parentheses. The intercept stands for an unassigned agricultural processing patent from a rural county in the East North Central region.

III. The Historical Patterns of Invention in the United States

On April 10, 1790, one hundred and fifty years after the first "patent" was issued in the State of Massachusetts for a new method of making salt (Cortada, 1998), the United States enacted the first federal Patent Act. The U.S. patent system was created "to promote the progress of science and useful arts by securing to authors and inventors the exclusive right to their respective writings and discoveries" (United States Constitution, Article I, §8). The Patent Act of 1790 provided protection for fourteen years. It did not allow foreigners to apply for patents in the U.S., and inventors could not apply for an extension. The Patent Act of 1793 defined the characteristics of inventions eligible to be patent,[13] and removed the examination process; but it led to extensive litigation mainly related to originality and lack of technical detail.[14] The number of patents issued increased from 3 in 1790 to 702 in 1836 (see Figure 1).

In 1836 the Patent Act was changed again. The Act of 1836 restored the examination procedure in which a technical expert was required to check the applications for originality and practicality. An official Patent Office was founded, separated from the Secretary of State, which improved the efficiency of the application process. Moreover, the inventors were required to provide information about their inventions that was made publically available. This allowed anyone to

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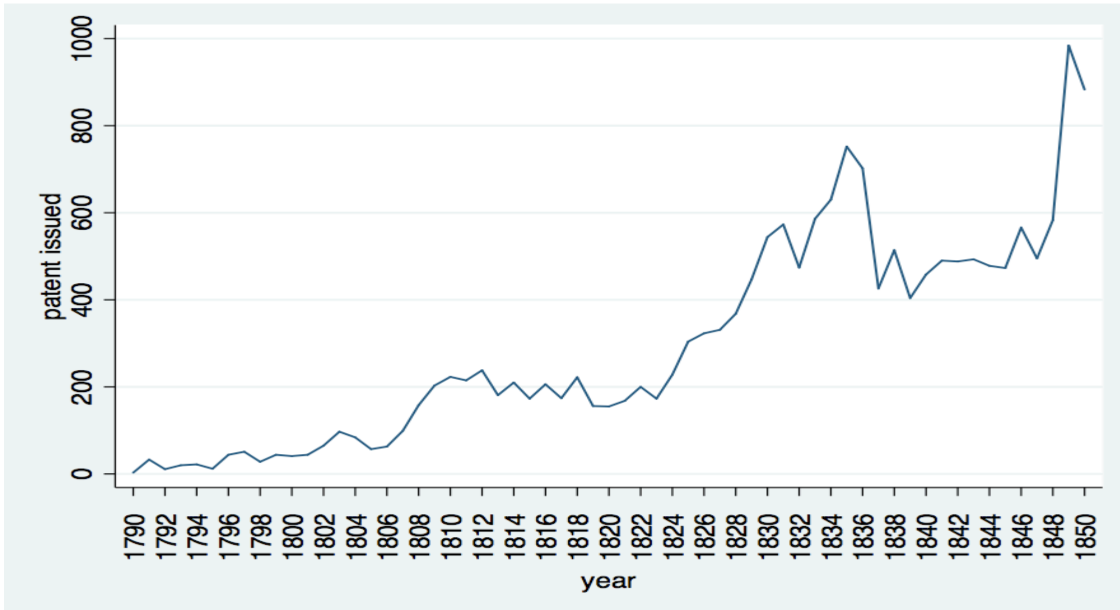
[13] "Any new and useful art, machine, manufacture or composition of matter and any new and useful improvement on any art, machine, manufacture or composition of matter." (Patent Act of 1793, Ch. 11, 1 Stat. 318-323 February 21, 1793)

[14] It was a system of registration. Inventors simply registered their patents, and there was no inspection of their originality or applications. (Sokoloff 1988)

