LEARNING-BY-PRODUCING AND THE GEOGRAPHIC LINKS BETWEEN INVENTION AND PRODUCTION: EXPERIENCE FROM THE SECOND INDUSTRIAL REVOLUTION

Dhanoos Sutthiphisal
Economics, McGill University and NBER

March 15, 2005

I am very grateful for insightful advice from Kenneth Sokoloff. I have also benefited from valuable comments offered by Daniel Ackerberg, Naomi Lamoreaux, Shih-tse Lo, Mary MacKinnon, Jean-Laurent Rosenthal, and participants at the DAE Conference at the NBER Summer Institute, the 2004 EHA Meeting and the UCLA Economic History Seminars. 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 the computing resources to access the USPTO on-line database.

Learning-by-producing and the Geographic Links between Invention and Production: Experience from the Second Industrial Revolution

Abstract

This paper investigates the impact of "learning-by-producing" on inventive activity and shows that, in both high-tech (electric) and low-tech (shoes and textiles) industries, the geographic association between invention and production was rather weak during the Second Industrial Revolution. Regional shifts in production were neither accompanied nor followed by corresponding increases in invention. Instead, this paper finds that the geographic location of inventive activity tended to mirror the geographic distribution of individuals with the advanced technical skills appropriate to the particular industry in question. Even in the craft-based shoe industry, much of the invention came from those with advanced technical skills. The findings suggest that scholars have over-emphasized the importance of learning-by-producing in accounting for the geographic differences in inventive activity, and underestimated the significance of technical skills or human capital amongst the population.

Dhanoos Sutthiphisal
Department of Economics
McGill University
855 Sherbrooke Street West
Montreal, Quebec H3A 2T7
CANADA
and NBER
dhanoos.sutthiphisal@mcgill.ca

Many scholars have long suggested that learning-by-producing plays an important role in the creation of new technical knowledge.[1, 2] 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 with, and opportunities for improvement in, the technology in use. Inventive activity in an industry, therefore, would be concentrated where the production in that industry is actually carried out. There is nonetheless good reason to question this conventional wisdom. Conditions conducive to invention may be different from those conducive to production. Thus, the generation of new technical knowledge for an industry could be geographically separated from production, and inventive activity might naturally concentrated in areas with an abundance of factors (and institutions) crucial to inventive activity other than being in proximity to production.[3]

Absent in most of these studies, however, is an investigation of the links between the location of invention and the location of production. They pay little attention to the possibility that a geographic divorce between the two activities may take place. In such studies, information on the location of production is simply employed to control for the effects of concentration in production on the clustering of invention.[4] This is unfortunate, especially because the issue of how much or whether the location of production influences the location of inventive activity is of considerable relevance today. In recent years, production in "technologically-mature" manufacturing industries has increasingly relocated from more-developed to less-developed countries with lower labor costs. By examining the geographic links between invention and production together with other factors that might also be conducive to invention, we may shed light on whether and to what extent a region that is a recipient of a shift in production capacity would come to realize a corresponding increase in its generation of new technical knowledge; and whether and how a region could maintain (or establish) comparative advantages in invention regardless of its level of production.

Given the recent surge of outsourcing in manufacturing and the growing attention to invention and innovation in international policy circles, this paper therefore focuses on evaluating the learning-by-producing hypothesis by examining the geographic association between invention and production. I have chosen to study this from the historical experience of three intriguingly contrasting American industries: two traditionally labor-

---

[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, "Economic Implication" for learning-by-doing theory.

[2] Although very few studies explicitly discuss the impact of production clustering, or learning-by-producing, on invention, many studies have treated experience at production as a source of invention and innovation, and thereby, the catalyst for technological change. See, for example, Young, "Learning" and "Invention," and Irwin and Klenow, "Learning-by-doing."

[3] These factors have been highlighted by several studies such as Jaffe, Trajtenberg and Henderson, "Geographic Localization," Saxenian, *Regional Advantage*, Feldman and Florida, "Geographic Sources," Audretsch and Feldman, "R&D Spillovers," Arora, Fosfuri and Gambardella, "Specialized Technology Suppliers."

