THE GEOGRAPHY OF INVENTION IN HIGH- AND LOW-TECHNOLOGY INDUSTRIES: EVIDENCE FROM THE SECOND INDUSTRIAL REVOLUTION

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This Version: November 26, 2003

Abstract

Production in "technologically-mature" manufacturing industries has in recent years increasingly relocated from more-developed to less-developed countries with lower costs of labor. It is not clear, however, if these latter countries will realize corresponding increases in their generation of new technological knowledge. More generally, we do not fully understand the sources of geographic clustering in invention, or how prevalent and persistent such clusters are. To investigate these issues, this paper explores the geographic patterns of invention in the shoe, textile and electric industries in the U.S. during the Second Industrial Revolution. The three industries offer intriguing contrasts: two traditional labor-intensive industries, one whose production migrates to a low-wage area and one that does not; as well as an industry based on a radically new technology. Using both U.S. patent records and information about the inventors drawn from census manuscripts and city directories, I find that in general the location of invention does not appear so directly, or closely, related to the location of production. The shifts in the location of production capacity were not followed by corresponding increases in invention (such as in the case of textiles moving to the South). Even in the more craft-based shoe and textile industries, a significant number of inventors had no experience in the production, and were instead primarily distinguished by possessing a high level of technical skills. The evidence also reveals sharp contrasts in the geographic patterns of where invention was taking place, and in the characteristics of the inventors, between the traditional and the new technology industries. The spatial association between invention and production was generally weaker in the electric industry than in either shoes or textiles. Moreover, inventors in the electric industry were far more educated, younger, and geographically mobile over their lives and careers than inventors in the traditional industries. The intriguing implication is that because individuals with the appropriate knowledge and skills to be effective contributors to new technology are often young and scarce in supply, they will be inclined to migrate to those areas where demand for the technology (and rents to their scarce human capital) is high and resources to support the R&D are available. The historical evidence appears to suggest that invention and production might not be clustered in the same location. This may be unwelcome news for developing countries that hope to emerge as centers of invention after having attracted shifts in manufacturing capacity from developed countries.

* I am very grateful for insightful advice from Ken Sokoloff. I have also benefited from valuable comments offered by Dan Ackerberg, Sanford Jacoby, Naomi Lamoreaux, Shih-tse Lo, Enrico Moretti, Jean-Laurent Rosenthal, and participants in the UCLA Economic History Proseminar and the UCLA IO Workshop. Finally, I would like to thank Eileen Chou, Hong Tran and Jicky Trantrong for their excellent assistance in constructing the patent dataset used in this paper as well as the staffs at the Science, Technology and Patents Department, Los Angeles Public Library for their patience with my demanding use of their computers to access the USPTO on-line database. All errors are mine. E-mail address: dhanooss@ucla.edu.

Technological progress has long been widely recognized as a crucial source of economic growth. Many countries have, accordingly, devoted considerable resources to promote more rapid generation and diffusion of technology in their economies. Yet recent studies reveal a persistence of stark contrasts across countries and geographic space more generally, not only in productivity, but also in the generation of new technological knowledge. What accounts for these geographic disparities is not well understood. Many scholars have suggested that patterns of invention tend to mirror geographic patterns in manufacturing production through processes such as learning by producing.[1] Others, however, highlight the possibility that because conditions conducive to invention may be different from those conducive to production, a geographic division of labor of sorts could easily develop between the two activities.[2] In this view, the rates of invention are high in areas where various factors favorable to invention are abundant.

Empirical studies of geographic variation in inventive activity often abstract from the question of whether invention pertaining to the technology of an industry is linked to production. Indeed, there has been virtually no systematic investigation of the specific factors that might lead a region to be specialized in invention but not in production, nor of whether the significance of such factors varies across industries. This is unfortunate, especially because these issues have important implications for our understanding of global economic development. The production of "technologically-mature" industries has, in recent years, increasingly relocated from more-developed countries to less-developed countries with lower costs of labor and other inputs. It is not clear, however, whether, and to what extent, the low-wage countries that have been the recipients of such shifts in production will come to realize corresponding increases in their generation of new technical knowledge, and in so doing develop a firmer basis for long-term growth.

Although some have suggested that this movement of industrial production should eventually stimulate self-sustaining technical change, the design and manufacture of sophisticated capital equipment used in these industries has thus far remained largely confined to the most-developed countries. There are, moreover, a number of reasons to doubt that the relocation of industrial production alone will be able to trigger increases in inventive activity in less-developed regions or economies. First, these areas might be expected to lack sufficient infrastructure (such as financial institutions geared toward funding investment in R&D) or suffer from a scarcity of relevant human capital. If indeed the generation of new technical knowledge for an industry can be geographically separated from production, inventive activity might naturally concentrate in those areas with an abundance of those factors intensive to inventive activity, such as capital to fund inventive activity or individuals with sufficient technical knowledge to be effective at inventing or otherwise operating at the technological frontier. Another reason why the more-developed countries have been so successful in retaining their technological leadership long after production moved elsewhere may be that they benefited from increasing returns in inventive activity generated by technological spillovers and by institutions carrying out trade in intellectual property.

The relative importance of these different factors on the location of where new technological knowledge is generated should, of course, vary across industries. For example, proximity to production may matter less in new-technology industries, where levels of production are still rather low and familiarity with the technical frontiers is scarce. Instead one would expect human capital considerations to loom larger in such industries, as working with more complex and novel technologies likely demands people with very special technical knowledge. Inventive activity should, in such cases, be concentrated where such individuals are relatively abundant, and where they can better exploit the opportunities to exchange ideas and receive the most up-to-date information on new development by clustering in close proximity to others working on the same problems.

I have chosen to study these issues by examining the historical experience of a single country, so as to avoid confounding effects due to differences across countries and to be able to follow the processes involved over a long period of time. Because the country under investigation should both have high levels of inventive activity and be large enough to have a great deal of interregional variation, I focus on the U.S., particularly the experiences of the shoe, textile and electric (electrical machinery, generation, wiring and lighting) industries during the so-called Second Industrial Revolution.

The Second Industrial Revolution, dating roughly from 1870 to 1920, was a golden era of scientific and technological breakthroughs. Benefiting from such discoveries, new industries such as electric machinery and lighting, automobiles, and modern chemicals were established, and even old industries were transformed. The new technologies were much more capital intensive and much more based on scientific knowledge than those in the First Industrial Revolution, and they induced radical changes in the scale of operations, in the reliance on finance and professional managers, and in the internal organization of enterprises.[3] Given that the magnitude of the technological and organizational changes that marked the Second Industrial Revolution rival those of our own age, it is an interesting and relevant period to study.

Shoes and textiles were among the most important industries of the First Industrial Revolution of the early 19th century, when the growth of the manufacturing sector accelerated sharply and methods of production were transformed from those based on craftsmen doing their work with hand tools to those of mechanized and inanimately-powered mass production. Both industries were originally concentrated in the Northeast, with shoe production centered in Massachusetts and textile production in Southern New England and the Middle Atlantic. Together they accounted for a substantial share of national manufacturing output, and an even higher proportion of the manufacturing workforce; in 1860, for example, the cotton textile and shoe industries accounted for about 7% and 6% of total U.S. manufacturing value added, respectively. By the late 19th century, however, the rate of growth of demand for the products of these industries slowed, and technological change in shoes and textiles took on more of an incremental character. By 1910, their respective shares of value-added had declined to only 3% and 2%.[4] Although both of these technologically-mature industries were in relative decline, their paths were very different in geographic terms. Textile production began a long process of relocation from the Northeast to the lower-wage South during the late 19th century. By 1910, the South employed nearly 20% of the U.S. textile workforce, as compared to only about 5% in 1870. Shoe production, however, remained concentrated in New England, and especially in Massachusetts, which was home to 40% of the industry workforce throughout the period from 1870 to 1910.

In contrast to shoes and textiles, the electric industry was just emerging as a major industry during the late 1800s. Because of the rapid growth in urbanization and manufacturing in the U.S., it was increasingly important to supply the public with cheap energy as well as factories and transport with efficient mechanical power. Inventive activity in the electric industry during the late 19th and early 20th centuries was chiefly focused on resolving two major issues. The first one was how to generate stable, reliable and ample electricity for household and commercial uses, for example by developing dynamos and generators. The other was how to improve the efficiency of electrically powered apparatus, the three main applications of which were lighting, traction (railway) and industrial equipment, in particular motors. Foreseeing the potential gain in successfully introducing electricity and electrical apparatus, a talented group of inventors established or joined labs and companies in several locations across the Northeast and Mid West regions.[5] High rates of invention characterized the industry. There were many more electric patents than patents in shoes and textiles in both 1890 and 1910. The production of electric machinery and lighting equipment was highly capital-intensive, but accounted for only a small share of value-added (or workforce) during the Second Industrial Revolution (about 1% of the total U.S. manufacturing workforce in 1910).[6]

These three industries exhibit three very different patterns of development: two traditional labor-intensive industries, one whose production migrated to a low-wage area (textiles) and one that did not (shoes), as well as an industry based on a radical new technology. This record provides us with an opportunity to study whether the geography of invention (and its relation to that of production) was different for industries based on new technologies than for those relying on more mature technologies. For this purpose, I employ U.S. patent records (1870, 1890 and 1910), linked to information about individual inventors drawn from population census manuscripts and city directories. The key questions focused on here are: (i) what are the factors contributing to geographic clustering in invention; and (ii) what is the relative importance of these factors, including proximity to production, across mature and emerging industries?

I find that, in general, the geographic patterns in the rate of invention were not directly associated with the location of production. The evidence indicates, for example, that although there were some increases in invention (learning by producing) associated with the relocation of textile production to the South, this sort of stimulus to invention was quite modest, both in strength and in how long it took for the effect to be realized. Well after the geographic shift of textile production had begun, rates of invention remained low in the South, whether gauged by patents per capita, per textile worker, or by measures that take into account the shorter terms of job experience and lower levels of technical skills among textile workers in the region. The evidence from Massachusetts, the state with the highest rate of textile (as well as shoe) invention, seem to indicate that it benefited from historically determined stocks of industry-specific technical skills, and perhaps from institutions supportive of trade and investment in technology that facilitated a division of labor between inventive activity and production. Those inventors who were the most specialized and productive at invention remained in Massachusetts, allowing the state to retain its leadership in technological change long after textile production had begun to move elsewhere.

The evidence also indicates that the geographic association between invention and production grew weaker, and the reliance on individuals with technical backgrounds stronger, with the complexity and capital intensity of technology. Inventive activity in the electric industry was concentrated in those areas where both individuals with a technical knowledge of electricity and financial resources were relatively abundant. During this period, in which the cutting edge of electrical technology was being pushed out rapidly, invention was dominated by the younger, the more entrepreneurial, and those educated in science or engineering. Not only were these groups more likely to have acquired the requisite human capital, but they were also mobile geographically in pursuit of opportunities. These circumstances, perhaps characteristic of new technology industries more generally, produced a much more dispersed pattern of inventive activity.

The organization of this paper is as follows. The next section reviews the literature and develops hypotheses concerning geographic patterns in inventive activity, as well as how I plan to test them. Section 3 describes the data. Section 4 compares and contrasts the geographic patterns of patenting and production as well as the characteristics of patentees, both within and across industries, and evaluates how consistent this evidence is with the various hypotheses. Then, I conclude with a discussion of the policy implications of the evidence.

2. PREVIOUS WORK AND HYPOTHESES

Our understanding of the geographic clustering of industrial activity has been enhanced by recent studies such as Kim (1995) and Dumais, Ellison, and Glaeser (2002). Regional differences in industrial composition can be largely attributed to different factor endowments or increasing returns to industry localization generated by positive externalities such as those associated with proximity to suppliers and customers or with technological spillovers. We still lack, however, a very good understanding of why some geographic areas seem more conducive to invention than others. Because the nature of comparative advantages, or of externalities, in industrial production could be different from those in the generation of new technological knowledge, and a division of labor between the resources involved in production and those involved in inventive activity might well be feasible, the production capacity of an industry could be located in very different places from those where the inventive activity of that industry is carried out.

Scholars such as Jaffe, Trajtenberg, and Henderson (1993) and Audretsch and Feldman (1996) focused directly on the spatial distribution of invention, and found that technological spillovers likely play a significant role in promoting inventive activity. However, they did not explore the possibilities of division of labor between manufacturing and inventive activity, and thereby, did not answer whether a region could be specialized at invention but not in production and vice versa. Lamoreaux and Sokoloff (2000) have done so, and in their study of the American glass industry between 1870 and 1925 they found that the major centers of American glass production had low rates of inventive activity in glass, as judged relative to the number of workers in the industry. Their results suggest that other institutional factors, such as market structures that facilitated trade in patented technology or that helped mobilize capital to invest in inventive activity, could support high levels of invention, even in a geographic area with little or no related manufacturing production nearby. Although intriguing, their focus on a single industry makes it difficult to generalize the findings. Moreover, they did not probe very deeply into whether the types of inventors who located in these clusters of high glass invention with only limited glass production were somehow different from inventors elsewhere, and what factors contributed to these geographic patterns.

There are a number of reasons why geographic concentrations of inventive activity might be observed. One derives from the theory of comparative advantage, where the traditional Heckscher-Ohlin framework suggests that regions specialize in industries that are intensive in those factors of production they have a relative abundance of. For example, if inventive activity was intensive in the use of individuals with particular technical training, then, according to this perspective, areas with an abundance of such people would be relatively specialized in that activity.

Another perspective on why the generation of technological knowledge might be localized comes from Marshall's observation that concentration of an industrial activity could arise from increasing returns associated with external economies.[7] Many argue, for example, that inventive activity in an industry will tend to be concentrated where the production in that industry is actually carried out (regardless of whether the geographic distribution of production was driven by comparative advantage or some other factors). The logic is that people in the manufacturing labor force (those involved in the production process) or those within proximity to production tend to have greater exposure to the problems and opportunities for improvement in the technology in use.[8] Some extend this idea that invention consists largely of *learning-by-producing* further, suggesting that people who are relatively new to the industry, or to the technology in use, benefit more from learning by producing than those who have long since become accustomed to standard practice, and thus might be expected to be more creative in conceiving of technical improvements. This implies that geographic areas with expanding production capacity or areas with newer firms might have disproportionately high rates of invention.[9]

Another way in which external economies could have a powerful effect on the geographic distribution of inventive activity is if inventors chose to locate near one another in order to lower their costs of acquiring/sharing new information on technological developments or of transacting in the market for technology. The notion that the value of access to technological spillovers could account for clusters of inventive activity has long been appreciated, and scholars have recently also begun to recognize that better access to market coordination mechanisms for trading technological knowledge, such as patent agents or financial intermediaries, might also play a critical role in promoting inventive activity because such intermediaries help to mobilize resources to invest in inventive activity as well as to facilitate division of labor between invention and production. Since the operations of such market-coordinating institutions typically exhibit economies of scale, the greater their role in supporting inventive activity, the more likely invention and these institutions will be concentrated in the same areas. One would expect the rate of invention to be disproportionately high in urban areas where these intermediaries tend to be concentrated. If proximity to such intermediaries was important, then one would expect the patentees in such places to be making extensive use of them – as reflected in higher rates of assignment (indicating a sale or transfer of a patent right) at issue in such areas.[10]

Of course, the relative importance of these different factors in explaining the geographic distribution of inventive activity likely varies across industries. For example, in new-technology industries, levels of production are still rather low and people with the skills and knowledge that allow for operating at the technological frontiers are extremely scarce. One would, therefore, expect inventive activity in these industries, where R&D programs are typically intensive in capital and in labor with special skills, to be drawn not only to regions with a relative abundance of people with the appropriate technical knowledge, but also to areas with financial institutions suited to mobilizing capital for what are likely risky investments and to supporting trade in intellectual property. This may not lead to a geographic association between invention and production in these newly emerging industries if the location of factors conducive to invention is different from the location of those favorable to production.

3. DATA

Following previous studies on invention and technological progress, such as the seminal work of Schmookler (1966), I use patent statistics to gauge inventive activity.[11] I construct cross-sections of patent records consisting of all shoe, textile and electric (machinery, generation, wiring and lighting) patents granted by the United States Patent and Trademark Office (USPTO) in 1870, 1890 and 1910. Among the information contained for each patent is: name and address of patentees and their assignees (individuals or firms who purchased the ownership of the inventions before the dates that the patents were granted); and the nature of the assignment (e.g. whether the patentees retained a stake in the invention after assignment). For each patentee, I have also retrieved the total number of patents awarded to the inventor over the 7-year period centered on the year of the sampled patent.[12]

The USPTO classification system is of limited use for our purposes because it is based on functional use. For example, a bobbin is classified under class 242: winding, tensioning, or guiding. Consequently, to identify all shoe and textile patents issued in the three years, I read over 72,000 patent descriptions granted during the cross-section years, so as to select only those intended for the shoe and textile industries. The patents selected for textiles exclude those associated with fiber decortications, dye, sewing and garment manufacturing. The shoe patents include shoe-trees and leave out non-shoe sewing machines and skate shoes. For those patents that are difficult to classify from the description, I reviewed the detailed information about the invention included the in drawing, specification and claims reported in the Official Gazette of the USPTO or the patent grant images in USPTO's on-line database.[13] Fortunately, the USPTO's patent classification works fine for electric invention, defined by U.S. Technical Committee on Industrial Classification (1957) as electric transmission and distribution equipment, electrical industrial apparatus and electric lighting and wiring equipment. These electric patents exclude electric transportation, welding, and communication equipment.[14] However, after obtaining the tentative list of patent numbers for electric invention, I checked the information for each patent by employing the USPTO patent grant image on-line database to verify that the invention is indeed an electric patent. In addition to the three industry-specific samples of patent records, I also use a cross-sectional sample containing similar patent information that was randomly drawn from patents in all industries granted in 1870-1871, 1890-1891, and 1910-11.[15] (See Table 1 for number of patent, and shares of patents and manufacturing labor force by industry.)