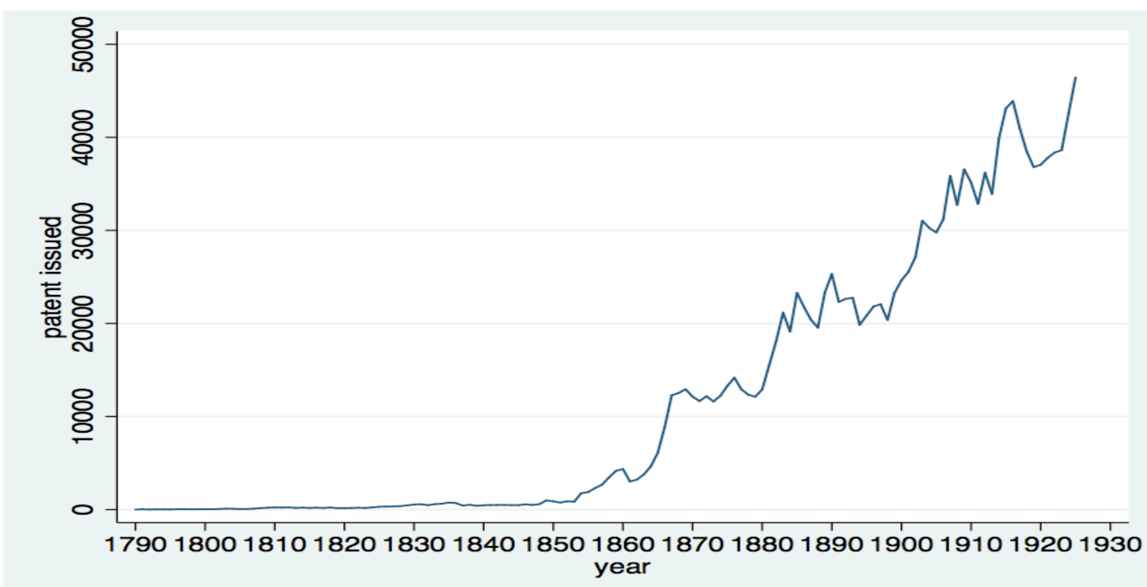
check the information when deciding whether or not to purchase or rent the property right. The Act also allowed for an extension of seven years, and gave foreigners permission to apply for patents in the U.S. The Patent Act of 1836 improved the U.S. patent system, while its tightening up of the examination procedure led to an increase in the rejection of applications from 20% to over 50%. This caused an initial sharp decline in the number of patents issued (See Figure 1). After 1848, the number of patents issued recovered rapidly. As Figure 2 shows, the disruptions of the American Civil War, the Panic of 1893, and World War I, caused temporary declines in patenting.

Figure 1



Note and Source: The data is obtained from the USPTO. Since there was a significant surge during 1850-1920, the scale cannot offer a clear display of the changes in early years. Hence I separate this part from Figure 2.

Figure 2



Note and Source: see Figure 1.

IV. Geographical Analysis of Inventive Activity

The geographical distribution of inventive activity in the U.S. was very concentrated. From 1891 to 1921, the top five states accounted for more than 50% of the patents issued, while the bottom states issued fewer than 1% (see Table 7). New York, Pennsylvania, Illinois, and Ohio were among the top five throughout the period, but their share of total patents declined, while the share of the bottom five states increased. Thus inventive activity at the state-level was converging. Sokoloff (1988) argues that inventive activity was closely related to market demand, and thus to market proximity. His research indicates that areas around navigable rivers or canals were highly active in invention during the period, 1790-1846. Therefore, as the great railway construction boom beginning in the 1840s offered more low-cost transportation to major markets, the geographical clustering of inventive activity was reduced.

Table 7.

Patenting by State, 1891-1921.