[4] An exception to this strand of literature is the work by Lamoreaux and Sokoloff, "Geography of Invention" which attributes market institutions that facilitated trade in patented technology or that helped mobilize capital to invest in inventive activity as the causes of the geographic divergence between production and invention in the American glass industry. Although intriguing, the study focuses on a single industry and does not probe deeply into other factors, for example, inventor skills that might help explain such geographic divergence.

intensive industries, one whose production migrated to a low wage area (textiles) and one which did not (shoes); as well as an industry based on a radically new technology (electric).[5] From the U.S. patent records, I gather information on all shoe, textile and electric patents granted by the United States Patent and Trademark Office (USPTO) in 1870, 1890 and 1910. For each patentee (inventor), I have also retrieved the total number of patents awarded to him over the 7-year period centered on the year of the sampled patents. Furthermore, in order to explore in detail the biographies of these patentees and whether they were directly associated with production, additional information such as year of birth, birthplace, detailed occupation, place of business, and place of residence at several points during an inventor's life is drawn from the U.S. census of population manuscripts (1850, 1860, 1870, 1880, 1900, 1910, 1920 and 1930) and U.S. city directories (mostly in 1890).

I find that the geographic association between invention and production seemed weak in both high-tech (electric) and low-tech (shoes and textiles) industries during 1870 and 1910. Regional shifts in production capacity were not followed by corresponding changes in the patterns of patenting. A significant number of inventors, even in the craft-based shoe industry, were distinguished by their advanced technical skills instead of direct involvement in production, and the location of invention appears to have mirrored the geographic distribution of individuals with such skills. These findings suggest that learning-by-producing was far less central in accounting for the geographic differences in inventive activity than has generally been thought.

EMPIRICAL STRATEGIES

Evaluating the Learning-by-Producing Hypothesis

One way of investigating the learning-by-producing hypothesis (whether exposure to problems and opportunities in production was conducive to inventive activity) is to examine the correlation between the geographic clustering of invention and production. Following previous studies on invention and technological progress that use patent statistics to gauge inventive activity, we can test the learning-by-producing hypothesis by comparing the shares of patents and the shares of manufacturing employment across regions.[6] 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 each region's share of patents and how it evolved over time would mirror that of the manufacturing labor force.

Nonetheless, problems may arise when using the above test to evaluate the effect of learning-by-producing on the location of invention. First, patent statistics do not fully reflect inventive activity. Moreover, discoveries associated with learning-by-producing might be innovations, or new applications of existing technical knowledge, rather than inventions, and thereby not patentable. Zvi Griliches, however, argues that patent statistics provide a reasonable, if not powerful, indicator of inventive activity.[7] We can also enhance the analysis by classifying patented inventions into different types (such as distinguishing between those

---

[5] Here, the electric industry refers to electrical machinery, generation, and wiring and lighting.

[6] See, for example, Schmookler, *Inventions* and Sokoloff, "Inventive Activity."

[7] See Griliches, "Patent Statistics."

related to improvement in product and those related to improvement in process), and focusing on those where proximity to production would likely be particularly important.[8]

In addition to the questions about the usefulness of patent statistics in measuring inventive activity, the test may not be sufficient even if the co-location of the two activities is indeed observed, that is, the regional distributions of patents and of labor force (production) closely resemble each other. Two problems would still arise in disentangling the impact of learning-by-producing on the location of invention. One comes from indirect causation. The observed geographic association between invention and production might not result from learning-by-producing. Instead, one or more resources crucial to both manufacturing and inventive activities may cause the two activities to co-locate. For example, inventive activity might be carried out by individuals working in a capital good sector that locates in proximity to production because of high transportation costs. To address this issue, we can look at the inventors more closely, examining their biographical information; for instance, examining their job description and the organization they belong to. In so doing, we can establish whether they are directly involved in production and have benefited from learning-by-producing, or they work for the capital good sector. The other problem in gauging the impact of learning-by-producing is caused by circular causation. Not only might production have effects on inventive activity, but manufacturing might also tend to locate where there have been new technological discoveries. Certainly, the resulting expansion of production could then feed back to generate more invention. Problems of this sort can also be resolved by determining how the locations and places of employment of inventors changed over time.[9]

Consequently, we need to enhance the comparison of the regional distributions of patents and labor force with investigation of biographical information on the inventors before we can conclude whether the location of production had a strong impact on the location of invention. This sort of evidence can also help us to identify other factors that exert strong influence on the location of invention.[10] Although such detail is rarely available for contemporary inventors, we can learn a great deal about early inventors from U.S. historical records such as census manuscripts and city directories. Among the information contained in these records is: year of birth, birthplace, detailed occupation, place of business, and place of residence at several points during one's life. The United States is also a country large enough to have a great deal of interregional variation in factor endowments, but without so many confounding effects as there are from institutional difference across countries.[11] I therefore have chosen to evaluate the learning-by-producing hypothesis from U.S. historical experience. Particularly, I focus on the experience of the American shoe,

---

[8] Also, patent statistics may not fully reflect inventive activity in industries that rely on other mechanisms to protect its investment in inventive activity, for example, secrecy. This would not be a major issue for the questions addressed in this paper. Unlike industries such as food and chemicals, the three industries selected in this study often employ patent rights to protect their invention. Even if there were some secrecy involved, it is unlikely that these practices would vary across regions.