In order to explore in detail the biographies of these patentees (inventors) and whether they were directly associated with production, additional information was collected on the patentees from both the U.S. population census manuscripts (1850-1880 and 1900-1930) and city directories (mostly in 1890).[16] Among the variables retrieved are: year of birth, birthplace, detailed occupation, place of business, and place of residence at several points during an inventor's life. In addition, for those inventors appeared in the 1850, 1860, or 1870 censuses, estimates of wealth could be obtained.[17]

4. EMPIRICAL ANALYSIS

If learning by producing has a strong impact on inventive activity, then we would expect the relocation of production to result in a corresponding increase in the rate of invention where production is located. However, if a geographic division of labor between invention and production arises, areas that are recipients of a shift in production might not experience a corresponding increase in the levels of inventive activity. Instead, invention might be more prevalent in areas where factors especially favorable to invention are abundant. Therefore, to understand the impact of relocation on the rates of invention, I begin with an evaluation of the learning-by-producing hypothesis.

4.1 Did Learning by Producing Have a Strong Impact on Invention?

One way of investigating whether exposure to problems and opportunities in production was conducive to inventive activity is to examine the correlation between the clustering of invention and production, in particular, whether the shares of patents were comparable to those of manufacturing employment across regions.[18] The logic behind this test is that if involvement in production stimulated invention, then the majority of inventors would be workers in, or in close proximity to, production, and hence the geography of invention and how it evolved over time would mirror that of production. Regional shares of patents and manufacturing employment for each industry, relative to those for all industries and population, are displayed in Figures 1-3.

Figures 1 and 2 seem at first to suggest that the location of invention was closely related to the location of production in the shoe and textile industries.[19] In general, shares of patenting corresponded to those of employment for the respective industries. However, a closer look at the patterns across regions reveals that shares of patents in some regions, such as Massachusetts and the South, significantly deviated from those of employment in both the shoe and the textile industries.

During the first half of the 19th century, textile production was concentrated in Massachusetts, Southern New England and the Middle Atlantic. In the 1880s, however, textile production began to relocate from the Northeast, especially Massachusetts, to the lower-wage South. Massachusetts' share of textile employment dropped from 29% to 22%, while South's employment share rose from 5% to 19% during the period from 1870 to 1910. It is striking that the regional shift in production did not result in much of an increase in textile invention in the South. The region's share of patenting in textiles remained very low, relative to textile employment. Its textile patent share was about a third of its employment share in 1910. In contrast, not only did Massachusetts maintain its leadership in textile technology after the relocation, but its lead over other regions grew even larger. The textile patent share of Massachusetts rose to 41% or nearly twice its employment share, in 1910.[20] The patterns of patenting in the shoe industry, as compared to that of employment, were similar. Shoe production remained highly concentrated in MA throughout the 19th century. Between 1870 and 1910, the generation of new technological knowledge in shoes grew ever more concentrated, while the region's shares of employment was roughly stable. MA's share of shoe patents increased to 56%, as compared to 42% for shoe employment in 1910. On the other hand, shoe patenting declined over time in areas where shoe employment expanded such as Northern New England and West North Central.

The divergence between invention and production is even more apparent in the electric industry as shown in Figure 3.[21] Perhaps befitting a newly emerging industry, the geographic patterns of invention and production in the electric industry were more variable over time than in shoes or textiles. However, it is clear from the patterns that where production took place did not have a powerful impact on where inventive activity in the electric industry was carried out. In 1890, although both MA and NY had the highest patents per capita in electric, their shares of patents were smaller than those for employment. Between 1890 and 1910, MA experienced a substantial drop in both electric invention and production, but far more in invention. NY, on the other hand, maintained its share of electric patenting during the same period while experiencing a 50% decline in electric employment. In contrast to MA and NY, Southern New England (SNE) and PA had higher shares of electric patents than employment, and they had even higher rates of invention in 1910.[22]

The fact that the levels of inventive activity (as measured by the shares of patents) generally corresponded to those of production (as measured by the share of employment) seems to be consistent with the idea that learning by producing would lead to the association between the location of invention and production. However, the considerable divergence between the shares of patents and those of employment in the electric industry and in the key textile regions, such as MA where the shares of textile patents increased after its textile production moved to the South, raises a question whether learning by doing alone could account for the clustering of invention.[23]

Moreover, even in regions where the shares of patents were comparable to those of employment, it would be premature to conclude that there was a direct causal association between production and invention arising from learning by producing. The association might result from the clustering of individuals who were associated with these industries but were not directly involved in the production of the goods. For example, shoe and textile invention could also come from individuals working in a capital good sector that produced tools and machinery for the respective industries. If the transportation costs were substantial, this capital good sector might locate in proximity to production, where the demand for tools and machinery were. As a result, the geographic association between the shares of shoe and textile patents and employment that we observe might be due to the fact that individuals working in the tool and machinery sector tended to co-locate where shoe and textile production was clustered.

Therefore, to test the learning-by-producing hypothesis, one should also examine work histories of inventors, in particular, how many of the inventors had work experience related to production, and what kind of work experience that inventors, with no experience in production, had. If a large proportion of inventors had no experience related to production, then factors other than learning by producing might account for the clustering of invention.

Table 2 reports work experiences of inventors who resided in the U.S., and the median number of patents they received within a 7-year period for different types of work experience across industries. (See Appendix 1 for work experience classification scheme in details.) The results seem to suggest that other factors might have stronger influence on the clustering of invention than learning by producing. For the two mature industries, inventors were primarily comprised of two types of inventors: those who had worked in the production of goods in their respective industries, and those who had worked in tools and machinery.

During the First Industrial Revolution, manufacturing was transformed from craft-based to mechanized production and industrial output rose sharply. The large extent of the market for capital goods led to the rise of the tool and machinery sector that were specialized in producing mechanically-powered machinery. Thus, individuals working in tools and machinery were likely to have some knowledge of mechanical technologies. As Figures A and B in Appendix 3 show that some shoe and textile invention was quite complicated and likely required familiarity with machinery. The knowledge of mechanical technologies, therefore, might be important for inventive activity in shoes and textiles.

The high fraction of inventors with experience in tools and machinery also appear to have been more productive in invention at an individual level, on average receiving many more patents within a 7-year period than those with production experience did.[24] In the shoe industry, the group of inventors who had worked in tools and machinery accounted for about one-third of shoe patents in 1890 and 1910. The important of such inventors to inventive activity is even more apparent in the textile industry. Inventors with experience in tools and machinery generated nearly a half of textile patents in 1890 and 1910. The work experiences of shoe and textile inventors seems to suggest that the clustering of invention might not directly arise from learning by producing in these two mature industries as a large fraction of shoe and textile patents were awarded to individuals who had worked in tools and machinery but did not have experience in production of shoes and textiles.

In the newly emerging electric industry, the majority of electric inventors were those with work experience in the electric industry.[25] Those with this background received much more patents within a 7-year period than any class of shoe and textile inventors.[26] With more than 10 patents received by a median inventor in a 7-year period, this seems to indicate that these inventors were rather specialized at invention. The skill composition of inventors who resided in the U.S. by industries reported in Table 3 also seems to support the idea that electric inventors were specialized at invention and might not be directly linked to production. (See Appendix 1 for more details on how the skills are derived from inventors' occupation history.) For all three industries, the prominence of inventors with technical skills grew over time. However, the reliance on technical skills was greater in industries where technology was more complex. Among these three industries, electric seemed to have the highest proportion of inventors with technical skills. By 1910, only 12% of electric inventors had never held jobs that required technical knowledge (e.g. model builders, machinists, draftsmen, engineers, and electricians), and about 72% of them had held jobs as electricians or electrical engineers that required technical knowledge specific to the electric industry. Unlike mechanical or other technologies that were possible to master by physical observation or construction, electric technology was abstract. It required knowledge on how to interpret and make sophisticated technical diagrams and scientific calculation. (See Figures A, B and C in Appendix 3 for an example of electric invention as compared to those of shoes and textiles.) It would, therefore, be unlikely that production workers would acquire such advanced skills through physical construction of electrical products. From the biographies of several famous electric inventors, it seems that they acquired their electric skills from either technical journals (self-taught) or technical training (attending engineering schools and working as apprentices to famous inventors), not from electric production.[27]

The evidence here seems to suggest that the location of invention might not be directly related to the location of production. As demonstrated by the comparisons of shares of patents and employment for the textile industry, the South did not experience a corresponding increase in the level of inventive activity after the relocation of production, while inventive activity grew ever more concentrated in Massachusetts after production moved elsewhere.

In addition to the major divergence between the shares of patents and employment, an examination of work experiences of inventors shows that there were significant numbers of inventors who did not have experience in production but seemed to be specialized at invention, as reflected by the number of patents received within a 7-year period. In the shoe and textile industries, the productive inventors were those who had worked in tools and machinery. In the electric industry, they were electricians or electrical engineers. These productive inventors seem to have high levels of technical skills that might be important for carrying out inventive activity. Therefore, the location of individuals with appropriate technical skills might be another factor influencing the clustering of invention other than the location of production.

In order to understand the sources of clustering in inventive activity, I turn to investigate whether there was an association between the location of individuals with appropriate skills and geographic patterns of inventive activity, and whether different skill requirements led to distinct patterns of clustering in invention across the three industries. Because electric technology was new, and hence the appropriate technical skills for the industry were likely to be different from those of other industries, I start my analysis with the two mature industries, shoes and textiles, and then turn to the electric industry.

4.2 The Reliance on Mechanical Knowledge in Shoe and Textile Inventive Activity

Technological progress from the First Industrial Revolution had changed manufacturing from craft-based to mechanized production. For example, in the shoe industry, hand operations such as lasting, cutting and bottoming once made by skillful shoemakers were replaced by mechanically-powered machines operated by less skilled workers. Similarly, in the textile industry, hand operated looms were replaced by mechanically-powered ones that were more reliable and produced more output at faster speeds.[28] Because these machines became increasingly more complex (and thereby manufacturing them required knowledge of mechanical technologies) and demand for capital goods grew larger, a tool and machinery sector that focused on designing and manufacturing production equipment emerged.[29]

A significant fraction of shoe and textile patents came from individuals with experience in tools and machinery (as shown in Table 2). By 1910, they accounted for about one-third and one-half of shoe and textile patents, respectively. As a result, the significant divergence between the shares of patents and employment in some regions, such as Massachusetts and the South, highlighted in the last section might be due to their abnormally high or low pool of people with knowledge of mechanical technologies. Furthermore, because the tool and machinery sector was not directly tied to the production of shoes and textiles, regions that were recipients of a shift in production might not experience a corresponding increase in inventive activity if the tool and machinery sector still remained in the more-developed regions.

The tool and machinery sector not only exploited existing technologies, but also generated incremental advances as well as new knowledge of mechanical technologies. Because such knowledge was important to carry out inventive activity in shoes and textiles, we would expect a region with a large tool and machinery sector also to have more shoe and textile inventions. Therefore, we can test the idea that the location of individuals with knowledge of mechanical technologies might influence the location of invention by examining the work experiences of inventors in different regions.

As reported in Tables 4 and 5, in both shoes and textiles, the proportions of inventors who had worked in production were similar across regions. Moreover, inventors with production experience who lived in MA – the center of invention in both industries – did not seem to have a productivity advantage over those resided elsewhere.[30] The median number of patents received within a 7-year period by such inventors living in MA was comparable to those of other regions.[31] On the other hand, in both shoe and textile industries, MA's shares of inventors with experience in tools and machinery were much higher than those of other regions, whether compared to the U.S. averages or to those of regions with substantial production such as WNC, ENC, NNE, NY and PA for shoes as well as NY and PA for textiles. In contrast to MA, the South had the lowest shares of textile inventors who had worked in tools and machinery.

The shares of inventors with experience in tools and machinery seem to be consistent with the regional development in the tool and machinery sector. One would expect the tool and machinery sector to be established in areas with high concentration of industrial production, and hence where there would be high demand for capital goods. Throughout the first half of the 19th century, MA was one of the top manufacturing states in the country.[32] When manufacturing became mechanized during the First Industrial Revolution, the tool and machinery sector also flourished in MA. With its large tool and machinery sector, MA had abundant population with knowledge of mechanical technologies. During the same time period, the South's economy was dominated by agricultural products and had a very small manufacturing sector as compared to the rest of the country. Therefore, workers with knowledge of mechanical technologies were relatively scarce in South.[33] The fact that the composition of inventor work experiences across regions was consistent with the regional development in the tool and machinery sector seems to suggest that the location of individuals with mechanical knowledge might, at least partially, accounted for the significant divergence between the shares of patents and employment in Massachusetts and the South.

However, a large tool and machinery sector and hence abundant population with knowledge of mechanical technologies does not seem to fully account for MA's high level of inventive activity in the shoe and textile industries. Regions that also had a large pool of population with mechanical knowledge (reflected by shares of machinists comparing to that of population in Table 6), such as SNE, NY and PA, did not realize an abnormally high rate of patenting in shoes and textiles like MA. One possible explanation for this is that, although the mechanical solution to a problem in one industry was also applicable to other industries during the First Industrial Revolution for the tool and machinery sector, as the demand for industry-specific capital goods grew over time, this might lead to specialization within the tool and machinery sector.[34] By making industry-specific capital goods, a region might develop and accumulate technical knowledge specific to certain industries. In this view, because of its large volume of shoe and textile production, MA's tool and machinery sector might be more focused on manufacturing machines for these two mature industries.[35]

The regional comparison of work experiences among shoe and textile inventors across regions seems to suggest that the divergence between shares of shoe and textile patents and employment in Massachusetts might arise from the specialized capital goods sector that built upon the pool of population with mechanical skills as well as sufficient demand for industry-specific tool and machinery. However, this explanation regarding the industry-specific capital goods sector is unlikely to be applicable to a newly emerging industry like electric because the industry employed a radically new technology.

4.3 The Importance of Electrical Knowledge in Electric Inventive Activity

The technological development in the electric industry during the Second Industrial Revolution involved the development of, and improvements to, rather complex equipment such as generators, dynamos and motors. The technology was radically different from that underlying steam- or water-powered machinery, and familiarity with even the basic principles was initially quite rare. Hence, a potentially important influence on the geographic patterns of electric invention might simply have been the location of individuals with the required technical knowledge. Section 4.1 demonstrated that the electric industry relied heavily on a rather restricted group of inventors who had knowledge specific to the industry and were quite specialized at invention. The novelty of the technology meant that no region would have had a historical legacy of such human capital, but we would expect regions where engineering schools or institutions offering training in related sciences were clustered to have some advantage. Those who attended engineering schools were likely more capable of dealing with technical diagrams, carrying out the necessary calculations and measurements, as well as working the relatively abstract principles involved in electric technology. Furthermore, the locations where people with technical knowledge were clustered were also presumably more likely to have institutions involved in marketing new technological knowledge. Such institutions were undoubtedly of great benefit to the mobilization of resources to support investment in emerging new-technology industries such as those based on electric power.

The evidence on the work experience and median productivity (as measured by the number of patents received within a 7-year period) of electric patentees reported in Table 7 seems to support the hypothesis that the regional distribution of individuals with technical knowledge might have had an impact on the regional distribution of electric invention. Regions that were known for engineering schools (ENC, MA, NY, NJ and PA) had high electric patenting rates in 1890 and 1910. Although the proportions of inventors with experience in the electric industry were comparable across regions, the median productivities of these inventors who lived in the regions where engineering schools were located were much higher than those of inventors living elsewhere.

Another way to test this technical knowledge hypothesis is to employ regression analysis to identify whether the geographic variation in patent rates can be explained by the pool of population with technical knowledge, after controlling for other relevant conditions. Table 8 reports a set of such regressions, with the regional patent share of the industry in question as the dependent variable, while the independent variables include the share of the manufacturing labor employed in the industry (reflecting rates of production), the regional share of individuals in occupations likely to be associated with the appropriate technical skills and knowledge (engineers for the electric industry), as well as regional dummies.[36] The results for the electric industry (equation 8) are of particular interest. Even after controlling for where production was being carried out, the coefficient of the regional share of the labor force likely to be engineers is positive, substantial in economic significance (0.318), and statistically significant. This evidence that electric invention was more prevalent in regions that had a relative abundance of people with a technical knowledge of electricity, together with the observation that the association across regions between invention in an industry and the skill composition of the population was markedly stronger for electric than for shoes and textiles (as reflected in the variable for the share of the labor force that had experience in tools and machinery), supports the idea that the new and science-based technologies of the Second Industrial Revolution were requiring more specialized knowledge among those who hoped to be effective at invention.[37]

4.4 The Distinct Dynamics of the Centers of Invention across Industries

Although the emphasis of section 4.1 was on demonstrating the irregularity of the regional correspondence between patenting and employment by industry at points in time, the discussion also highlighted stark differences across industries in how the geography of invention varied over time. In the two technologically-mature industries (shoes and textiles), Massachusetts not only maintained its dominance at invention throughout the period from 1870 to 1910, but by many measures actually widened its lead over time despite a marked shift of textile production to the South and rather stagnant shoe production in MA. While there was essential stability in where new technology was emanating from in these traditional industries, however, the geographic patterns of invention in the electric industry were more dynamic. In 1890, MA and NY were the two main centers, but by 1910 PA and the East North Central (ENC) had largely displaced MA, and joined NY, as the leading locations for where the new technological discoveries were being made. What accounts for the contrast between the technologically-mature and the new technology industries? As we have seen, in each industry the most productive inventors, and those disproportionately concentrated in the geographic centers of invention, were those that had work histories or educations that reflect stronger technical backgrounds and knowledge specific to the industry in question. Although the importance of having the appropriate human capital is common to all the cases, the role of this factor may play out differently in different industries. Because the technical background needed by inventors varied, and over time, we should expect differences in geographic distributions of invention, as well as in how they evolved over time, across the shoe and textile, and electric industries.

Electricity was first introduced to the American public during the 1880s. The major applications were in street lighting, and that fact as well as the substantial scale economies in generating power meant that the industry was concentrated in large cities. There was enormous enthusiasm for electric lighting, and great optimism about the potential benefits to come from harnessing electricity as a more general power source, and – not surprisingly – the demand for individuals with technical knowledge of electric technology was extremely high in these locations. Such individuals would be sought after by investors (for example, venture capitalists) who saw large potential gains from commercialization of new technology, as well as by users of electrical equipment and products, who needed on-site service and maintenance. Yet, there were no regions with established stocks of individuals with such knowledge of the new technology. At first, only a very small group of individuals were familiar with the basic elements of this radically new technology, and many of them were able to realize extraordinarily impressive returns to their human capital.[38] These high returns to technical knowledge about electricity naturally stimulated a supply response, attracting a disproportionate (as compared to say the larger, but declining traditional industries such as shoes and textiles) share of the younger and technologically-creative entrepreneurs to invest in acquiring the necessary technical background. As a result, inventors in this emerging new technology industry came to be composed of young inventors with advanced technical skills. Both because young adults are typically quite mobile, and because of the extremely high returns available in certain (largely urban) locations, they were more inclined (as compared to inventors in the other industries) to migrate. This process might reasonably have contributed to the evolution of multiple centers of invention in the electric industry (and some centers of invention being replaced) if other regions could offer conditions and terms favorable to this class of inventors.