1891/ Top	Number	Share (%)	1891/ Bottom	Number	Share (%)
New York	3,907	18.41	Wyoming	3	0.01
Pennsylvania	2,197	10.35	Oklahoma	6	0.03
Massachusetts	2,122	10	Arizona	9	0.04
Illinois	1,968	9.28	Nevada	10	0.05
Ohio	1,513	7.13	Idaho	14	0.07
Total		55.18			0.2
1901					
New York	4,098	17.19	Nevada	7	0.03
Pennsylvania	2,837	11.9	Wyoming	14	0.06
Illinois	2,430	10.19	Arizona	19	0.08
Massachusetts	1,905	7.99	New Mexico	23	0.1
Ohio	1,720	7.22	Idaho	29	0.12
Total		54.5			0.39
1911					
New York	4,777	16.07	Wyoming	26	0.09
Illinois	3,172	10.67	Nevada	39	0.13
Pennsylvania	2,919	9.82	Arizona	41	0.14
Ohio	2,233	7.51	New Mexico	50	0.17
Massachusetts	1,842	6.2	Delaware	56	0.19
Total		50.26			0.71
1921					
New York	6,450	17.46	Nevada	33	0.09
Illinois	3,893	10.54	New Mexico	40	0.11
Pennsylvania	3,223	8.72	Mississippi	57	0.15
Ohio	2,906	7.87	Arizona	61	0.17
California	2,363	6.4	Vermont	62	0.17
Total		50.98			0.68

Note and Source: The data collected from the United States Annual Report of the Commissioner of Patents, 1790-1947. (http://catalog.hathitrust.org/Record/002137544?type%5B%5D=all&lookfor%5B%5D=Report%20of%20the%20Commissioner%20of%20Education%20for%201890%20united%20states&ft=) It includes the patents and designs issued to citizens.

Table 8 reports patenting rates expressed as population per patent issued. It can be seen that the rankings are quite different. Besides Massachusetts, the other four previously highest-ranked states no longer appear in the top five. Connecticut has the lowest ratio of population to patents issued during the period from 1891 to 1921. At the beginning of this period there was approximately one inventor for every 1,000 people in Connecticut, which had been consistently near the top of the list, but it is clear that the state experienced a convergence effect over the period. The number increased from 1018 citizens per inventor in 1891 to 1354 in 1921, a significant decline. This trend was exhibited in almost all the top five states, while the bottom states experienced a slight decrease in the ratio over the thirty-year period. It also should be noted that the bottom states were from the South.

Figure 3 shows patents granted per million residents by state from 1891 to 1921. In 1891 states in the Middle Atlantic and East North Central regions had the highest rates. They accounted for 50% of the patents issued. Connecticut, Massachusetts, and New York had especially high rates of patenting. The only three states that performed well outside of these regions were Montana, Colorado, and California. There was, however, a significant increase in patenting activity in the West between 1911 and 1921. In the west, the ratio of the population per patent decreased from 6,613 in 1891 to 3,515 in 1921. Although patenting increased especially in California, Illinois, Ohio, and Washington, inventive activity remained concentrated in the Northeast.

Table 8.

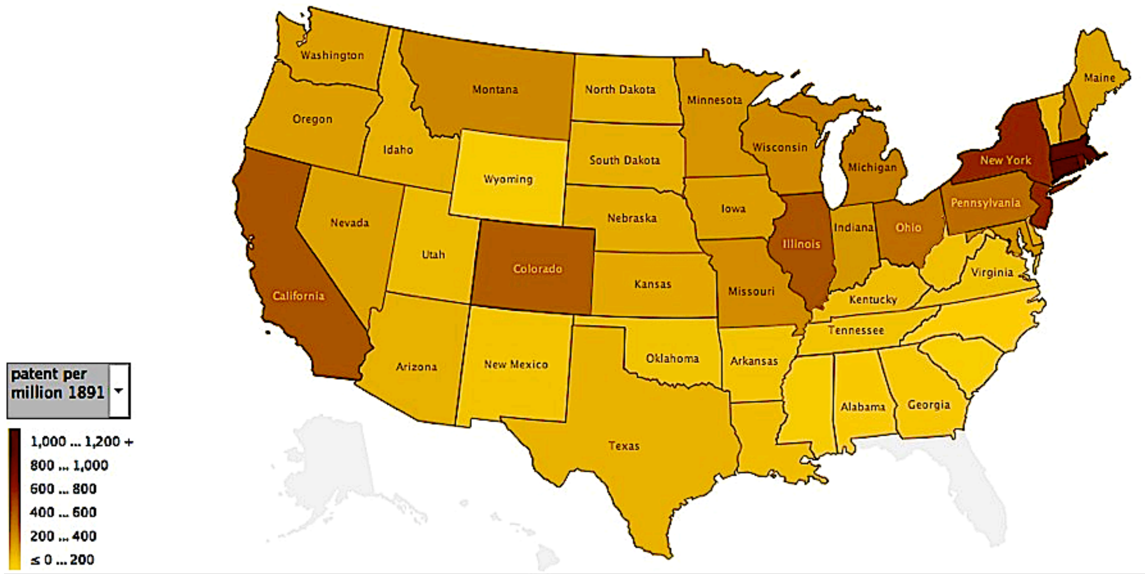
Population to Each Patent Granted and Patent per Million Residents, 1891-1921.