[9] Another way to deal with the circular causation problem is to examine the change in inventive activity of industries whose centers of production are relocated to new areas. Such a case would allow us to focus on the impact of production shifts on the location of invention.

[10] For example, distribution of inventor's skills might tell us the type of knowledge that is crucial to carry out inventive activity and the extent to which the reliance of such knowledge influences the location of invention.

[11] For example, different industrial policies and patent regimes.

textile and electric (electrical machinery, generation, wiring and lighting) industries during the so-called Second Industrial Revolution.

Period and Industries Chosen for the Study

The Second Industrial Revolution 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 developed during 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. Given that the magnitude of the technological and organizational changes that marked the Second Industrial Revolution rival those of our own age, it is both an extremely interesting and relevant period for this study.

The three industries examined offer three intriguing contrasts. Although shoes and textiles were among the most important manufacturing industries of the First Industrial Revolution of the early 19th century (they were far and away the largest by employment or value added at 1850), they had become mature or maturing industries by the late 19th century. They were still based on the mechanical technologies that had been introduced and elaborated during the early- and mid-1800s, and technological change was largely of an incremental character for the remainder of the century. Their shares of manufacturing production, moreover, dropped by more than half, whether measured by output or by value added.[12]

However, the two maturing industries had very different development paths in geographic terms. Textile production began a long process of relocation from the Northeast (Southern New England and the Middle Atlantic) to the lower-wage South during the late 19th century. By 1910, the South employed nearly 20 percent of the U.S. textile workforce, as compared to only about 5 percent in 1870. Shoe production, on the other hand, remained concentrated in New England, and especially in Massachusetts, which was home to 40 percent 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, employing a radically new technology that marked a profound break from any other previously existing. High rates of invention characterized the industry. Even though the production of electric machinery and lighting equipment accounted for only a small share of manufacturing value added (or labor force, where it employed only about 1% of all manufacturing workers) during the Second Industrial Revolution, in both 1890 and 1910 there were many more patents granted in these areas than in shoes and textiles. The electric industry was also different in being much more capital-intensive, and science-based, than the two more traditional counterparts.

In sum, 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 that was based on a radical new technology. This record provides us with an opportunity to study whether the geography of

---

[12] Temin, "Manufacturing" reports that in 1860, the cotton textile and shoe industries accounted for about 7 and 6 percent of total U.S. manufacturing value added, respectively, and their respective shares of value-added had declined to only 3 percent and 2 percent by 1910.

invention and its relation to that of production was different for industries based on new frontier technologies than for those relying on more mature technologies.

DATA

I construct cross-sections of patent records consisting of all shoe, textile and electric patents granted by the United States Patent and Trademark Office (USPTO) in 1870, 1890 and 1910. 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. The electric patents are inventions associated with electric transmission and distribution equipment, electrical industrial apparatus and electric lighting and wiring equipment. I exclude patents that were related to electric transportation, welding, and communication equipment.[13]

To select only patents intended for the shoe and textile industries, the USPTO patent classification system is of limited use because it is based on functional use. For example, a bobbin is classified under class 242: winding, tensioning, or guiding. Consequently, I read through the description of over 72,000 patents reported in the *Annual Reports of the Commissioner of Patents* for the three cross-section years. Information about the invention such as drawing and specification was also obtained from the Official Gazette of the USPTO or the patent grant images in USPTO's on-line database if from the description I cannot identify an industry the patent was intended for. In contrast to the shoe and textile invention, the USPTO patent classification works fine for electric inventions. I therefore use it to obtain a tentative list of electric patents. Then, I check 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.

Among the information collected 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 the 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 patents.[14]

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. census of population manuscripts, 1850, 1860, 1870, 1880, 1900, 1910, 1920 and 1930; and city directories (mostly in 1890).[15] The U.S. census of population manuscripts and city directories are gathered from on-line resources such as www.ancestry.com, www.familysearch.org and www.genealogy.com.[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.[17]

---

[13] See U.S. Technical Committee on Industrial Classification, *Standard Industrial Classification* for more details on the electric industry classification.

[14] Although the total number of patents awarded to the inventor over the 7-year period might include invention in other industries, most of the patentees sampled only created invention in the industry of interest.

[15] The majority of the 1890 census of population manuscripts were lost because of the 1921 fire at the U.S. Department of Commerce.