In contrast to the electric industry, which was largely compelled to rely on younger people for the generation of new technological knowledge (because few of the older generation had the opportunity or experience to accumulate the requisite technical background), the mature industries were likely to rely on older inventors who were less apt to move (because of their age) from centers of invention such as Massachusetts, even after the textile production capacity expanded in the South. As discussed above, much of the inventive activity in shoes and textiles was carried out by individuals with experience in the tools and machinery industry that had developed in Southern New England during the First

Industrial Revolution of the mid-19th century when transportation costs were high, and it was necessary for the tool and machinery sector to be in close proximity to customers.[39] It may seem puzzling that the tool and machinery sector that manufactured shoe and textile production equipment remained concentrated in Massachusetts, even as production in these industries shifted elsewhere, but this may be because proximity to customers may have mattered less as the costs of transporting goods and information declined sharply near the end of the century, and as successful textile capital equipment manufacturers such as Draper built up sales networks in other regions.[40] Given their age, and that there was no significant relocation of tool and machinery firms to other regions, shoe and textile inventors were unlikely to move to other regions. This might explain why MA remained the center of invention even after textile production moved elsewhere.

Evidence from Table 9 supports this hypothesis that electric inventors were younger and more likely to migrate (inferred from place of birth) than shoe and textile inventors.[41] While shoe and textile inventors had similar average ages, electric inventors were, on average, at least 8 years younger than inventors in the two mature industries in 1890 and 1910. Furthermore, among the three industries, electric had the highest proportion of inventors born in different regions from where they resided when they received their patents.[42] To systematically test the difference in age and mobility across regions and industries, I also perform a regression analysis of log age on year, sector, and regional dummies as well as a probit analysis of whether the inventors were born in the states other than their places of residence. The results are reported in Table 10. Equations 1 and 2 show that electric inventors were much younger than shoe and textile inventors, even after controlling for other factors of possible relevance such as region. Likewise, equations 3 and 4 indicate that electric inventors were significantly more likely to have moved than inventors in the traditional industries, after controlling for age and other variables.[43] This evidence offers support to the notion that Massachusetts long remained the leading center of invention in shoes and textiles because of its historically-determined (tracing back to the first half of the 19th century) stocks of technical knowledge, as well as perhaps as the evolution of institutions and other conditions over time that made it easier to trade in technology across regions.

Electrical technology was new, and there was no analogous regional concentration of individuals with the appropriate human capital when the industry began to take off at the end of the 19th century. Moreover, because those with the appropriate technical knowledge were typically younger and more inclined to migrate (than their counterparts in shoes and textiles), there was greater potential in electricity for the development of new centers of electric invention if a region could offer other conditions conducive to inventive activity in that industry. One condition that was likely important, in addition to high demand for the technology in attracting inventive activity in electricity, were institutions that facilitated the mobilization of capital to support R&D and/or trade in technological knowledge (often embodied in patent rights). Funds to carry out inventive activity were especially important in industries such as electricity, where the technology was complex and capital-intensive, and inventive activity often involved large teams of researchers, expensive equipment, and long series of experiments by trial and error. Consequently, to be able to raise funds and mobilize resources for their inventive activity, inventors in such industries would be expected to tend to cluster in proximity to where institutions that facilitated trade and investment in technology, such as banks, security markets, and patent agents, were clustered.

Because such institutions were located in urban areas, one way of examining their importance on inventive activity is to look at the rates of patenting in urban areas as compared their rural counterparts. Table 11 reports the shares of patents granted to patentees who resided in U.S. urban areas for each industry.[44] The evidence seems consistent with the hypothesis that such institutions (and other conditions distinctive to cities) were conducive to inventive activity. By 1910, more than 50% of the shoe, textile and electric patents were granted to inventors living in counties of at least 100,000 residents in their biggest cities (counties in which 26.7% of the population resided). Furthermore, the electric industry had the highest shares of patents (just under two-thirds) granted to inventors living in counties with at least 100,000 residents in their biggest cities. This pronounced concentration of electric inventors in big cities was likely at least partially due to them being especially dependent on institutions facilitating trade and investment in technology.

The clustering of invention in urban areas is even more apparent when we examine the shares of patents as compared to employment by urban areas (with at least 25,000 residents in the county's biggest city in MA, NY and PA for each industry illustrated in Figures 4-6. The county-level record also seems to suggest that such institutions associated with the biggest cities might have an impact on the location of invention. The most urbanized cities in the three states (class 250): Boston (Suffolk county), New York, Philadelphia and Pittsburgh (Allegheny county) had disproportionate patenting rates as compared to employment in each of the three industries. So did the counties in MA that were adjacent to the city of Boston for shoe invention.[45]

To systematically examine the impact of market institutions on the clustering of invention, I employ a probit analysis to estimate whether the probability that a patentee lived in an urban area (county with at least 100,000 residents in its biggest city) was associated with the industry of the invention, with whether the inventor had moved from another state, the age of the inventor, region, or time (equations 1 and 2 of Table 12). Because some scholars such as Lamoreaux and Sokoloff (1999, 2000) suggest that assignment seems to reflect the propensity or ability of inventors to mobilize support for their activity and/or the degree of individual specialization at invention, I also use probit analysis to estimate whether the probability that the patentees assigned their patents at issue was associated with the industry that the inventors worked for, whether the inventors had moved from other states, and whether the inventors lived in urban areas, controlling for time trends, the age of the inventor and other regional characteristics (equations 3 and 4 of Table 12). The results presented in Table 12 support the view that access to institutions for trading intellectual property and mobilizing resources to support inventive activity mattered, especially in an industry based on a new and capital-intensive technology. Inventors in the electric industry were much more likely to live in urban areas than those involved in other industries, and those who migrated across state boundaries were also more likely to be residing in cities than their sedentary counterparts. These findings are consistent with the notion that conditions in cities were very attractive to inventors during this era, and especially attractive to those focused on a new and capital-intensive industry. That cities were distinctive for their more extensive opportunities to mobilize capital for inventive activity, or to trade in patent rights, is further suggested by the results that inventors residing in urban areas, as well as those patenting inventions pertaining to the electric industry, were much more likely to assign at issue.

Because the ability to raise funds and to mobilize resources was particularly important for electric inventors, and because they were more willing to move to areas that could offer them better opportunities, there was more potential for change over time in centers of invention. One region might replace existing centers of electric invention and become a new center if it could develop effective means for financing inventive activity – and accordingly attracting highly productive inventors from other areas. Not only do our general samples of patents suggest this pattern, but the early history of the electric industry is replete with many examples of how finance influenced famous electric inventors in their choice of location:

> A lawyer from New Britain, CT, Frederick H. Churchill, came to Philadelphia early in 1880 and asked [Elihu] Thomson to become the electrician (that is, the electrical engineer) of a new electrical manufacturing company that was being organized in New Britain. The American Electric Company was then established in New Britain, CT in July 1880. Later in 1882, a group of Lynn businessmen formed a syndicate to buy American Electric after talking with Thomson. In April 1883, the company was renamed to the Thomson-Houston Electric Company and established its manufacturing plant in Lynn, MA in fall 1883.[46]

> By 1879, he [Charles J. Van Depoele] was lighting his own shops and had given several arc-lighting exhibitions in Detroit [where his shop was located]. In 1880, he began thinking seriously of manufacturing and selling arc-lighting equipment. At first he planned to set up a factory in Detroit, but as a result of the financial support of Aaron K. Stiles, a Chicago capitalist, the new firm was located in Chicago. The Van Depoele Electric Light Company was incorporated on April 25, 1881, and very shortly afterward began marketing an arc-lighting system.[47]

If our interpretation is correct, the inventors that had more technical skills, migrated across states, and that assigned their patents at issue should all have been more productive or specialized at patenting than their counterparts. Table 13 reports a set of regressions with the number of patents granted to each inventor over 7 years (our gauge of productivity at invention) on: (i) whether he assigned his patent at issue, (ii) whether he had moved from another state or country, (iii) his work experience, and (iv) unobservable region-specific characteristics, controlling for time trends and age. Equations 1-9 seem to support the findings from previous sections. First, inventors who assigned the rights to their invention to other parties were more productive than those who did not. Second, in shoes and textiles, inventors with mechanical knowledge (reflected by their experience in tools and machinery) were more productive than inventors associated with shoe and textile production. In electric, inventors with experience in the electric industry also received more patents. Third, inventors who had migrated appeared to be more productive – at least in the shoe and electric industries. This is because places that offered attractive conditions for inventors would both encourage/help inventors there to focus more on invention as well as attract the more ambitious and talented. Finally, shoe and textile inventors who lived in Massachusetts, the very region that seemed to benefited from stocks of industry-specific technical knowledge, were much more productive than those resided elsewhere. On the other hand, in the South, the region that had relatively low human capital, inventors, appeared to be less productive than those resided elsewhere, especially in the electric industry.[48]

5. CONCLUSION

To investigate the influence of the location of production and other factors on the location of invention, as well as the relative importance of such factors across industries, this paper has examined the experience of selected technologically-mature and "high-tech" industries during the Second Industrial Revolution. Both the evidence drawn from geographic patterns of patenting and production, as well as from close examination of the work histories and experience of patentees, suggests that invention was overall not directly associated with production. Not only were there important discrepancies in each of the industries between the geographic distributions of inventive activity and production, but the most productive inventors, and those disproportionately located in the centers of invention, were distinguished more by their strong technical backgrounds than by their actual involvement in production. Moreover, regional shifts in where production was carried out seldom inspired corresponding increases in invention. Regions that had high rates of patenting in an industry were those that had abundance of individuals with the technical skills appropriate to the technology in that sector.

Although regional differences in the availability of individuals with the appropriate technical skills may have been partially due to the location of contemporaneous production, I argue that other factors played a more important role. The dominance of Massachusetts in accounting for new technologies in shoes and textiles came from the concentration of the tools and machinery sector in that state (and in southern New England more generally) since the early- and mid-19th century. It was individuals with the technical knowledge that had accumulated through experience in tools and machinery (or in some sense, the industry that produced the capital goods for a wide range of industries that had mechanized during the First Industrial Revolution) who were the most productive generators of new technologies in the shoe and textile industries, such that even as production in these industries shifted to the South and elsewhere late in the century, the locations of the centers of invention remained the same. Indeed, their centrality, if anything, increased. With improvements in transportation, communication, and institutions involved in the transfer of technology across regions, it was not necessary for those equipped with the technical knowledge to be effective at invention to locate where their inventions would be applied to production.

The sources of regional differences in the abundance of individuals with the specialized knowledge required to be effective at invention in the electric industry (one that was based on a new and radically different technology) were somewhat different. Here, the reliance on individuals with technical knowledge was even stronger because of the greater complexity of the technology. However, because the technology was just beginning to be introduced in the 1880s, and because familiarity with the basic elements of electricity was scarce, there were no long established concentrations of individuals with the requisite human capital. The closest analogue, perhaps, were the locations of engineering schools or other institutions of higher learning with programs in other fields related to electricity. The enormous enthusiasm about the future prospects for the electric industry meant that technologically creative individuals could realize substantial returns if they had obtained the proper training from through these schools or through other means. Perhaps because of the extraordinary returns that were available to them, and perhaps because those just out of school are often footloose, the inventors were highly mobile and attracted to the major cities and regions where the capital to support R&D and/or trade in technological knowledge (often embodied in patent rights) was abundant. Funds to carry out inventive activity were especially important in industries such as electricity, where inventive activity often involved large teams of researchers, expensive equipment, and long series of costly experiments. Although the geographic patterns of invention in the new technology industry offer striking contrasts with those in shoes and textiles, in that the former was characterized by grater variability over time in the locations of high rates of invention, again the location of inventive activity was not so directly associated with production.

The historical experience we have examined in this paper suggests that those less-developed countries that are recipients of shifts of production today may have to wait a long time before they develop into important contributors to new technological knowledge. The build up of stocks of industry-specific technical knowledge sufficient to support high levels of inventive activity will not follow smoothly from an increase in production. Even if these countries undertake policies aimed at promoting human capital formation, the process would likely take many years. Indeed, in many ways the difficulties facing follower countries that seek to move quickly to the technological cutting edge seem even more formidable in the early 21st century than they were in the 19th century. Operating at the technological frontier requires much more technical and specialized knowledge today than it did a century ago, and those countries that have only recently begun to industrialize are much further behind the leaders than were the developing nations of the late-19th century (i.e. Germany, Sweden, and Japan). The challenge is certainly daunting, and it would not be surprising if many observers found the prospects gloomy. However, a more optimistic perspective on the same circumstances can be reasonably offered. An enormous gap between the technology at the cutting edge and the technology in use suggests that there is ample room for advance in a less-developed country's total factor productivity. In other words, it is both quite possible and desirable for a follower to realize substantial productivity and economic growth, even without being responsible for shifting out the technology frontier. Even as regards developing a potential for high rates of invention, improvements in transportation and communication have made it easier for developing countries today to send their people to receive formal training abroad, or to otherwise access technological information, than it was during the Second Industrial Revolution.[49] The examples of South Korea and Taiwan give confidence that the case for optimism is based on more than mere hope.

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III. Internet Resources

www.ancestry.com

www.familysearch.org

www.genealogy.com

www.ieee.org

www.uspto.gov

ENDNOTES

[1] The term "learning by doing" has meanings in many different contexts. For example, it is applicable to learning arise from both production and invention. In this paper, I, therefore, use the term "learning by producing" when there is a learning effect associated with production of goods. See, for example, Arrow (1962) for learning by doing theory.
[2] For discussions of mechanisms that allow division of labor between invention and production, see Arora et al. (2001) and Lamoreaux and Sokoloff (2000).
[3] See Chandler (1977) for details of vertical integration and Lamoreaux (1985) for horizontal mergers.
[4] See Temin (1972) for more details.
[5] The Edison General Electric Company was at Menlo Park, NJ and later moved to New York, NY. The Westinghouse Electric Company was located in Pittsburgh, PA. The Thomson-Houston Electric Company was established in Lynn, MA after its brief stay in Philadelphia, PA and New Britain, CT. (The company was called the American Electric Company when it was located at New Britain, CT.) The Brush Electric Company was located in Cleveland, OH.
[6] Most of these inventions were only applicable in labs and merely a few inventions were reliable and cost-effective enough to be exploited commercially. See Passer (1953) and Hughes (1983) for more details on the electric industry.
[7] See Krugman (1991a) for a formalization of Marshall's theory.
[8] However, one needs to interpret the correlation between manufacturing labor force and invention suggested by the data, if any, with caution because the "circular causation" problem could arise. Manufacturing might tend to locate where there has been new discoveries of technology, and the resulting expansion of production could then feed back to generate more invention. In order to get around this circular causation problem, one may use measures contributing to production concentration such as transportation costs and region-specific natural resources as instruments for production. Even though one could identify all inputs of the industries of interests and find sensible instruments for manufacturing concentration, this might not allow for cross-industry comparisons. The second way to test the (clustering of production) hypothesis while avoiding circular causation is to examine the change in inventive activity of industries with exogenous manufacturing shocks that move centers of production to the new areas. The third way is to examine the actual work histories of inventors up to the time of invention.
[9] This is a slight variation of Alchian (1963). In the paper, he suggests that higher learning rates occur at the beginning of production and will dissipate over time.
[10] For example, see Adams and Jaffe (1996) for discussion of technological spillovers and Lamoreaux and Sokoloff (1999) for a discussion of market institutions.
[11] Because not every invention is patentable and not every patentable invention is patented, patent statistics may not reflect inventive activity in industries that rely on other mechanisms such as secrecy. However, this would not be a major issue for the questions addressed in this paper. First, unlike the food, chemical and pharmaceutical industries, the three industries selected often employ patent rights to protect their invention. Second, even if there were some secrecy involved, it is unlikely that these practices would vary across regions. Third, previous literature has shown that patent statistics are a reasonable economic indicator. See Griliches (1990) for more detailed discussion.
[12] Therefore, it might include invention in other industries.
[13] The number of shoe and textile invention is comparable to the time series patent data collected by Schmookler (1972).
[14] In the Census of Manufactures, the U.S. Bureau of Census reported all electric-related production in one single category: electrical apparatus and supply that includes production of goods that are not included in my electric invention classification such as electric transportation equipment. Therefore, the electric production data in this dataset might not reflect the actual level of manufacturing activity in electric industry.
[15] The random sample was collected by Lamoreaux and Sokoloff. See Lamoreaux and Sokoloff (1999) for more details.
[16] The majority of 1890 census manuscripts were lost because of the 1921 fire at the U.S. Department of Commerce.
[17] The construction of this inventor dataset is made possible by recent development in imaging and internet technology. Genealogy.com and Ancestry.com provide the searchable census manuscript images. In addition, Ancestry.com supplies city directory information. Only household heads are searchable in the on-line databases for most of the census years, except those for 1880 and 1930 that allow users to search for

individuals who were not household heads. Therefore, I look for other information to identify the inventor's head of household when I cannot find him from the census manuscripts. Such information includes family history data on name as well as on date and place of birth of inventor, parents, siblings, spouses and in-laws, and children (to infer inventor's place of residence from children's place of birth) provided by Ancestry.com and Familysearch.org. Moreover, for the more prolific inventors, especially in the electric industry, their biographical information could often be retrieved from other on-line sources such as Ancestry.com and IEEE history center. Whenever possible, I cross check information obtained from the census manuscripts with other information and vice versa. But, there would still be a small bias in my sample. First, young, single, and foreign-born inventors are least likely to be heads of households, and thus cannot be located. Second, there are too many people with the same information for inventors who had common names and/or lived in urban areas. The probabilities that I have birth and age information of inventors (weighted by number of patents) are 87% for 1870, 69% for 1890, and 81% for 1910. However, the occupation matching rates would be lower because I could not locate the inventors in every census throughout their adult life.