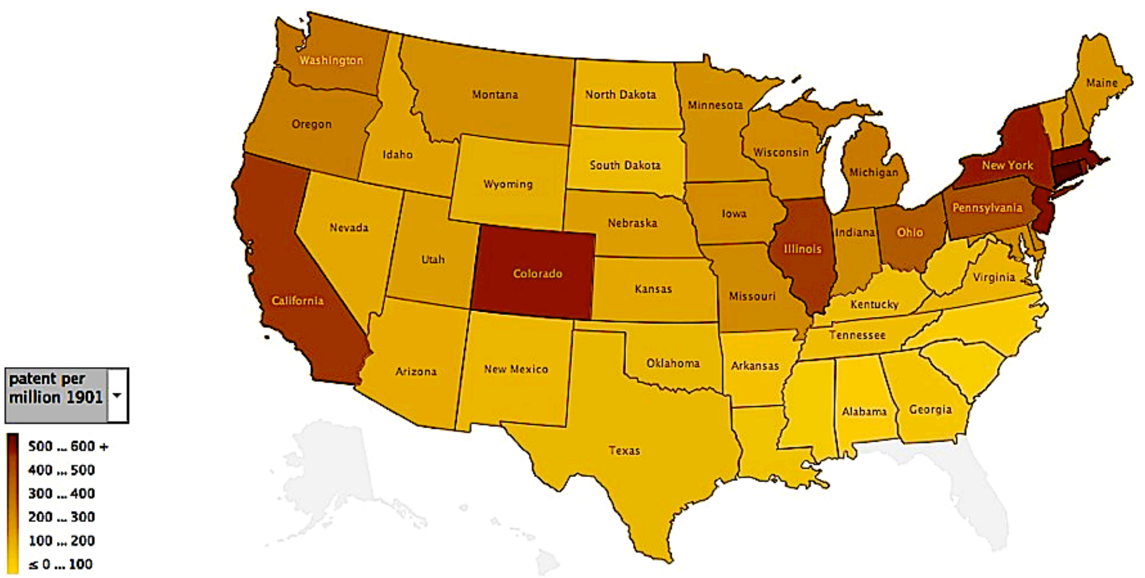
1891/ Top	One to every	Patent per Million	1891/ Bottom	One to every	Patent per Million
Connecticut	1,018	982	South Carolina	23,492	43
Massachusetts	1,055	947	North Carolina	21,288	47
Rhode Island	1,191	840	Mississippi	20,469	48
New Jersey	1,505	664	Wyoming	20,235	49
New York	1,535	651	Alabama	18,457	54
U.S. average				3,506	285
1901					
Connecticut	1,198	834	South Carolina	28,517	35
Massachusetts	1,472	679	Alabama	22,300	45
New Jersey	1,572	636	North Carolina	18,386	54
Rhode Island	1,581	633	Mississippi	18,038	55
Colorado	1,718	582	Georgia	14,874	67
U.S. average				3,705	270
1911					
Connecticut	1,319	758	South Carolina	23,314	43
California	1,516	722	Mississippi	15,904	63
Colorado	1,675	597	Alabama	13,117	76
Rhode Island	1,723	580	Tennessee	12,484	80
Illinois	1,778	562	Arkansas	11,663	86
U.S. average				3,450	290
1921					
Connecticut	1,354	739	Mississippi	31,414	32
California	1,450	690	South Carolina	21,046	48
New Jersey	1,516	659	Arkansas	19,046	53
New York	1,610	621	North Carolina	17,292	58
Illinois	1,666	600	Alabama	17,016	59
U.S. average				3,302	303