[16] See Appendix 2 for notes on missing inventor biographical information.

[17] See Sutthiphisal, "Geography of Invention," Appendix A for more details on the samples.

THE GEOGRAPHY OF SHOE AND TEXTILE INVENTION

The Location of Production and the Location of Invention

To probe whether the location of invention in the shoe and textile industries was influenced by the location of production because of learning-by-producing, I begin with examining the regional shares of patents and the regional shares of manufacturing employment for each industry. If learning-by-producing led to a geographic association between production and invention, each region's share of patents in an industry would be roughly similar to that of its share of the industry's labor force.

The comparative results presented in Figure 1 seem at first to suggest that the location of invention was closely related to the location of production in the shoe and textile industries. In general, shares of patenting corresponded to shares of employment for the respective industries. A closer look at the patterns across regions however reveals that shares of patents in some regions, such as Massachusetts and the South, significantly deviated from their shares 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. The share of textile employment in Massachusetts dropped from 29 to 22 percent, while the share of employment in the South share nearly quadrupled from 5 to 19 percent during the period from 1870 to 1910. Strikingly, the pronounced 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 in relative terms, with its textile patent share in 1910 only about one third of the share of employment. In stark 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 42 percent, nearly twice its employment share in 1910.

The geographic patterns of patenting in the shoe industry, as compared to those of employment, were similar. Shoe production remained highly concentrated in Massachusetts 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. Massachusetts accounted for 56 percent of all shoe patents in 1910, though it employed only 42 percent of the works in the industry. On the other hand, shoe patenting declined over time in areas where shoe employment expanded such as in Northern New England and West North Central.

The absence of a corresponding increase in the South's share of invention in cotton textiles after the relocation of production, as well as Massachusetts' ever-larger lead in shoe and textile invention without increases in its shoe and textile production shares, are neither trivial in quantitative significance nor statistical outliers. These regions were major centers of invention and/or production. These divergent patterns of invention and production raise the question of whether learning-by-producing, or learning-by-doing, was indeed an important contributor to the geographic clustering of invention in shoes and textiles. Moreover, as discussed above, even in regions where the shares of patents were comparable to those of employment, one cannot infer a direct causal association between production and invention arising from learning-by-producing.

The Identity of Inventors

To better understand the relationship between the geographic patterns of invention and production, and the impact of learning-by-producing in particular, we can explore whether inventors in the two traditional manufacturing industries were directly linked to production, as well as their work experience, technical skills and productivity at invention (defined here as number of patents an inventor received over a seven-year period). We posit that if the location of production had a strong influence on the location of invention, then a large proportion of patents in the industry in question would be awarded to inventors whose jobs or occupations seemed connected to production.

Estimates of the number of patents received by inventors with various types of work experience are reported in Table 1. The results seem to cast further doubt on the notion that the geographic clustering of invention arose directly from learning-by-producing. Patents in shoes and textiles appear to have been primarily generated by two types of inventors: those who had worked in the production of goods in their respective industries, and those who had worked in the tools and machinery sector. In neither of the mature industries do individuals with experience in production seem to have dominated in the generation of new knowledge. Only about 40 percent of patents in shoes and textiles were awarded to people involved in production. Moreover, even in product and process related inventions (inventions where we would expect production involvement to be crucial for being effective at generating inventions), only half went to inventors with production experience by 1910 (as shown in Table 2).

Furthermore, shoe and textile inventors with experience in tools and machinery were generally more productive in invention at an individual level, on average receiving significantly more patents within a seven-year period than those with production experience did.[18] In the more craft-based shoe industry, the group of inventors who had worked in tools and machinery received as many patents as (if not more than) those directly involved in production. For example, William C. Stewart, a rather prolific shoe inventor receiving 25 patents in total during 1907 and 1913, spent his entire career in the tool and machinery sector and had never had any experience in shoe manufacturing. Stewart grew up in a family of machinists. Both his father and older brother were machinists. By the age of 16, Stewart had started working as a machinist apprentice. He filed his first shoe invention, a machine for holding heel stiffeners, in 1891 at the age of 26. By the time he retired from inventing in 1932 at the age of 68, Stewart had received about 87 patents in the shoe industry.[19] Inventors like William C. Stewart who had experience in tools and machinery accounted for about 40 percent of shoe patents in 1890 and 1910.