[18] Precisely, whether there was a one-to-one relationship between shares of patents and those of employment.

[19] The three figures clearly demonstrate that the shares of population cannot explain the geographic variation in each industry's inventive activity, as measured by patent shares.

[20] One might argue that the rise in shoe and textile patenting shares in MA may be because the two industries were declining sectors in technologies. Table 2, however, shows that the total number of patents in both industries still increased over time.

[21] One might argue that for inventors with close ties with multi-state firms – especially those in electric industry, the addresses from patent records might be their business addresses not their actual place of residence. However, among inventors that I can find a match in the census manuscript, most of them probably lived in various places in one year (by drawing inference from their children's birth places).

[22] At first, the finding that shoe and textile invention were more clustered than those for the electric industry might seem to be inconsistent with the hypothesis that inventors in emerging-technology industries might be especially likely to cluster in geographic pockets, as compared to those in mature industries, in order to exploit the opportunities to exchange ideas and receive the most up-to-date information on new development. However, this finding does not necessarily contradict the technological spillovers hypothesis. Because the patent shares are calculated from regional level statistics, they only indicate the extent to which the patenting rates vary across regions, not whether inventive activity was highly clustered in a few areas within a region. To test the technological spillovers hypothesis, one would need to examine the geographic patterns at a civil division smaller than a state. In section 4.4, I will show that electric invention was, indeed, much more concentrated in urban areas than shoe and textile invention.

[23] One might argue that the abnormally high levels of shoe and textile inventive activity in Massachusetts might be due to increasing returns associated with the clustering of production. However, were the clustering of production the only crucial factor favorable to invention, we would expect the South to have much more textile invention because its share of employment was comparable to that in Massachusetts by 1910.

[24] One might argue that a patent count might not be an appropriate measure for inventor productivity because it does not take into account the quality of each invention. A possible way to correct for quality is to use citation data. Unfortunately, such information is not available for historical data. However, from my preliminary investigation of detailed description for invention in the sample, I do not find a systematic variation in quality or type of invention across regions.

[25] I cannot make a distinction between production of electrical goods and electrical equipment because the population census manuscript did not provide a detailed description that differentiated the two occupation types. However, almost all of electric inventors did not seem to be involved in production because the majority of them had their occupations reported as electricians or electrical engineers.

[26] The fall in inventor productivity in electric inventions probably reflects the fact that 1875-1890 was the era of great discoveries in electric technology.

[27] These inventors might be involved in production. However, it would be because they had better ideas on how to construct the electrical products because they helped design them. Their primary jobs were not in production. See, for example Passer (1953) and the IEEE History Center for more details.

[28] See, for example, Thomson (1989) and Copeland (1909) for the technological development in the shoe and textile industries, respectively.

[29] See Rosenberg (1963) and Hounshell (1984) for the development of the machinery sector and Thomson (1989) for discussion on cross-over invention between shoe and other industries.

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30 Another striking finding is that although the South's shares of textile inventors with work experience in the production of textile goods grew larger, median productivity (as measured by the number of patents granted to an inventor in a 7-year period) of such inventors was much lower than those in other regions. The textile production workers in the South did not appear to have had as many skills conducive to invention as did their counterparts elsewhere. See, for example, Wright (1981) for discussion of the South's low skilled labor during this period.

31 In 1910, inventors with experience in production of shoes living in NJ and PA had median productivity comparable to that of their counterpart in MA.

32 Other states are NY, PA and CT.

33 See Table 6 for shares of machinists comparing to those of population by regions.

34 Nathan Rosenberg calls this single solution to the common problems as "technological convergence." See Rosenberg (1963) and Hounshell (1984) for the development of the machinery sector and Thomson (1989) for discussion on cross-over invention between shoe and other industries.

35 Evidence from Tables 4 and 5 also appears to be consistent with this idea that specialization might result from sufficient demand for industry-specific capital goods. Comparing work experiences of inventors in regions with a nontrivial tool and machinery sector but less shoe and textile production than MA – such as NY and PA – *across industries*, although much smaller than MA in both industries, their shares of inventors with experience in tools and machinery were larger for textiles – an industry of which they had a higher production level – than those for shoes – an industry of which they have a small production volume. (Although SNE had small shoe production, we would expect the region to have some access to market in MA given the short distance between the two regions.)

36 One should be careful at interpreting these simple regressions. The regressions do not deal with endogeneity of the factors influencing geographical patterns of invention. For example, there might be a circular causality between geographical clustering of invention and production. Production is likely to spread from the birthplace of new technology and the expansion of production would feed back to generate more invention. However, the relocation of textile industry to the South, several systematic deviations of inventive activity from production and work experiences of inventors discussed previously suggest that the endogeneity problem should not be strong.

37 After regional dummies are added to the electric regression (Equation 12), the coefficient for shares of engineers is no longer significant. However, such an inclusion of regional dummies does not pass the F-test. The loss of significant level could be due to either the small number of observations or the fact that Equation 8 might fit the electric data better. In addition, the regressions reinforce earlier findings. Although proximity to production, or learning by producing, matters, it does not generate more than average patenting, i.e. no increasing returns associated with production clustering. Moreover, the unusual cluster of shoe and textile invention in MA seemed to stem from factors other than production. As discussed in section 4.2, a pool of population with knowledge of mechanical technologies combined with large demand for industry-specific capital goods might influence the location of invention. (The fact that the coefficients for the share of machinists were not distinguishable from 0 in Equations 6, 7, 10, and 11 seems to suggest that this simple proxy might not be able to capture the historically-determined industry-specific technical knowledge that built upon both a pool of population with mechanical technologies and a sufficient demand for industry-specific capital goods.) The employment coefficients in all equations are not distinguishable from 1 in Equations 6 and 7, and become much smaller than 1 after the regional dummies enter the regression (Equations 10 and 11), while the coefficients for MA dummy in Equations 10 and 11 are positive and statistically significant. The significant decrease in employment share coefficients after regional dummies enter the regressions (Equations 9-12) as well as the nontrivial regional coefficients seems to suggest that there might be latent regional characteristics affecting the patent shares other than production and shares of workers in technical fields. The inclusion of regional dummies in Equations 9-11 passes the F-test suggesting that the specification with regional dummies may fit the shoe and textile data better and without controlling for such regional characteristics, the employment coefficient might be biased. (A possible way to correct this bias is to find an appropriate instrument for production. However, this would not be an easy task, and the instrument would not be informative in identifying other regional differences that were conducive to invention. An alternative way to understand the relationship between production and invention and to identify regional characteristics that influence the patenting rates is to examine each region at a micro level like what is done in previous sections.)

38 See Lamoreaux, Levenstein, and Sokoloff (2003) for details about the extraordinary returns to electric inventors in Cleveland during the 1880s.

[39] Another reason for why the tool and machinery sector located nearby the manufacturing sector was that machines had not been standardized and it was necessary to provide on-site maintenance service.

[40] Machinery firms with multi-state sales networks were such as the Draper Companies for textiles and the McKay Shoe Machinery Company, which later became the United Shoe Machinery Company in 1899 after merging with another 4 firms, for shoes. For more details, see Feller (1966) and Thomson (1989), respectively. Large machinery firms in MA extended credits to mill owners in the South allowing them to install newer machinery for textile production, while the Northeast mills still used older equipment after the relocation. See, for instance, Kane (1988) for more details.

[41] There were no systematic variation in age and birthplace across regions.

[42] The difference between the shares of electric inventors who were born in regions other than their place of residence and those of shoe and textile inventors would be underestimated because the measures do not take into account the fact that electric inventors were much younger than those in shoes and textiles.

[43] The age coefficient is positive and statistically significant because the older an inventor was, the more likely we observe his migration given the longer time duration.

[44] I did not compare the shares of employment in urban areas with those of patents because the Census Bureau did not report employment in small or medium cities nor employment in cities with less than 3 manufacturing establishments.

[45] A comparison of how the centers of invention within each state evolved across industries also reveals an interesting finding. While over time some centers of shoe and electric invention were replaced by other counties of the same states, textile invention was increasingly concentrated in one county – Worcester. This seems to indicate that there might be increasing returns associated with technological spillovers in Worcester. In fact, the county of Worcester was home to many leading textile machinery firms such as the Crompton and Knowles Loom Works and the Draper Companies. In contrast, for shoes and electric, other factors might have more influence on the clustering of invention than the spillovers effect.

[46] Passer (1953), pp. 22, 24 and 26.

[47] Passer (1953), p. 230.

[48] Nonetheless, the impact of assignment and work experiences on productivity estimated by the regression (equations 1-6) seems to be biased because the coefficients decline substantially after regional dummies entered the regression (equations 7-9), especially for shoes and textiles. This seems to suggest that assignment, work experiences as well as some regional characteristics might be correlated with one another. Therefore, other instruments might be more appropriate to estimate their effects on inventor productivity. This would be, however, beyond the scope of this paper.

[49] There is also a limit for the extent to which the findings from the paper can be generalized to explain the contemporary events. Because this paper examines the historical evidence of one single country, it does not take into account the possibility of different legal regimes and lesser inventor mobility. Furthermore, Massachusetts still had substantial textile production (about 20% in 1910) even after the relocation of production. Were the region to have an insignificant share of textile production after the relocation, the geography of invention might have been different.

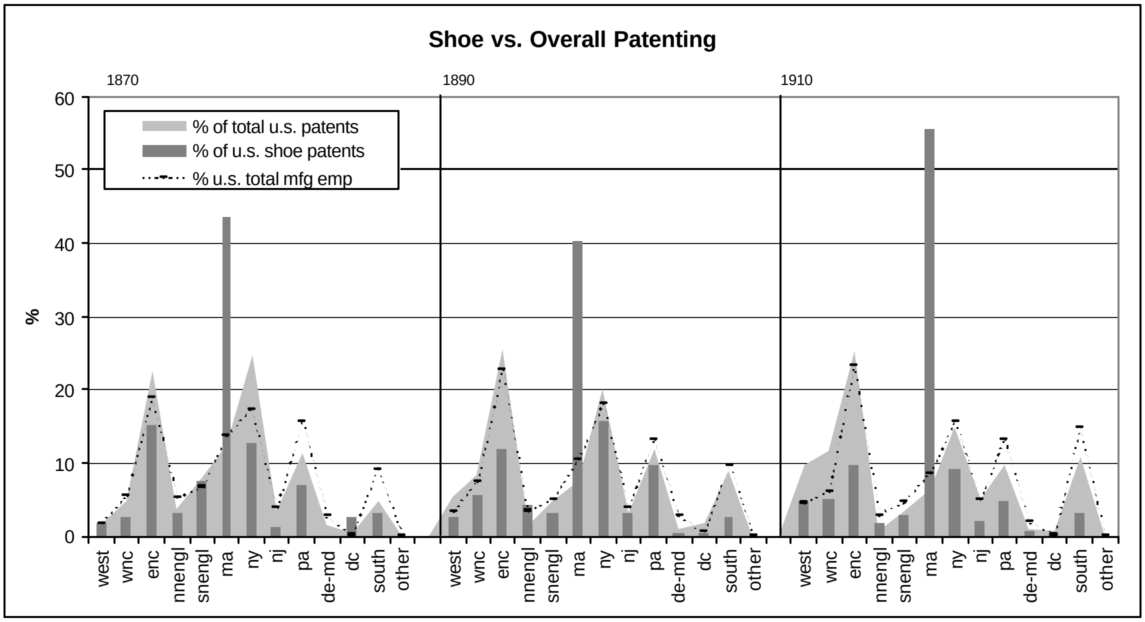
Table 1: Number of Patents, and Shares of Patents and Manufacturing Labor Force by Industries

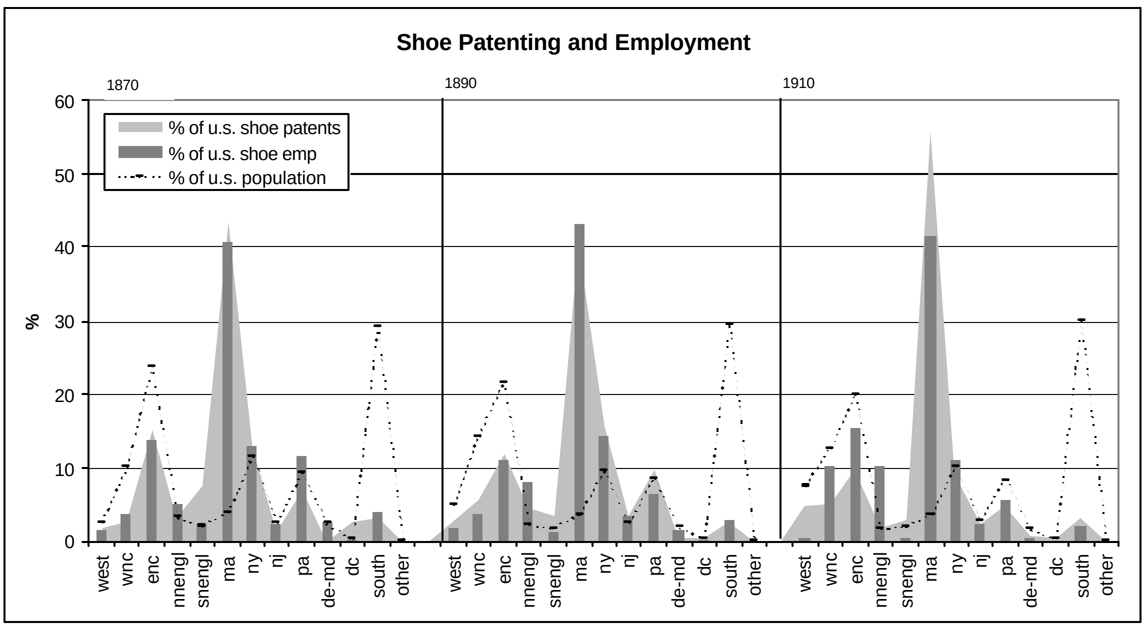
	number of patents			share of patents (%)			share of mfg labor force (%)		
year	shoes	textiles	electric	shoes	textiles	electric	shoes	textiles	electric
1870	165	255	18	1.4	2.1	0.1	6.8	13.9	0.0
1890	289	511	582	1.1	2.0	2.3	4.1	11.1	0.2
1910	462	582	754	1.3	1.7	2.1	2.8	11.6	1.4

Notes: (1) The electric industry was an emerging industry during the late 19th and early 20th centuries, and thus there were no manufacturing data reported for it in 1870. (2) The share of manufacturing labor force is calculated from manufacturing employment in each industry over the total U.S. manufacturing employment. (3) The share of patents is estimated from the number of patents in each industry over the total number of patents. (4) The share of patents and number of patents include patents granted to patentees who did not resided in the U.S. The analyses in the following sections, however, employ only information of patentees who resided in the U.S.

Sources: (1) Annual Report of the Commissioner of Patents for 1870, 1890, and 1910. (2) U.S. Census of Manufactures Reports for 1870, 1890, and 1910.

Figure 1: Regional Shares of Employment and Patents for the Shoe Industry as Compared to Those of All Industries and Regional Shares of Population

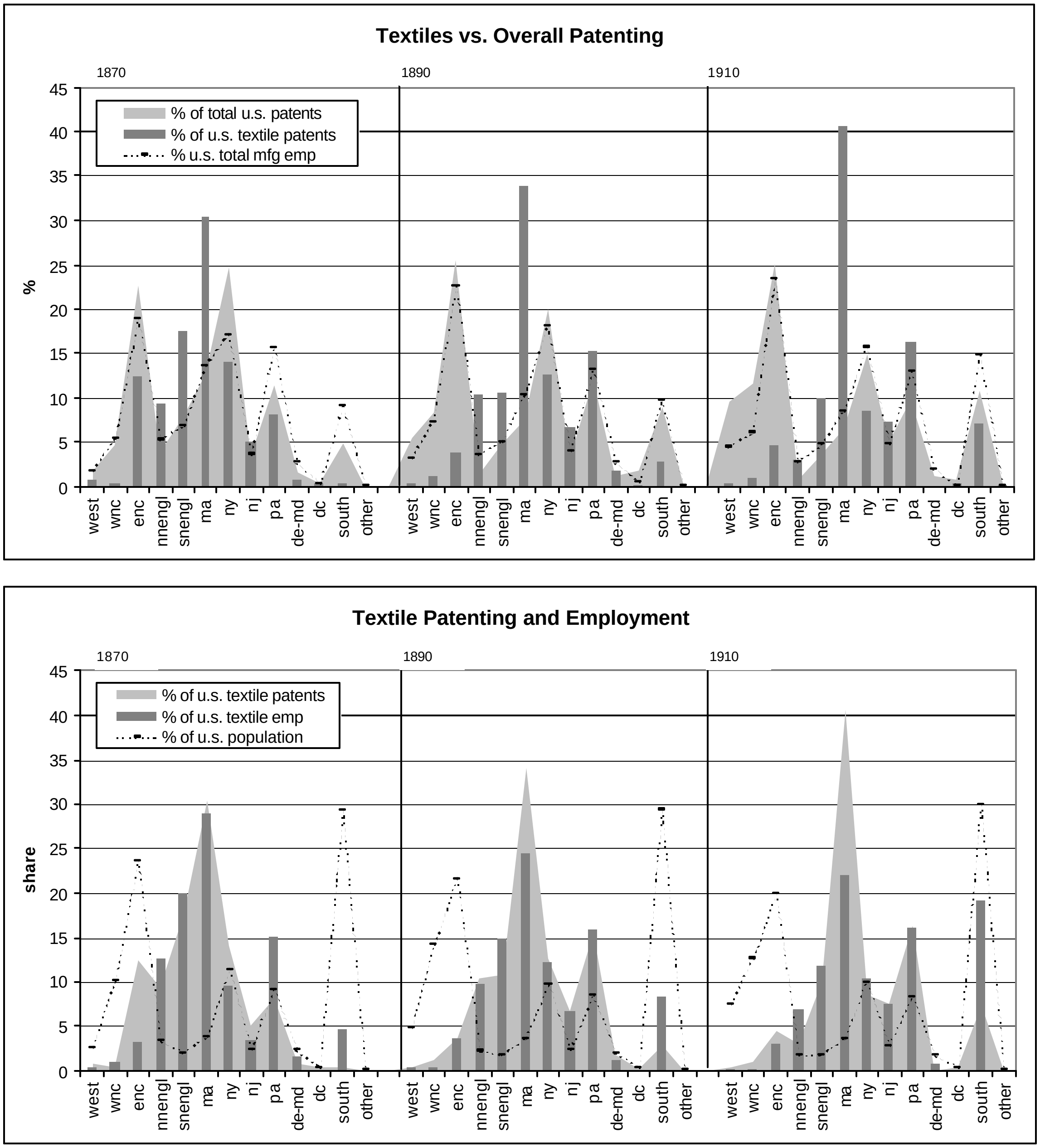




Notes: (1) Created from statistics reported in Table A of Appendix 2. (2) See Appendix 1 for the geographic classification scheme.