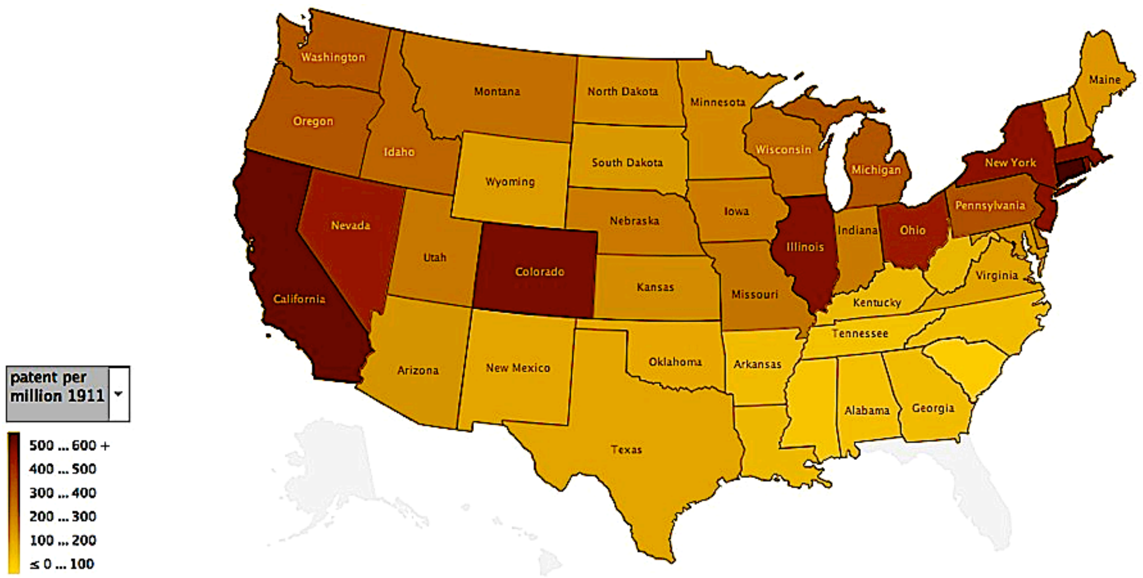
Note and Source: The data is from the *United States Annual Report of the Commissioner of Patents, 1790-1947*. Patent per million residents is calculated based on the ratio of population to each patent granted in each state.