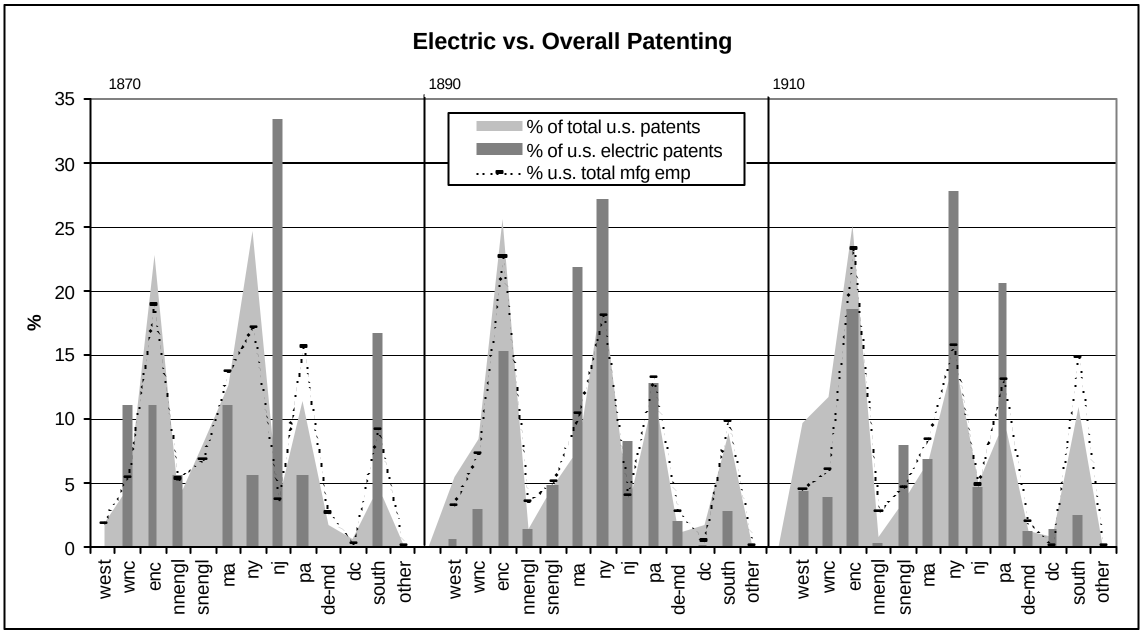
Sources: (1) Annual Report of the Commissioner of Patents for 1870, 1890, and 1910. (2) U.S. Census of Manufactures Reports for 1870, 1890, and 1910. (3) Lamoreaux-Sokoloff random sample of all patents granted in 1870, 1871, 1890, 1891, 1910, and 1911. (4) U.S. Census of Population Reports for 1870, 1890, and 1910.

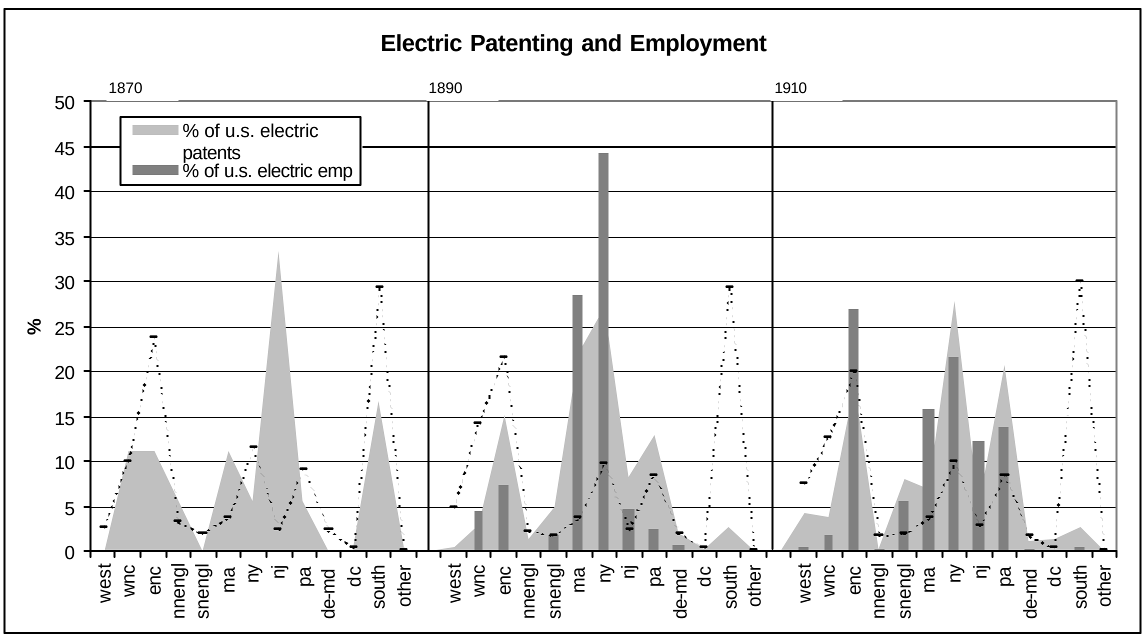
Figure 2: Regional Shares of Employment and Patents for the Textile Industry as Compared to Those of All Industries and Regional Shares of Population



Notes: See Figure 1.
Sources: See Figure 1.

Figure 3: Regional Shares of Employment and Patents for the Electric Industry as Compared to Those of All Industries and Regional Shares of Population





Notes: See Figure 1.
Sources: See Figure 1.

Table 2: Work Experiences of Patentees who Resided in the U.S.

industry	year	number of patents	work experience (normalized share): production	tool & machinery	electric	electrically related	other	missing experience (share)	7-yr pat / inventor (median): production or other	tool & mach or electric
shoes	1870	159	0.57	0.16			0.28	0.35	2	3
	1890	270	0.44	0.33			0.23	0.34	1.5	5
	1910	421	0.52	0.31			0.18	0.22	5	9
textiles	1870	234	0.44	0.38			0.18	0.30	2	3
	1890	429	0.43	0.45			0.12	0.33	2	6
	1910	457	0.42	0.47			0.12	0.23	2	8
electric	1870	18		0.13	0.50	0.00	0.38	0.11	2	11
	1890	539		0.07	0.71	0.07	0.15	0.32	4	19
	1910	670		0.07	0.80	0.05	0.08	0.26	5	10

Notes: (1) The indexes for work experience are drawn from inventor's occupation history up to the cross-section year. See Appendix 1 for more details on work experience classification. (2) To obtain the work experience composition, I omit inventors with missing information and normalized the reported shares so that all types of work experience add up to 1. (3) For the median number of patents granted to each inventor within a 7-year period, the statistics for shoes and textiles are reported for two types of inventors: those with experience in product and those with experience in tool and machinery. For electric, the statistics are reported for two types of inventors: those with experience in electric and those without experience in electric or electrically related. (4) The experience composition and the median number of patents received within a 7-year period are weighted by the number of patents.
Sources: (1) Annual Report of the Commissioner of Patents for 1870, 1890, and 1910. (2) U.S. Census of Population Manuscripts for 1850, 1860, 1870, 1880, 1900, and 1910. (3) U.S. City Directories. (4) IEEE History Center.

Table 3: Skills of Patentees who Resided in the U.S.

industry	year	skills (normalized share): no technical skills	model & pattern makers	machinists	draftsmen & engineers	electricians & electrical engineers	probably have technical experience	missing skills (share)
shoes	1870	0.77	0.00	0.13	0.07	0.00	0.03	0.37
	1890	0.54	0.01	0.31	0.05	0.00	0.08	0.46
	1910	0.52	0.02	0.28	0.12	0.00	0.07	0.31
textiles	1870	0.53	0.01	0.34	0.03	0.00	0.10	0.35
	1890	0.37	0.02	0.36	0.05	0.00	0.21	0.48
	1910	0.35	0.00	0.39	0.15	0.01	0.09	0.45
electric	1870	0.59	0.00	0.06	0.00	0.35	0.00	0.06
	1890	0.22	0.00	0.04	0.03	0.51	0.20	0.27
	1910	0.12	0.00	0.07	0.08	0.72	0.00	0.33

Notes: (1) The indexes for technical skills are inferred from inventor's occupation history up to the cross-section year. See Appendix 1 for more details on skill classification. (2) To obtain the skill composition, I omit inventors with missing information and normalized the reported shares so that all types of skills add up to 1. (3) The skill composition is weighted by the number of patents.
Sources: See Table 2.

Table 4: Work Experiences of Shoe Patentees Residing in Selected Regions

year	region	number of patents	shoes: % u.s. emp	shoes: % u.s. patents	% u.s. workers in technical fields	experience (normalized share): production	experience (normalized share): tool & mach	experience (normalized share): other	missing experience (share)	7-yr pat/inventor (median): production	7-yr pat/inventor (median): tool & machinery
1870	ma	69	40.7	43.4	11.3	0.63	0.32	0.05	0.41	2.50	3.00
	snengl	12	2.2	7.5	7.8	0.50	0.17	0.33	0.00	3.00	3.00
	ny	20	12.9	12.6	21.5	0.54	0.08	0.38	0.35	4.00	3.00
	pa	11	11.6	6.9	13.9	0.63	0.00	0.38	0.27	3.00	
	south	5	3.9	3.1	8.9	1.00	0.00	0.00	0.80	1.00	
1890	ma	109	43.2	40.4	8.2	0.42	0.45	0.13	0.29	2.00	5.00
	snengl	9	1.1	3.3	5.3	0.50	0.38	0.13	0.11	3.00	14.00
	ny	42	14.2	15.6	14.4	0.50	0.07	0.43	0.33	1.00	5.00
	pa	26	6.3	9.6	13.3	0.59	0.24	0.18	0.35	1.00	7.00
	south	7	2.8	2.6	11.7	0.50	0.00	0.50	0.71	1.00	
1910	ma	234	41.7	55.6	6.6	0.53	0.44	0.03	0.11	11.00	8.50
	snengl	12	0.3	2.9	3.8	0.50	0.20	0.30	0.17	2.50	11.00
	ny	39	11.1	9.3	14.4	0.60	0.12	0.28	0.36	4.00	10.00
	pa	20	5.5	4.8	12.2	0.58	0.00	0.42	0.40	14.00	
	south	13	2.1	3.1	10.6	0.11	0.00	0.89	0.31	1.00	

year	region	number of patents	experience (count): production	experience (count): tool & mach	experience (count): other	experience (normalized share): production	experience (normalized share): tool & mach	experience (normalized share): other	missing experience (share)	7-yr pat/inventor (median): production	7-yr pat/inventor (median): tool & machinery
1870	us	159	59	16	29	0.57	0.16	0.28	0.35	2	3
1890	us	270	79	58	41	0.44	0.33	0.23	0.34	1.5	5
1910	us	421	168	101	59	0.52	0.31	0.18	0.22	5	9

Notes: (1) See Table 2. (2) Regional shares of technical workers are calculated from the total number of individuals who reported their occupation as machinists, millwrights, engineers (stationary, mechanical, civil, mining and electrical), electricians, toolmakers, pattern and model makers, designers, draftsmen, and inventors in the Census of Population. (3) See Table B in Appendix 2 for statistics of other regions.
Sources: (1) U.S. Census of Manufactures Reports for 1870, 1890, and 1910. (2) See Table 2.

Table 5: Work Experiences of Textile Patentees Residing in Selected Regions

year	region	number of patents	textiles: % u.s. emp	textiles: % u.s. patents	% u.s. workers in technical fields	experience (normalized share): product	experience (normalized share): tool & mach	experience (normalized share): other	missing experience (share)	7-yr pat/inventor (median): production	7-yr pat/inventor (median): tool & machinery
1870	ma	71	28.8	30.3	11.3	0.40	0.50	0.10	0.27	2.00	4.50
	snengl	41	19.8	17.5	7.8	0.64	0.24	0.12	0.20	2.00	2.00
	ny	33	9.5	14.1	21.5	0.53	0.27	0.20	0.55	1.00	3.00
	pa	19	15.1	8.1	13.9	0.42	0.17	0.42	0.37	1.00	10.50
	south	1	4.7	0.4	8.9	0.00	0.00	1.00	0.00		
1890	ma	146	24.5	34.0	8.2	0.34	0.63	0.03	0.19	3.00	11.00
	snengl	46	15.0	10.7	5.3	0.58	0.33	0.09	0.28	2.00	4.00
	ny	54	12.2	12.6	14.4	0.50	0.21	0.29	0.48	1.50	1.50
	pa	66	15.9	15.4	13.3	0.63	0.32	0.05	0.38	3.00	3.00
	south	12	8.3	2.8	11.7	0.60	0.00	0.40	0.58	1.00	
1910	ma	186	22.1	40.6	6.6	0.30	0.63	0.06	0.13	2.00	12.00
	snengl	46	11.8	10.0	3.8	0.46	0.46	0.08	0.20	3.00	3.00
	ny	39	10.3	8.5	14.4	0.27	0.35	0.38	0.33	2.00	3.00
	pa	75	16.2	16.4	12.2	0.50	0.40	0.10	0.33	3.00	4.50
	south	33	19.2	7.2	10.6	0.70	0.13	0.17	0.30	1.00	6.00

year	region	number of patents	experience (count): production	experience (count): tool & mach	experience (count): other	experience (normalized share): production	experience (normalized share): tool & mach	experience (normalized share): other	missing experience (share)	7-yr pat/inventor (median): production	7-yr pat/inventor (median): tool & machinery
1870	us	234	72	63	29	0.44	0.38	0.18	0.30	2	3
1890	us	429	125	130	34	0.43	0.45	0.12	0.33	2	6
1910	us	457	147	166	41	0.42	0.47	0.12	0.23	2	8

Notes: See Table 4.
Sources: See Table 4.

Table 6: Shares of Machinists and Population by Regions

	% of u.s. population			% of u.s. machinists			machinists per capita (normalized)		
region	1870	1890	1910	1870	1890	1910	1870	1890	1910
west	2.6	4.8	7.4	0.9	5.0	6.2	0.37	1.03	0.84
wnc	10.0	14.2	12.7	3.5	7.2	6.4	0.35	0.51	0.50
enc	23.7	21.5	19.8	17.9	23.1	30.0	0.76	1.07	1.51
nnengl	3.3	2.2	1.7	5.0	2.6	1.9	1.52	1.18	1.14
snengl	2.0	1.7	1.8	9.2	6.8	5.0	4.72	3.87	2.78
ma	3.8	3.6	3.7	15.1	10.6	8.0	4.00	2.97	2.18
ny	11.4	9.6	9.9	20.8	14.5	13.6	1.83	1.51	1.37
nj	2.3	2.3	2.8	3.2	5.1	4.8	1.38	2.22	1.73
pa	9.1	8.4	8.3	15.1	13.8	13.1	1.65	1.65	1.57
de-md	2.3	1.9	1.6	2.3	2.1	1.5	0.98	1.07	0.91
dc	0.3	0.4	0.4	0.6	0.4	0.5	1.75	1.09	1.40
south	29.2	29.4	30.0	6.2	8.8	9.1	0.21	0.30	0.30

Notes: (1) Machinists includes those who were apprentices to machinists. (2) Normalized machinists per capita are equal to the share of machinists divided by the share of population.
Sources: (1) U.S. Census of Population Reports for 1870, 1890, and 1910. (2) U.S. Census of Manufactures Reports for 1870, 1890, and 1910.

Table 7: Work Experiences of Electric Patentees Residing in Selected Regions

			electric			experience (normalized share)				7-yr pat/inventor (median)	
year	region	number of patents	% u.s. emp	% u.s. patents	% u.s. workers in technical fields	electric	mach & elec-rel	other	missing experience (share)	other	electric
	enc	2		11.1	18.3	1.00	0.00	0.00	0.00		11.00
	snengl			0.0	7.8	0.00	0.00	0.00	0.00		
	ma	2		11.1	11.3	0.00	1.00	0.00	0.00	7.00	
	ny	1		5.6	21.5	0.00	0.00	1.00	0.00	1.00	
	nj	6		33.3	3.9	1.00	0.00	0.00	0.00		11.00
	pa	1		5.6	13.9	0.00	0.00	1.00	0.00	1.00	
	south	3		16.7	8.9	0.00	0.00	1.00	0.00	9.00	
	enc	82	7.5	15.2	22.8	0.61	0.26	0.13	0.54	3.00	20.00
	snengl	26	1.8	4.8	5.3	0.36	0.45	0.18	0.15	4.00	7.00
	ma	118	28.5	21.9	8.2	0.85	0.05	0.10	0.10	4.00	49.00
	ny	146	44.3	27.1	14.4	0.71	0.21	0.08	0.51	11.00	19.00
	nj	44	4.6	8.2	4.6	0.78	0.03	0.19	0.16	4.50	77.00
	pa	69	2.4	12.8	13.3	0.78	0.08	0.14	0.26	1.50	33.00
	south	15	0.0	2.8	11.7	0.38	0.38	0.25	0.47	3.00	2.00
	enc	124	27.1	18.5	26.3	0.71	0.16	0.13	0.33	4.00	10.50
	snengl	53	5.5	7.9	3.8	0.63	0.26	0.11	0.34	5.00	17.50
	ma	46	15.8	6.9	6.6	0.89	0.11	0.00	0.17	14.50	8.00
	ny	186	21.6	27.8	14.4	0.86	0.11	0.03	0.20	6.00	17.00
	nj	32	12.3	4.8	4.6	0.79	0.21	0.00	0.41	11.00	12.00
	pa	138	13.9	20.6	12.2	0.90	0.04	0.07	0.24	8.00	11.00
	south	17	0.5	2.5	10.6	0.54	0.08	0.38	0.24	2.00	2.00
			experience (count)			experience (normalized share)				7-yr pat/inventor (median)	
year	region	number of patents	electric	mach & elec-rel	other	electric	mach & elec-rel	other	missing experience (share)	other	electric
1870	us	234	8	2	6	0.50	0.13	0.38	0.11	2	11
1890	us	429	257	51	56	0.71	0.14	0.15	0.32	4	19
1910	us	457	395	60	40	0.80	0.12	0.08	0.26	5	10

Notes: See Table 4.
Sources: See Table 4.

Table 8: Regressions of Regional Patent Shares on Shares of Employment, Shares of Individuals with Appropriate Skills, and Regional Dummies

	(1) Pooled	(2) Shoes	(3) Textiles	(4) Electric	(5) Pooled	(6) Shoes	(7) Textiles	(8) Electric	(9) Pooled	(10) Shoes	(11) Textiles	(12) Electric
Constant	0.733	-0.412	-0.391	3.137*	0.632	0.040	-0.920	1.036	2.446	2.482	4.397*	6.359*
	(0.626)	(0.764)	(1.195)	(1.151)	(0.833)	(0.982)	(1.428)	(1.399)	(1.672)	(1.938)	(1.985)	(2.665)
% U.S. Labor Force in the Industry	0.927**	1.061**	1.059**	0.643**	0.882**	1.081**	1.034**	0.576**	0.633**	0.297	0.671**	0.251
	(0.048)	(0.055)	(0.105)	(0.082)	(0.059)	(0.061)	(0.112)	(0.081)	(0.072)	(0.206)	(0.139)	(0.140)
% U.S. Machinists					0.204	-0.073	0.088		-0.123	0.071	-0.194	
					(0.159)	(0.099)	(0.128)		(0.198)	(0.175)	(0.171)	
% U.S. Engineers					-0.148			0.318*	0.222			0.395
					(0.149)			(0.139)	(0.165)			(0.200)
Massachusetts									12.448**	30.738**	15.897**	0.435
									(2.444)	(7.715)	(2.762)	(3.704)
Southern New England									1.396	1.240	-0.693	-1.763
									(1.960)	(2.254)	(2.233)	(3.375)
New York									1.324	5.046	3.340	7.166
									(2.067)	(2.615)	(2.386)	(4.816)
East North Central									0.156	4.109	4.843	-2.911
									(2.789)	(3.179)	(3.709)	(4.502)
South									-4.521*	-0.982	-6.541**	-9.098*
									(1.985)	(2.170)	(2.056)	(3.483)
Other U.S.									-2.474	-1.280	-3.322	-6.801*
									(1.505)	(1.747)	(1.814)	(2.429)
Observations	96	36	36	24	96	36	36	24	96	36	36	24
R-squared	0.80	0.92	0.75	0.74	0.80	0.92	0.75	0.79	0.86	0.96	0.93	0.89

Standard errors are in parentheses. * significant at 5% level and ** significant at 1% level.

Notes: (1) Electric data for 1870 are excluded from the regressions because there are no production data available for that year. (2) Regional shares of engineers are calculated from the total number of individuals who reported their occupation as stationary, mechanical, civil, mining and electrical (or electrician) engineers in the Census of Population. (3) For Equations 9-12, the constant term reflects Pennsylvania, and Other U.S. includes West, West North Central, Northern New England, and DE-MD.

Sources: (1) Annual Report of the Commissioner of Patents for 1870, 1890, and 1910. (2) U.S. Census of Manufactures Reports for 1870, 1890, and 1910. (3) U.S. Census of Population Reports for 1870, 1890, and 1910.

Table 9: Age and Migration Experience of Patentees who Resided in the U.S.

industry	year	number of inventors	number of patents	age: mean	age: s.d.	birth place composition (normalized share): foreign born	birth place composition (normalized share): born outside region resided	birth place composition (normalized share): born outside state resided	missing birthplace (share)
shoes	1870	155	159	39.8	9.5	0.17	0.47	0.48	0.26
	1890	268	270	43.0	10.9	0.22	0.55	0.56	0.28
	1910	405	421	48.0	10.0	0.24	0.59	0.62	0.18
textiles	1870	228	234	41.3	10.9	0.27	0.58	0.61	0.18
	1890	426	429	44.1	11.4	0.29	0.63	0.65	0.32
	1910	449	457	47.0	12.0	0.37	0.60	0.64	0.18
electric	1870	10	18	44.3	9.7	0.13	0.63	0.75	0.11
	1890	505	539	35.6	8.6	0.31	0.68	0.74	0.25
	1910	653	670	38.5	7.7	0.19	0.69	0.74	0.15

Notes: (1) For each inventor, his age is determined from an average of his age as reported in the census manuscripts. (2) An inventor's birthplace is determined from the birthplace with the highest report frequency in the census manuscripts. (3) The categories "born outside the region resided" and "born outside the state resided" include inventors who were foreign born. If an inventor was born in MI but lived in IL when he was granted the patent, he would be classified as "born in the region resided (ENC)" but "born outside the state resided." (4) To obtain the birthplace composition, I omit inventors with missing information and normalized the reported shares so that they add up to 1. (5) All shares are weighted by the number of patents.
Sources: (1) Annual Report of the Commissioner of Patents for 1870, 1890, and 1910. (2) U.S. Census of Population Manuscripts for 1850, 1860, 1870, 1880, 1900, 1910, 1920, and 1930.

Table 10: Regression Analysis of Log Age and Probit Analysis of Whether Inventors Were Born in the States Other than Their Places of Residence.

	(1) OLS age (log)	(2) OLS age (log)	(3) Probit moved	(4) Probit moved
Constant	3.695**	3.633**	-1.895**	-1.885**
	(0.016)	(0.021)	(0.405)	(0.411)
1890	0.048**	0.044**	0.134	0.131
	(0.017)	(0.017)	(0.086)	(0.087)
1910	0.133**	0.133**	0.114	0.138
	(0.016)	(0.016)	(0.083)	(0.085)
Textiles	-0.008	-0.003	0.167*	0.180**
	(0.013)	(0.013)	(0.066)	(0.068)
Electric	-0.193**	-0.169**	0.523**	0.548**
	(0.013)	(0.013)	(0.070)	(0.074)
Age (log)			0.526**	0.487**
			(0.107)	(0.109)
Massachusetts		0.086**		0.114
		(0.017)		(0.089)
Southern New England		0.069**		-0.010
		(0.022)		(0.116)
New York		0.027		-0.029
		(0.018)		(0.097)
East North Central		0.005		0.136
		(0.020)		(0.108)
South		-0.003		-0.155
		(0.032)		(0.165)
Other U.S.		0.086**		0.488**
		(0.018)		(0.104)
Observations	2497	2497	2497	2497
R-squared/Pseudo R-squared	0.14	0.15	0.03	0.04

Standard errors in parentheses. * significant at 5% level and ** significant at 1% level.

Notes: A patentee is classified as moved if, at the time he received the patent, he lived in the state that differed from the place where he was born. The intercept reflects Pennsylvania. Other U.S. includes West, West North Central, Northern New England, and DE-MD. Also, see notes (1) and (2) in Table 9.

Sources: See Table 9.

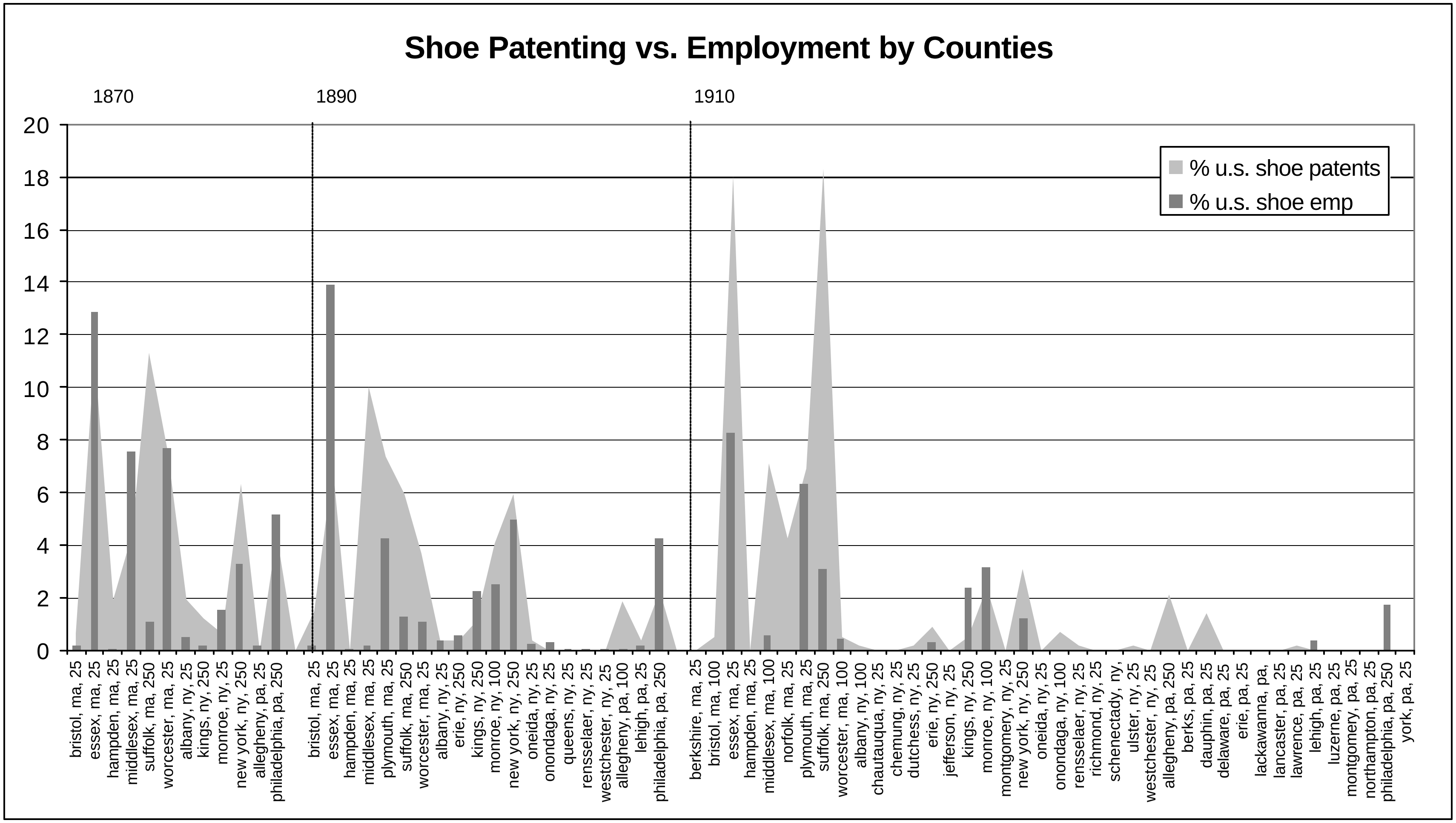
Table 11: Shares of Patents Granted to Patentees who Resided in U.S. Urban Areas

	total number of u.s. patents			county of at least 100,000 residents in biggest city (% u.s. patents)			county of at least 25,000 residents in biggest city (% u.s. patents)		
year	shoes	textiles	electric	shoes	textiles	electric	shoes	textiles	electric
1870	159	234	18	32.1	19.7	44.4	67.3	61.5	66.7
1890	270	429	539	35.2	31.9	59.7	70.7	76.0	89.2
1910	421	458	670	49.9	64.0	65.7	86.5	86.7	92.5

Notes: The share of patents granted to patentees who resided in the county with 25,000-100,000 residents in its biggest city is equal to the differences between the numbers in the last three column and the numbers in the middle three co lumn, respectively.

Sources: (1) Annual Report of the Commissioner of Patents for 1870, 1890, and 1910. (2) U.S. Census of Population Reports for 1870, 1890, and 1910.

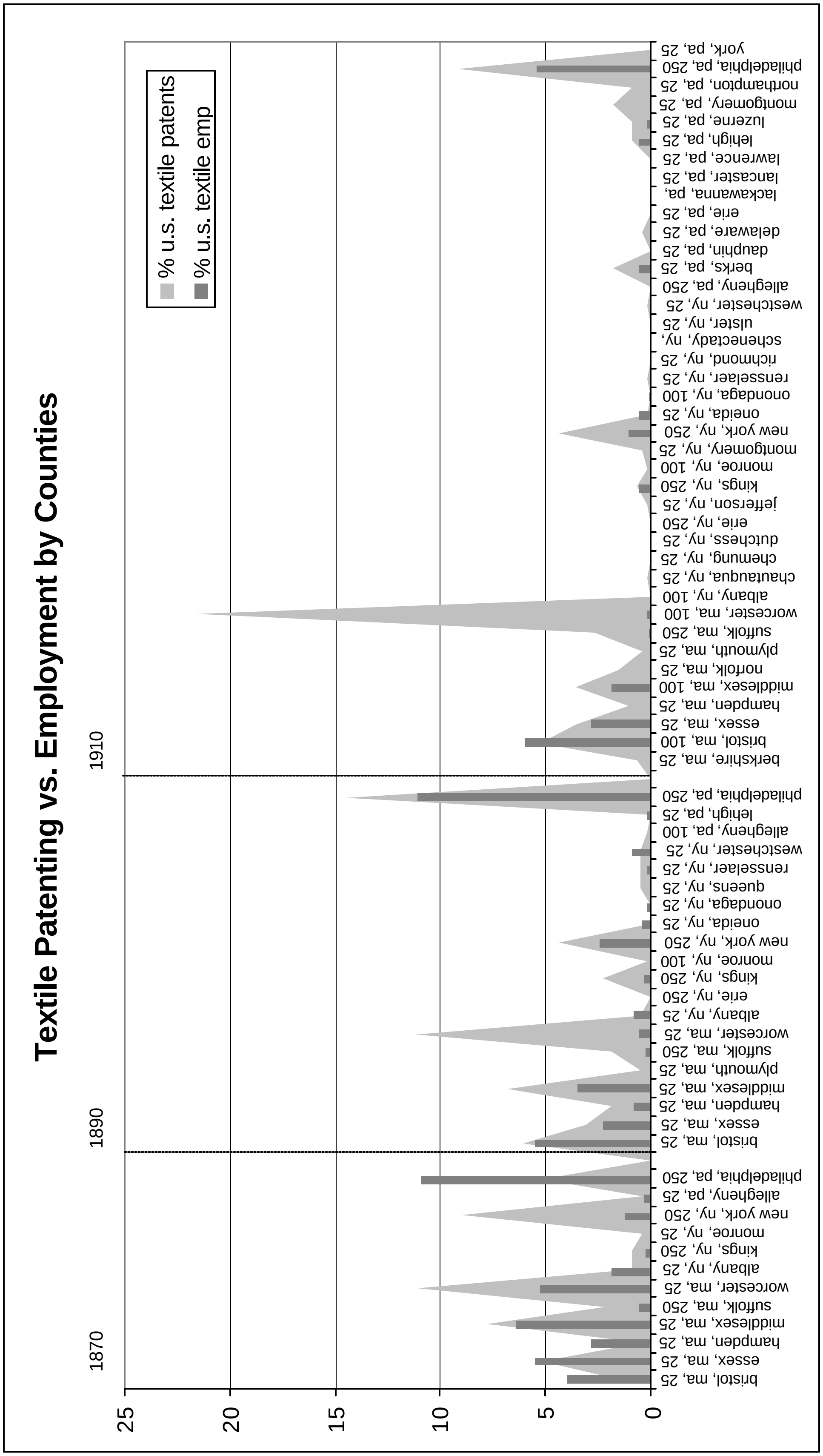
Figure 4: Shares of Shoe Patents and Employment for Urban Areas in MA, NY and PA



Notes: (1) The patent shares are calculated from the total number of industry patents in a county divided by the total number of industry patents in the U.S. (2) To obtain consistent manufacturing data for civil divisions smaller than a state is not straightforward. The U.S. Bureau of Census employed three different geographic organizations for the reporting of manufacturing data in the three cross-section years. In 1870, the Bureau reported the figures by counties, and then made a move to report the numbers for only important cities in later years with more than 20,000 residents for 1890 and with more than 50,000 residents for 1910. Therefore, for 1870, the employment shares are calculated from the total employment in a county divided by the total number of patents in the U.S. For 1890 and 1910, the employment shares are calculated from the total employment in all reported cities of a county divided by the employment in the U.S. (3) The counties are divided into 4 urbanization classes based on the total number of population of the biggest city in each county. (a) The county is of class 0 if its biggest city had less than 25,000 residents. (b) The county is of class 25 if its biggest city had 25,000-100,000 residents. (c) The county is of class 100 if its biggest city had 100,000-250,000 residents. (d) The county is of class 250 if its biggest city had over 250,000 residents. (4) Because of the reasons discussed in (2), some counties of class 25 had missing employment shares. Also, the Census Bureau did not report employment in counties with less than 3 manufacturing establishments.