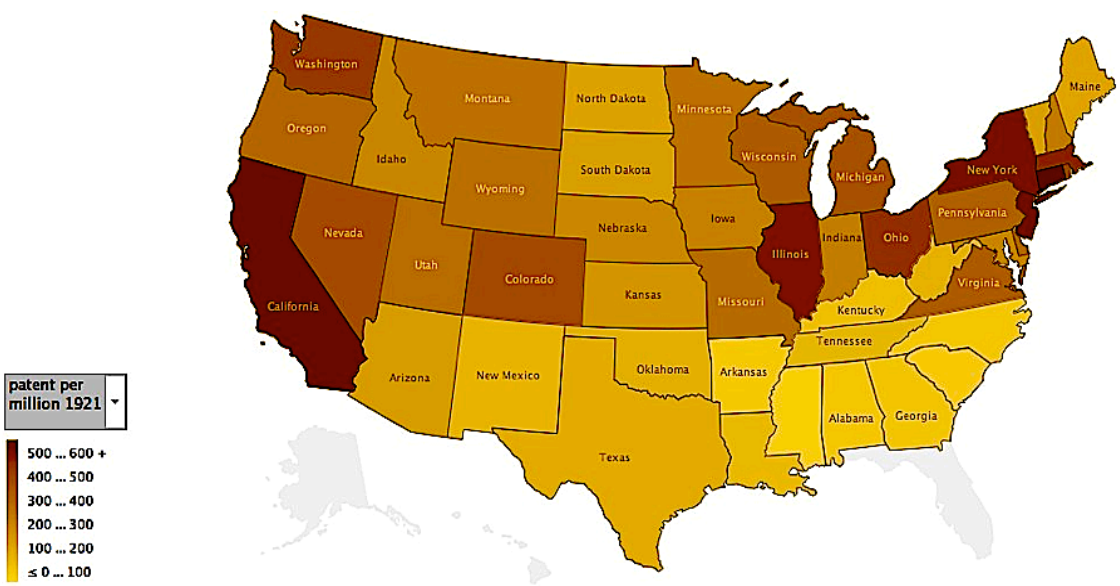
Figure 3

Geographical Mapping of the Ratio of Patent Granted per Million Residents









Note and Source: The map is drawn according to patents granted per million of residents, not including Florida. The darkest color denotes the region with the highest ratio. Source: see Table 8.

Table 9
Patenting by Region, 1891-1921.

1891	Number	Share (%)	Population per Patent	1901	Number	Share (%)	Population per Patent
Middle Atlantic	7,064	33.2	1,811	Middle Atlantic	8,133	34.1	1,855
East North central	5,329	25.1	2,841	East North central	6,097	25.6	3,063
New England	3,486	16.4	2,763	New England	3,271	13.7	2,869
South	2,149	10.1	11,391	South	2,419	10.2	11,783
West North Central	2,101	9.9	5,008	West North Central	2,341	9.8	5,633
West	1,088	5.1	6,613	West	1,576	6.6	4,753
1911				1921			
Middle Atlantic	9,056	30.5	2,133	Middle Atlantic	11,755	31.8	1,944
East North central	7,869	26.5	2,734	East North central	10,151	27.5	2,448
South	3,392	11.4	9,721	West	4,331	11.7	3,515
New England	3,286	11.1	3,542	South	3,655	9.9	11,657
West	3,184	10.7	3,458	New England	3,598	9.7	3,630
West North Central	2,944	9.9	4,225	West North Central	3,458	9.4	4,356

Note and Source: The regional classifications are based on the Census of 1910 Urban and Rural Population except no Hawaii Alaska in West. Source: see Table 8.

V. Explaining Invention: The Impact of Education

In this section, I explore the impact of education on patenting activity by comparing patenting rates across states over the period 1900 to 1920. The OLS model is as follows:

$$\text{Log } patent = \alpha + \beta_1 \log high\ school + \beta_2 \log university + \beta_3 \log railroad + \beta_4 \log manufacturing + \beta_5\ South + \varepsilon, \text{ with } \varepsilon \sim N(0,\sigma^2). \quad (1)$$

where *patent* is number of patents per million residents; *education* is the number of male students enrolled as a share of the school-age population. To allow for the entry of students into the labour force these enrollment rates are lagged by ten years.[15] *University* represents tertiary education, and consists of the number of preparatory, collegiate, and graduate students as a share of the population aged 19-22. *Railroad* is the mileage in each state. *Manufacturing* is the share of the labour force in the manufacturing sector. A dummy variable for states in the South is included. For details see the appendix.[16]

The results are reported in Table 10. There is a strong association between tertiary education and inventive activity. The coefficient for 1900 is 0.21, significant at the 5% level. The coefficient is similar in 1910 but increases to 0.56 in 1920. The reason for the greater effect of this variable may have been due to the increase in the number of engineering professionals. In 1913, engineering became the second

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[15] Educational attainment of the workforce would be a better measure, but the share of the students enrolled was very close to that number. For example, Goldin and Katz (2008, p. 32) provide the fraction of the population with 12 to 16 years educational attainment in 1915 in the U.S. and Iowa. Their weighted averages are 0.035 and 0.044 respectively, which are very close to the share in this study, 0.037 in the U.S. and 0.047 in Iowa in1900.