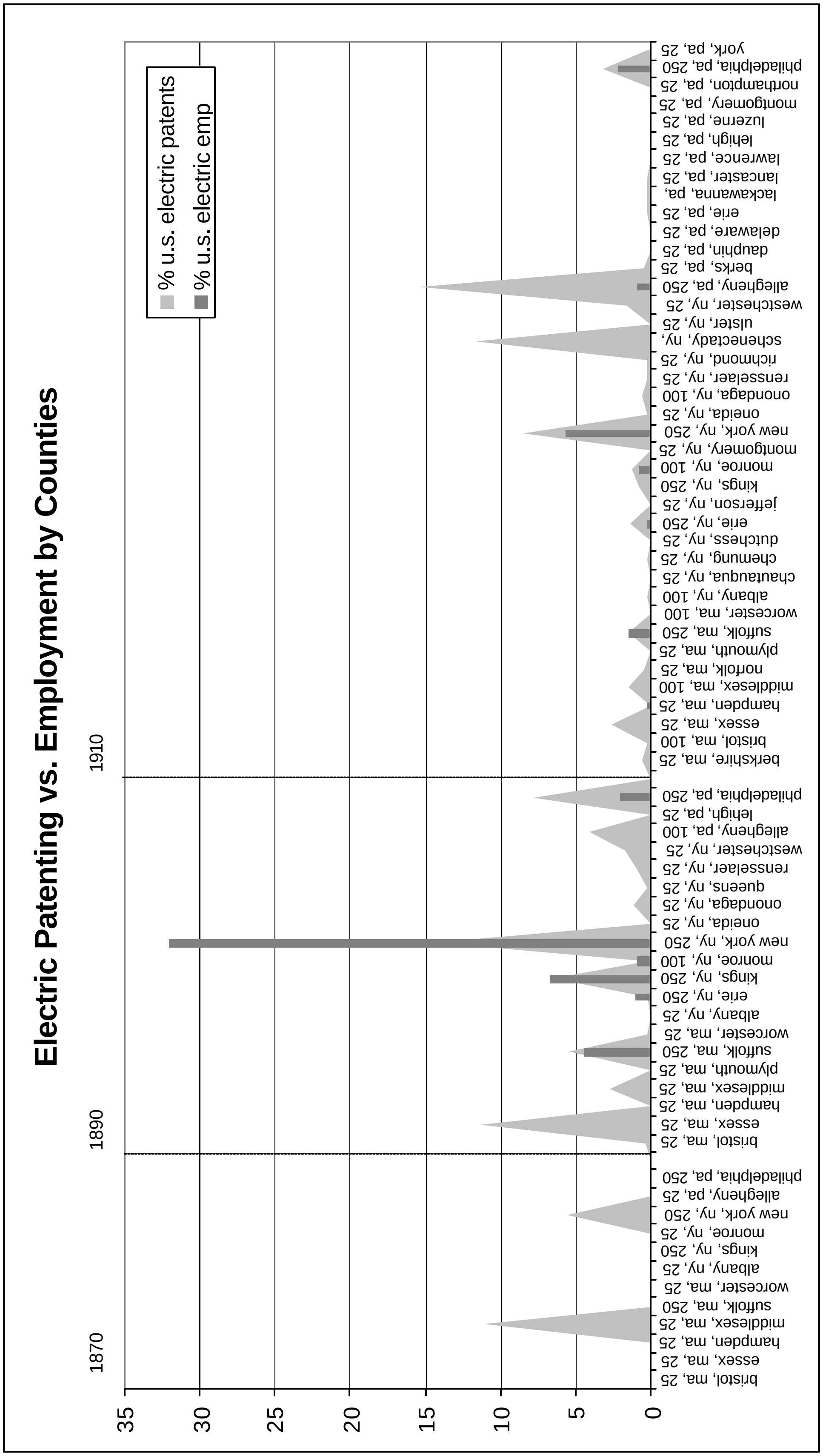
Sources: (1) Annual Report of the Commissioner of Patents for 1870, 1890, and 1910. (2) U.S. Census of Manufactures Reports for 1870, 1890, and 1910. (3) U.S. Census of Population Reports for 1870, 1890, and 1910.

Figure 5: Shares of Textile Patents and Employment for Urban Areas in MA, NY and PA



Notes: See Figure 4.
Sources: See Figure 4.

Figure 6: Shares of Electric Patents and Employment for Urban Areas in MA, NY and PA



Notes: See Figure 4.
Sources: See Figure 4.

Table 12: Probit Analysis of Whether a Patentee Lived in a County with at least 100,000 Residents in Its Biggest City and Whether a Patentee Assigned the Rights to His Invention by the Time He was Granted the Patent

	(1) Urban 100	(2) Urban 100	(3) Assigned	(4) Assigned
Constant	-0.504	-0.239	-0.536	-0.236
	(0.403)	(0.422)	(0.399)	(0.409)
1890	0.533**	0.568**	0.258**	0.259**
	(0.094)	(0.097)	(0.091)	(0.092)
1910	0.979**	1.020**	0.720**	0.747**
	(0.091)	(0.094)	(0.090)	(0.091)
Age (log)	-0.163	-0.017	-0.127	-0.162
	(0.107)	(0.111)	(0.106)	(0.107)
Moved	0.268**	0.320**	0.146**	0.164**
	(0.056)	(0.058)	(0.056)	(0.056)
Urban 25			0.434**	0.233**
			(0.080)	(0.088)
Urban 100			0.347**	0.189*
			(0.079)	(0.085)
Textiles	0.124	0.055	0.008	0.033
	(0.068)	(0.071)	(0.067)	(0.069)
Electric	0.408**	0.225**	0.227**	0.332**
	(0.070)	(0.075)	(0.070)	(0.074)
Massachusetts		-1.077**		0.094
		(0.095)		(0.093)
Southern New England		-0.768**		-0.051
		(0.123)		(0.118)
New York		-0.559**		-0.244*
		(0.103)		(0.098)
East North Central		-0.570**		-0.209
		(0.114)		(0.109)
South		-1.932**		-0.722**
		(0.201)		(0.182)
Other U.S.		-0.964**		-0.267**
		(0.106)		(0.101)
Observations	2497	2497	2497	2497
Pseudo R-squared	0.08	0.14	0.06	0.08

Standard errors are in parentheses. * significant at 5% level and ** significant at 1% level.

Notes: For equation (2) and (4), the intercept reflects Pennsylvania. Other U.S. includes West, West North Central, Northern New England, and DE-MD. Also, see Figure 4.

Sources: See Figure 4.

Table 13: Regressions of the Number of Patents Granted to Each Inventor within a 7-Year Period

	(1) Shoe	(2) Textile	(3) Electric	(4) Shoe	(5) Textile	(6) Electric	(7) Shoe	(8) Textile	(9) Electric
Constant	-1.005	-1.824**	-2.676**	-0.745	-1.286**	-2.764**	-0.284	-1.057*	-2.677**
	(0.738)	(0.519)	(0.844)	(0.730)	(0.495)	(0.806)	(0.716)	(0.496)	(0.795)
1890	-0.218	0.266*	1.169**	-0.192	0.247*	1.087**	-0.155	0.222*	0.733*
	(0.142)	(0.108)	(0.349)	(0.140)	(0.103)	(0.334)	(0.135)	(0.103)	(0.330)
1910	0.377**	0.311**	0.207	0.366**	0.310**	0.046	0.332*	0.278**	-0.191
	(0.136)	(0.106)	(0.346)	(0.134)	(0.101)	(0.331)	(0.129)	(0.102)	(0.327)
Assigned	0.468**	0.476**	0.475**	0.338**	0.259**	0.422**	0.192	0.245**	0.371**
	(0.096)	(0.082)	(0.092)	(0.102)	(0.081)	(0.088)	(0.098)	(0.080)	(0.087)
Had moved from the state where he was born	0.305**	-0.037	0.491**	0.288**	-0.023	0.425**	0.347**	-0.016	0.489**
	(0.095)	(0.083)	(0.100)	(0.094)	(0.078)	(0.095)	(0.090)	(0.078)	(0.094)
Age	0.512*	0.731**	1.042**	0.374	0.531**	0.971**	0.258	0.507**	1.011**
	(0.200)	(0.140)	(0.205)	(0.200)	(0.135)	(0.196)	(0.191)	(0.135)	(0.192)
Had experience in production				0.409**	-0.021		0.151	-0.102	
				(0.111)	(0.101)		(0.110)	(0.102)	
Had experience in tools & machinery				0.557**	0.785**		0.158	0.609**	
				(0.135)	(0.105)		(0.137)	(0.109)	
Had experience in the electric industry						0.853**			0.752**
						(0.087)			(0.089)
Massachusetts							0.614**	0.242*	0.608**
							(0.196)	(0.121)	(0.148)
Southern New England							-0.169	-0.058	0.297
							(0.276)	(0.147)	(0.183)
New York							0.111	-0.16	0.224
							(0.220)	(0.157)	(0.126)
East North Central							-0.345	-0.297	0.027
							(0.226)	(0.185)	(0.142)
South							-0.456	-0.511*	-0.821**
							(0.334)	(0.215)	(0.278)
Other U.S.							-0.446*	-0.271*	-0.352*
							(0.218)	(0.138)	(0.143)
Observations	657	853	986	657	853	986	657	853	986
R-squared	0.13	0.1	0.14	0.16	0.19	0.21	0.25	0.22	0.26

Standard errors are in parentheses. * significant at 5% level and ** significant at 1% level.
Notes: See Table 13.
Sources: See Table 2.

APPENDIX 1: CLASSIFICATION SCHEMES

Geographic Regions

The geographic classification scheme that divides the U.S. into 13 regions are based on the U.S. Bureau of Census' scheme with finer divisions utilized for areas with higher inventive activity such as New England and Middle Atlantic. The regions are as follows. (a) West – AZ, CA, CO, ID, MT, NM, NV, OR, UT, WA, and WY. (b) West North Central – IA, KS, MN, MO, ND, NE, and SD. (c) East North Central – IL, IN, MI, OH, and WI. (d) Northern New England – ME, NH, and VT. (e) Southern New England – CT and RI. (f) Massachusetts. (g) New York. (h) New Jersey. (i) Pennsylvania. (j) DE-MD – DE and MD. (k) District of Columbia. (l) South – AL, AR, FL, GA, KY, LA, MS, NC, OK, SC, TN, TX, VA, and WV. (m) Other – AK and HI.

Work Experiences

The indexes for work experiences are drawn from inventor's occupation history up to the cross-section year. The classification scheme is as follows. (a) The product category is only applicable to shoe and textile inventors. For the shoe industry, it includes inventors with experience in the production and trading of boots and shoes as well as lasts. For the textile industry, it includes inventor with experience in the production and trading of textile goods as well as those who had worked as loom fixers. (b) For the shoe industry, the tool and machinery category includes those who were model and pattern makers (for machinery use not for shoe production), draftsmen, machinists, mechanical engineers, toolmakers and workers in machinery – both for shoe tool and machinery and for unspecified industries, except those specifically work for other manufacturing industries. For the textile industry, the tool and machinery category includes those who were millwrights, shuttle makers, and needle makers as well as model and pattern makers, draftsmen, machinists, mechanical engineers, toolmakers and workers in machinery – both for textile tool and machinery and for unspecified industries, except those specifically work for other manufacturing industries. For the electric industry, the tool and machinery category includes those who are in general tools and machinery such as machinist, draftsmen, and engineers, except those specifically in electric. (c) The electric and electrically related categories are only applicable to electric inventors. An inventor is classified as having experience in electric if he was an electrician, an electrical engineer, or had worked in production and trading of electrical goods and equipment, except those related to electrical communication equipments. An inventor is classified as having electrically related experience if he was involved in electrical communication equipments. (d) The other category includes those who were not classified as having production, tools and machinery, electric, or electrically related experience. For example, they were farmers, lawyers (both patent and general practice), dentists, teachers, carpenter, and blacksmiths.

Skills

The indexes for technical skills are inferred from inventor's occupation history up to the cross-section year. Draftsmen and engineers include all types of engineers (e.g. civil and mechanical), except electrical engineers. An inventor is classified as probably having unspecified technical experience if he had work experience in machinery. An inventor is classified as having no technical skills if his work experience up to the cross-section years was not related to technical fields, for example, being farmers, lawyers, dentists, physicians, shoemakers, and carpenters. An inventor is classified as having missing skills information if there are no work experience data available or no inference on technical skills can be drawn from the available work experience.

Note that because they are also constructed from inventor's occupation, the skill composition is closely related to work experience composition. For example, a machinist would also be classified as experience in tool and machinery. But, there would be some inventors in tool and machinery who did not have technical skills. Because it is more difficult to drawn an inference on skills from occupation information, there were more inventors with missing skill information than those with missing work experience information.

APPENDIX 2: UNABRIDGED TABLES

Table A: Regional Shares of Patents and Employment for Each Industry as Compared to Those of All Industries and Regional Shares of Population

			oveall		shoes		textiles		electric		number of patents		
year	region	% of u.s. pop	% u.s. emp	% u.s. patents	% u.s. emp	% u.s. patents	% u.s. emp	% u.s. patents	% u.s. emp	% u.s. patents	shoes	textiles	electric
1870	west	2.6	1.8	1.9	1.4	1.9	0.3	0.9		0.0	3	2	0
	wnc	10.0	5.4	4.6	3.5	2.5	0.9	0.4		11.1	4	1	2
	enc	23.7	18.8	22.7	13.7	15.1	3.3	12.4		11.1	24	29	2
	nnengl	3.3	5.3	3.8	4.9	3.1	12.6	9.4		5.6	5	22	1
	snengl	2.0	6.8	7.9	2.2	7.5	19.8	17.5		0.0	12	41	0
	ma	3.8	13.6	12.5	40.7	43.4	28.8	30.3		11.1	69	71	2
	ny	11.4	17.1	24.7	12.9	12.6	9.5	14.1		5.6	20	33	1
	nj	2.3	3.7	3.5	2.3	1.3	3.4	5.1		33.3	2	12	6
	pa	9.1	15.6	11.4	11.6	6.9	15.1	8.1		5.6	11	19	1
	de-md	2.3	2.7	1.6	2.6	0.0	1.6	0.9		0.0	0	2	0
	dc	0.3	0.2	0.5	0.2	2.5	0.0	0.4		0.0	4	1	0
	south	29.2	9.1	4.8	3.9	3.1	4.7	0.4		16.7	5	1	3
	none	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0	0	0
1890	west	4.8	3.2	5.5	1.9	2.6	0.5	0.5	0.0	0.6	7	2	3
	wnc	14.2	7.3	8.5	3.6	5.6	0.4	1.2	4.6	3.0	15	5	16
	enc	21.5	22.6	25.6	11.1	11.9	3.7	3.7	7.5	15.2	32	16	82
	nnengl	2.2	3.5	1.4	8.1	4.4	9.7	10.3	0.0	1.5	12	44	8
	snengl	1.7	5.0	4.7	1.1	3.3	15.0	10.7	1.8	4.8	9	46	26
	ma	3.6	10.3	7.6	43.2	40.4	24.5	34.0	28.5	21.9	109	146	118
	ny	9.6	18.0	20.0	14.2	15.6	12.2	12.6	44.3	27.1	42	54	146
	nj	2.3	4.0	3.1	3.2	3.3	6.7	6.8	4.6	8.2	9	29	44
	pa	8.4	13.2	12.0	6.3	9.6	15.9	15.4	2.4	12.8	26	66	69
	de-md	1.9	2.7	1.1	1.6	0.4	1.3	1.9	0.7	2.0	1	8	11
	dc	0.4	0.5	1.7	0.2	0.4	0.0	0.2	0.0	0.2	1	1	1
	south	29.4	9.7	8.9	2.8	2.6	8.3	2.8	0.0	2.8	7	12	15
	none	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
1910	west	7.4	4.5	9.6	0.5	4.8	0.2	0.4	0.6	4.3	20	2	29
	wnc	12.7	6.0	11.7	10.3	5.0	0.3	1.1	1.7	3.9	21	5	26
	enc	19.8	23.3	25.2	15.2	9.7	3.0	4.6	27.1	18.5	41	21	124
	nnengl	1.7	2.8	0.7	10.2	1.7	7.0	3.1	0.2	0.3	7	14	2
	snengl	1.8	4.6	3.4	0.3	2.9	11.8	10.0	5.5	7.9	12	46	53
	ma	3.7	8.4	6.6	41.7	55.6	22.1	40.6	15.8	6.9	234	186	46
	ny	9.9	15.7	14.9	11.1	9.3	10.3	8.5	21.6	27.8	39	39	186
	nj	2.8	4.8	5.0	2.1	2.1	7.5	7.4	12.3	4.8	9	34	32
	pa	8.3	13.1	9.9	5.5	4.8	16.2	16.4	13.9	20.6	20	75	138
	de-md	1.6	1.9	1.1	0.3	0.7	0.8	0.0	0.3	1.2	3	0	8
	dc	0.4	0.1	0.7	0.0	0.5	0.0	0.4	0.0	1.3	2	2	9
	south	30.0	14.8	10.9	2.1	3.1	19.2	7.2	0.5	2.5	13	33	17
	none	0.0	0.0	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0	1	0

Notes: The U.S. Bureau of Census reported all electric-related production in one single category: electrical apparatus and supply that includes production of goods that are not included in my electric invention classification such as electric transportation equipment. Therefore, the electric production data in this dataset might not reflect the true level of manufacturing activity in electric industry.

Sources: (1) Annual Report of the Commissioner of Patents for 1870, 1890, and 1910. (2) U.S. Census of Manufactures Reports for 1870, 1890, and 1910. (3) Lamoreaux-Sokoloff random sample of all patents granted in 1870, 1871, 1890, 1891, 1910, and 1911. (4) U.S. Census of Population Reports for 1870, 1890, and 1910.

Table B: Work Experiences of Shoe Patentees who Resided in the U.S.

			shoes		% u.s.	experience (normalized share)				7-yr pat/inventor (median)	
year	region	number of patents	% u.s. emp	% u.s. patents	workers in technical fields	production	tool & mach	other	missing experience (share)	production	tool & machinery
1870	west	3	0.01	0.02	0.02	0.00	0.00	1.00	0.67		
	wnc	4	0.04	0.03	0.05	0.25	0.00	0.75	0.00	1.00	
	enc	24	0.14	0.15	0.18	0.53	0.00	0.47	0.29	2.00	
	nnengl	5	0.05	0.03	0.04	0.40	0.00	0.60	0.00	1.50	
	snengl	12	0.02	0.08	0.08	0.50	0.17	0.33	0.00	3.00	3.00
	ma	69	0.41	0.43	0.11	0.63	0.32	0.05	0.41	2.50	3.00
	ny	20	0.13	0.13	0.21	0.54	0.08	0.38	0.35	4.00	3.00
	nj	2	0.02	0.01	0.04	1.00	0.00	0.00	0.00	2.00	
	pa	11	0.12	0.07	0.14	0.63	0.00	0.38	0.27	3.00	
	de-md		0.03	0.00	0.02	0.00	0.00	0.00	0.00		
	dc	4	0.00	0.03	0.01				1.00		
	south	5	0.04	0.03	0.09	1.00	0.00	0.00	0.80	1.00	
1890	west	7	0.02	0.03	0.07	0.50	0.50	0.00	0.71	1.00	1.00
	wnc	15	0.04	0.06	0.08	0.50	0.13	0.38	0.47	1.50	2.00
	enc	32	0.11	0.12	0.23	0.42	0.32	0.26	0.41	2.00	3.00
	nnengl	12	0.08	0.04	0.02	0.25	0.13	0.62	0.33	2.00	1.00
	snengl	9	0.01	0.03	0.05	0.50	0.38	0.13	0.11	3.00	14.00
	ma	109	0.43	0.40	0.08	0.42	0.45	0.13	0.29	2.00	5.00
	ny	42	0.14	0.16	0.14	0.50	0.07	0.43	0.33	1.00	5.00
	nj	9	0.03	0.03	0.05	0.29	0.57	0.14	0.22	1.00	5.00
	pa	26	0.06	0.10	0.13	0.59	0.24	0.18	0.35	1.00	7.00
	de-md	1	0.02	0.00	0.02	1.00	0.00	0.00	0.00	9.00	
	dc	1	0.00	0.00	0.01	0.00	1.00	0.00	0.00		6.00
	south	7	0.03	0.03	0.12	0.50	0.00	0.50	0.71	1.00	
1910	west	20	0.01	0.05	0.10	0.30	0.00	0.70	0.50	4.00	
	wnc	21	0.10	0.05	0.07	0.38	0.00	0.62	0.38	1.00	
	enc	41	0.15	0.10	0.26	0.54	0.12	0.35	0.37	1.00	1.00
	nnengl	7	0.10	0.02	0.02	0.33	0.17	0.50	0.14	1.50	1.00
	snengl	12	0.00	0.03	0.04	0.50	0.20	0.30	0.17	2.50	11.00
	ma	234	0.42	0.56	0.07	0.53	0.44	0.03	0.11	11.00	8.50
	ny	39	0.11	0.09	0.14	0.60	0.12	0.28	0.36	4.00	10.00
	nj	9	0.02	0.02	0.05	0.75	0.00	0.25	0.11	10.00	
	pa	20	0.05	0.05	0.12	0.58	0.00	0.42	0.40	14.00	
	de-md	3	0.00	0.01	0.02				1.00		
	dc	2	0.00	0.00	0.01	0.00	0.00	1.00	0.50		
	south	13	0.02	0.03	0.11	0.11	0.00	0.89	0.31	1.00	

		number	experience (count)			experience (normalized share)			missing	7-yr pat/inventor (median)	
year	region	of patents	product	tool & mach	other	product	tool & mach	other	experience (share)	product	tool & machinery
1870	us	159	59	16	29	0.57	0.16	0.28	0.35	2	3
1890	us	270	79	58	41	0.44	0.33	0.23	0.34	1.5	5
1910	us	421	168	101	59	0.52	0.31	0.18	0.22	5	9

Notes: (1) The indexes for work experiences are drawn from inventor's occupation history up to the cross-section year. See section 7.2 for more details on work experience classification. (2) To obtain the skill composition, I omit inventors with missing information and normalized the reported shares so that all types of work experience add up to 1. (3) The experience composition and the median number of patents each inventor received within a 7-year period are weighted by the number of patents. (4) The regional shares of technical workers are calculated from the total number of people who reported their occupation as machinists, millwrights, engineers (stationary, mechanical, civil, mining and electrical), electrician, toolmakers, pattern and model makers, designers, draftsmen, and inventors in the Census of Population.

Sources: (1) U.S. Census of Manufactures Reports for 1870, 1890, and 1910. (2) Annual Report of the Commissioner of Patents for 1870, 1890, and 1910. (3) U.S. Census of Population Manuscripts for 1850, 1860, 1870, 1880, 1900, and 1910. (4) U.S. City Directories. (5) IEEE History Center.

Table C: Work Experiences of Textile Patentees who Resided in the U.S.

			textiles			experience (normalized share)				7-yr pat / inventor (median)	
year	region	number of patents	% u.s. emp	% u.s. patents	% u.s. workers in technical fields	production	tool & mach	other	missing experience (share)	production	tool & machinery
1870	west	2	0.00	0.01	0.02				1.00		
	wnc	1	0.01	0.00	0.05	0.00	0.00	1.00	0.00		
	enc	29	0.03	0.12	0.18	0.21	0.42	0.37	0.34	2.00	3.00
	nnengl	22	0.13	0.09	0.04	0.22	0.61	0.17	0.18	3.00	2.00
	snengl	41	0.20	0.18	0.08	0.64	0.24	0.12	0.20	2.00	2.00
	ma	71	0.29	0.30	0.11	0.40	0.50	0.10	0.27	2.00	4.50
	ny	33	0.09	0.14	0.21	0.53	0.27	0.20	0.55	1.00	3.00
	nj	12	0.03	0.05	0.04	0.64	0.36	0.00	0.08	1.00	2.50
	pa	19	0.15	0.08	0.14	0.42	0.17	0.42	0.37	1.00	10.50
	de-md	2	0.02	0.01	0.02	1.00	0.00	0.00	0.00	2.00	
	dc	1	0.00	0.00	0.01				1.00		
	south	1	0.05	0.00	0.09	0.00	0.00	1.00	0.00		
1890	west	2	0.00	0.00	0.07				1.00		
	wnc	5	0.00	0.01	0.08	0.00	0.00	1.00	0.60		
	enc	16	0.04	0.04	0.23	0.00	0.43	0.57	0.56		3.00
	nnengl	44	0.10	0.10	0.02	0.36	0.48	0.15	0.25	1.50	6.00
	snengl	46	0.15	0.11	0.05	0.58	0.33	0.09	0.28	2.00	4.00
	ma	146	0.25	0.34	0.08	0.34	0.63	0.03	0.19	3.00	11.00
	ny	54	0.12	0.13	0.14	0.50	0.21	0.29	0.48	1.50	1.50
	nj	29	0.07	0.07	0.05	0.47	0.37	0.16	0.34	2.00	4.00
	pa	66	0.16	0.15	0.13	0.63	0.32	0.05	0.38	3.00	3.00
	de-md	8	0.01	0.02	0.02	1.00	0.00	0.00	0.75	1.00	
	dc	1	0.00	0.00	0.01	0.00	0.00	1.00	0.00		
	south	12	0.08	0.03	0.12	0.60	0.00	0.40	0.58	1.00	
1910	west	2	0.00	0.00	0.10				1.00		
	wnc	5	0.00	0.01	0.07	0.25	0.00	0.75	0.20	7.00	
	enc	21	0.03	0.05	0.26	0.41	0.29	0.29	0.19	2.00	12.50
	nnengl	14	0.07	0.03	0.02	0.73	0.18	0.09	0.21	5.00	4.00
	snengl	46	0.12	0.10	0.04	0.46	0.46	0.08	0.20	3.00	3.00
	ma	186	0.22	0.41	0.07	0.30	0.63	0.06	0.13	2.00	12.00
	ny	39	0.10	0.09	0.14	0.27	0.35	0.38	0.33	2.00	3.00
	nj	34	0.07	0.07	0.05	0.68	0.32	0.00	0.26	2.00	6.00
	pa	75	0.16	0.16	0.12	0.50	0.40	0.10	0.33	3.00	4.50
	de-md		0.01	0.00	0.02				0.00		
	dc	2	0.00	0.00	0.01				1.00		
	south	33	0.19	0.07	0.11	0.70	0.13	0.17	0.30	1.00	6.00

			experience (count)			experience (normalized share)				7-yr pat / inventor (median)	
year	region	number of patents	product	tool & mach	other	product	tool & mach	other	missing experience (share)	product	tool & machinery
1870	us	234	72	63	29	0.44	0.38	0.18	0.30	2	3
1890	us	429	125	130	34	0.43	0.45	0.12	0.33	2	6
1910	us	457	147	166	41	0.42	0.47	0.12	0.23	2	8

Notes: See Table B.
Sources: See Table B.

Table D: Work Experiences of Electric Patentees who Resided in the U.S.

			electric			experience (normalized share)				7-yr pat/inventor (median)	
year	region	number of patents	% u.s. emp	% u.s. patents	% u.s. workers in technical fields	electric	mach & elecally related	other	missing experience (share)	production	tool & machinery
1870	west			0.00	0.02	0.00	0.00	0.00	0.00		
	wnc	2		0.11	0.05		0.00	0.00	1.00		
	enc	2		0.11	0.18	1.00	0.00	0.00	0.00		11.00
	nnengl	1		0.06	0.04	0.00	0.00	1.00	0.00	1.00	
	snengl			0.00	0.08	0.00	0.00	0.00	0.00		
	ma	2		0.11	0.11	0.00	1.00	0.00	0.00	7.00	
	ny	1		0.06	0.21	0.00	0.00	1.00	0.00	1.00	
	nj	6		0.33	0.04	1.00	0.00	0.00	0.00		11.00
	pa	1		0.06	0.14	0.00	0.00	1.00	0.00	1.00	
	de-md			0.00	0.02	0.00	0.00	0.00	0.00		
	dc			0.00	0.01	0.00	0.00	0.00	0.00		
	south	3		0.17	0.09	0.00	0.00	1.00	0.00	9.00	
1890	west	3	0.00	0.01	0.07	0.00	0.00	1.00	0.67	1.00	
	wnc	16	0.05	0.03	0.08	0.50	0.10	0.40	0.38	6.00	4.00
	enc	82	0.07	0.15	0.23	0.61	0.26	0.13	0.54	3.00	20.00
	nnengl	8	0.00	0.01	0.02	0.43	0.14	0.43	0.13	5.50	2.00
	snengl	26	0.02	0.05	0.05	0.36	0.45	0.18	0.15	4.00	7.00
	ma	118	0.28	0.22	0.08	0.85	0.05	0.10	0.10	4.00	49.00
	ny	146	0.44	0.27	0.14	0.71	0.21	0.08	0.51	11.00	19.00
	nj	44	0.05	0.08	0.05	0.78	0.03	0.19	0.16	4.50	77.00
	pa	69	0.02	0.13	0.13	0.78	0.08	0.14	0.26	1.50	33.00
	de-md	11	0.01	0.02	0.02	0.36	0.09	0.55	0.00	13.00	9.00
	dc	1	0.00	0.00	0.01	1.00	0.00	0.00	0.00		6.00
	south	15	0.00	0.03	0.12	0.38	0.38	0.25	0.47	3.00	2.00
1910	west	29	0.01	0.04	0.10	0.68	0.11	0.21	0.34	3.00	1.00
	wnc	26	0.02	0.04	0.07	0.71	0.19	0.10	0.19	2.00	1.00
	enc	124	0.27	0.19	0.26	0.71	0.16	0.13	0.33	4.00	10.50
	nnengl	2	0.00	0.00	0.02	0.50	0.00	0.50	0.00	2.00	1.00
	snengl	53	0.06	0.08	0.04	0.63	0.26	0.11	0.34	5.00	17.50
	ma	46	0.16	0.07	0.07	0.89	0.11	0.00	0.17	14.50	8.00
	ny	186	0.22	0.28	0.14	0.86	0.11	0.03	0.20	6.00	17.00
	nj	32	0.12	0.05	0.05	0.79	0.21	0.00	0.41	11.00	12.00
	pa	138	0.14	0.21	0.12	0.90	0.04	0.07	0.24	8.00	11.00
	de-md	8	0.00	0.01	0.02	0.88	0.13	0.00	0.00	2.00	16.00
	dc	9	0.00	0.01	0.01	0.00	0.50	0.50	0.56	23.00	
	south	17	0.01	0.03	0.11	0.54	0.08	0.38	0.24	2.00	2.00

			experience (count)			experience (normalized share)				7-yr pat/inventor (median)	
year	region	number of patents	electric	mach & elec-rel	other	electric	mach & elec-rel	other	missing experience (share)	other	electric
1870	us	234	8	2	6	0.50	0.13	0.38	0.11	2	11
1890	us	429	257	51	56	0.71	0.14	0.15	0.32	4	19
1910	us	457	395	60	40	0.80	0.12	0.08	0.26	5	10

Notes: See Table B.
Sources: See Table B.

Appendix 3: Examples of Invention

Figure A: Shoe Invention

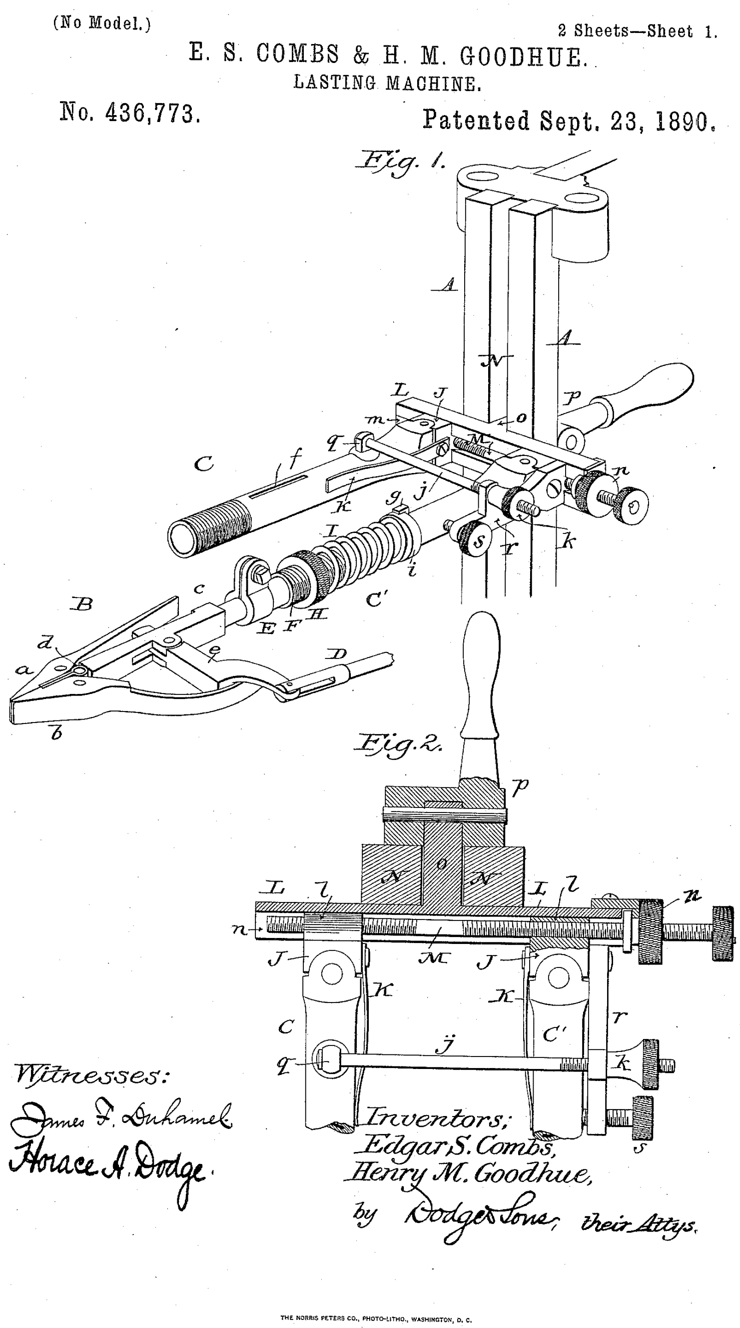


Figure B: Textile Invention

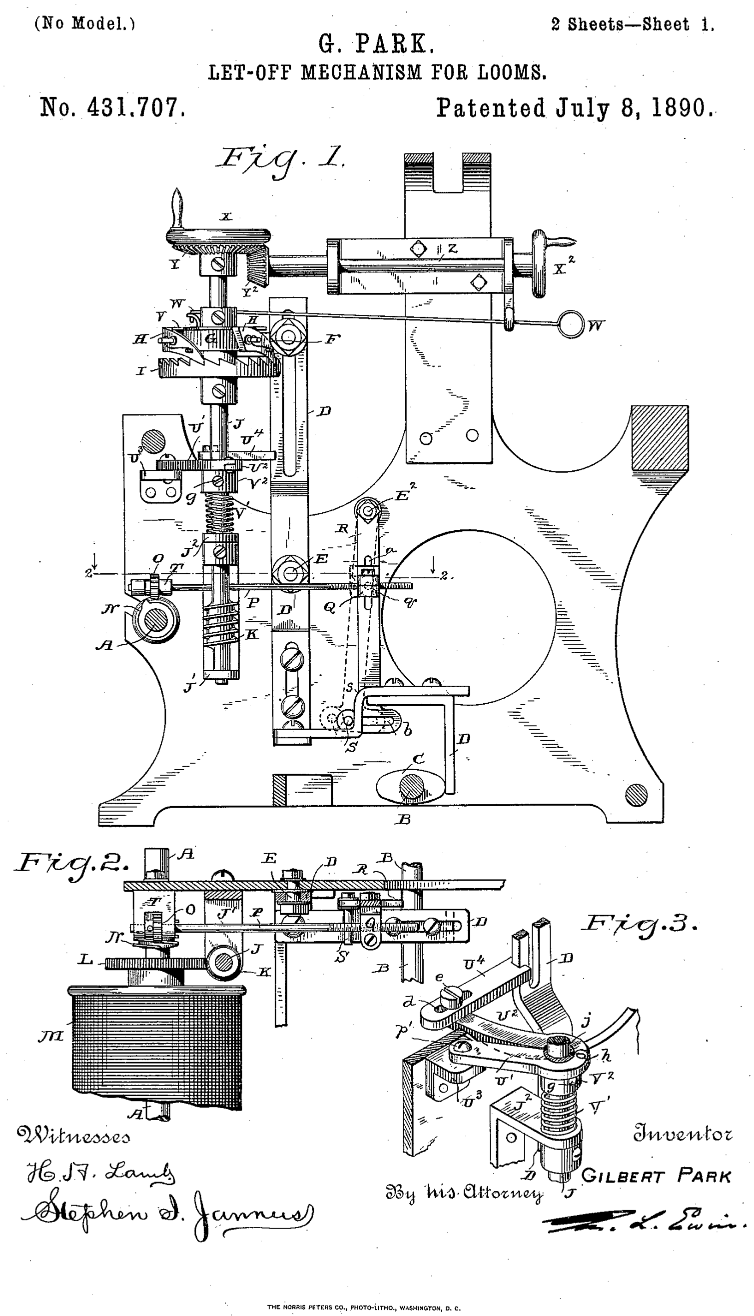


Figure C: Electric Invention