[16] I also included the share of the urban population, but it is strongly correlated with manufacturing (0.81 in 1900, 0.78 in 1910, and 0.78 in 1920); and so it is dropped.

largest major in terms of degrees granted (Edelstein 2009, p. 201). The coefficient on high school education does not show a significant effect. These results are consistent with Chi and Qian (2010), which shows that Chinese tertiary education had a stronger effect on patenting than high school.[17]

It is noteworthy that the railway mileage variable has a significant effect on patenting activity. This result is consistent with the Sokoloff's (1988) finding that accessibility to markets is important. Sokoloff showed that in the early nineteenth century being located on a navigable river or canal had a positive and statistically significant relation with patenting activity. My results offer further support that inventive activity is related to market demand. Not surprisingly, the share of the male labour force in the manufacturing sector is strongly associated with patenting activity, consistent with Sokoloff's results.

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[17] I also tested the effect of high school and university using a twenty-year lag. The results are not significant.

Table 10

Determinants of Patenting Rates, 1900-1920

	1900	1910	1920
High School	0.05(0.11)	0.07(0.10)	-0.42 (0.19)
University	0.21** (0.11)	0.23* (0.13)	0.56**(0.24)
Railway Mileage	0.13* (0.07)	0.08* (0.07)	0.12* (0.06)
Manufacturing	0.93*** (0.15)	0.27*** (0.10)	0.85*** (0.17)
South	-0.20*** (0.08)	-0.32***(0.07)	-0.23*** (0.09)
Intercept	0.59(0.37)	1.9***(0.31)	0.51(0.43)
R-squared	0.78	0.83	0.78
Adj R-squared	0.76	0.80	0.75

Notes and Sources: Dependent variable is the patent issued per million residents in each. Standard errors are in the parentheses. Coefficient estimates are reported with *, **, and *** indicating 10%, 5%, and 1% significance levels respectively. South includes: Delaware, Maryland, District of Columbia, Virginia, West Virginia, North Carolina, South Carolina, Georgia, Florida, Kentucky, Tennessee, Alabama, Mississippi, Arkansas, Louisiana, Oklahoma, and Texas. Source: see Appendix.

In conclusion, the OLS regression exhibits a significant and positive relationship between tertiary education and invention. There is also a strong effect of railroad mileage and the manufacturing labour force, which are other features, which coincides with Lamoreaux and Sokoloff (1999, 2000).

VI. Conclusion

This paper has investigated the determinants of inventive activity, and has addressed, in particular, the question of whether or not education stimulates invention. Other scholars have found that education has a positive effect on innovative activity. Toivanen and Vaananen (2011) use an instrumental approach, finding that a university engineering degree increases the likelihood of invention by 23% to 30%. Akhmedjonov (2010) finds that employee education levels have a significant impact on firms' innovative activities in transitional economies, such as Hungary, Slovenia, and Turkey. He also constructs a cost-benefit model showing the mechanics of how a firm's characteristics can affect its research and development activity. Chi and Qian (2010) employ Chinese provincial data, and also find a strong relation between education and invention. Importantly, they find that tertiary education has a stronger effect on invention than secondary education. Lamoreaux and Sokoloff's studies show that market demand also affects regional innovative activity.

Motivated by these studies, I estimated an OLS model that includes state-level measures of high school and university education. I also include railroad mileage as an indication of access to markets. The results support the previous work that education can significantly increase the patenting rates, and that patenting is also related to the availability of transportation. This study, which employs a somewhat different historical data to determine the factors affecting innovation, as measured by patent records, provides support for other studies in the literature.

Appendix

The patent data is from the *United States Annual Report of the Commissioner of Patents, 1900-1920*. It includes the patents and designs that were granted. In the model, the dependent variable is the logarithm of patents issued per million residents. *High school* is measured as male students in public and private high schools, and *university* is the number of preparatory, collegiate and graduate male students in universities and technology schools in each state, each as a share of the corresponding population. The education data is from the *Annual Report of the Commissioner of Education, 1890-1920*. I divided the number of male students in *high school* by the male population aged 14-18 in each state, and the number of male students in the *university* category by the male population, 19-22. Railway mileage is obtained from *The Statistical Abstract of the United States, 1900-1920*. Manufacturing stands for the share of labour force in manufacturing sector as derived from the *Census*.

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