The importance of such inventors to inventive activity is even more apparent in the textile industry. For instance, Alonzo E. Rhoades, an extremely productive textile inventor receiving 91 patents in 7 years between 1907 and 1913, began his career as a farm laborer like his father and by 1880 had become a machinist. Rhoades obtained his first patent in 1888 for a roving machine. In total, he was awarded about 284 textile patents over his

---

[18] For each patentee, I retrieved the total number of patents awarded to him over the seven-year period centered on the year of the sampled patent. For example, I count the number of patents an inventor in the 1870 cross-section received from 1867-1873. Although this statistic may include inventions in other industries, it should fairly reflect the productivity of each inventor at invention in the respective shoe and textile industries because only few inventors generated crossover inventions in other industries.

[19] Information obtained from *U.S. Census of Population manuscripts*, 1880, 1900,1910, 1920 and 1930; and *LexisNexis,* U.S. Patents.

career.[20] Inventors with experience in tools and machinery similar to Alonzo E. Rhoades' generated nearly half of textile patents in 1890 and 1910.

The findings concerning the background of inventors also suggest that the geographic distribution of individuals with appropriate technical skills might instead be a more important factor influencing the location of invention than proximity to production. These inventors based in tools and machinery were rather distinguished individuals. From Table 3, in all three cross-section years, more than two-thirds of shoe and textile patentees with experience in tools and machinery were people who had worked as machinists or draftsmen and engineers, positions that required high levels of technical skills. In contrast, less than one-eighth of shoe and textile patentees with production experience had worked as machinists or draftsmen and engineers.

The Location of Individuals with Technical Knowledge and the Location of Invention

Could the divergences between the shares of patents and the shares of employment highlighted in the previous section be attributed to the geographic distribution of individuals with different levels of technical skills? To answer this question, I review the types of technical skills crucial to carry out inventive activity in the two mature industries and the regions in which individuals with such skills were located. I then compare the regional patterns of individuals with appropriate technical skills with the geography of invention.

The level and complexity of technology in shoes and textiles changed dramatically during the First Industrial Revolution, as manufacturing in these industries went from a reliance on craft-based production to one on machinery driven by inanimate sources of power. Production with hand tools by skilled workers came to be displaced by relatively capital-intensive production carried out by less skilled workers.[21] In order to make an improvement on an existing machine, an inventor was much advantaged by having some mechanical knowledge, such as how the machine, or machines in general, functioned and how its parts were connected to one another.

Throughout the 19th century, such mechanical knowledge was generated and transferred within the tool and machinery sector. The tool and machinery sector emerged during the First Industrial Revolution as the introduction and spread of mechanical technology transformed one manufacturing industry after another from hand to ever-more mechanized production. The sector was specialized in designing and manufacturing production equipment. Tool and machinery firms were typically established in areas with high concentrations of industrial production, and hence where there was large demand for new machinery or other capital equipment. Southern New England (and Massachusetts especially) emerged during the early 19th century as the leading manufacturing region in the country (on a per capita basis). When manufacturing became mechanized during the First Industrial Revolution, the tool and machinery sector also flourished in Southern New England, and it remained centered there even into the Second Industrial Revolution.[22] As shown in Table 4, Southern New England (and Massachusetts reported separately as a distinct region) had the highest concentration of machinists (individuals with knowledge of

---

[20] Information obtained from *U.S. Census of Population manuscripts*, 1880, 1900,1910, 1920 and 1930; and *LexisNexis,* U.S. Patents.

[21] See, for example, Thomson, *Path* for technological development in the shoe industry, and Copeland "Technical Development" and Weld, "Specialization" for the textile industry.

[22] See Rosenberg, "Technological Change" and Hounshell, *American System* for the development in the tool and machinery sector during the First Industrial Revolution.

mechanical technologies) in the country throughout the second half of the 19th century. In contrast, the South's economy was dominated by agricultural production, and had a very small manufacturing sector in both relative and absolute terms. Not surprisingly, therefore, individuals with knowledge of mechanical technologies, as measured by machinists per capita, were relatively scarce there.

Did the abundance of individuals with mechanical knowledge (workers in the tool and machinery sector) in Massachusetts and the scarcity of such individuals in the South contribute to the wide divergences between the shares of production and the shares of invention in these regions? If individuals with mechanical knowledge played a highly disproportionate role in carrying out inventive activity in shoes and textiles, regions with high concentration of such individuals would be expected to generate more inventions than could be explained by their manufacturing workforce (production), and these regions would have a higher proportion of their patented inventions in these industries made by tool and machinery workers than in regions with populations less familiar with tools and machinery.

Indeed, a comparison of the work experience of inventors in Massachusetts, the South and in other regions does appear to corroborate the idea that the geographic divergences between invention and production arose from the regional differences in their stocks of mechanical knowledge. As shown in Table 5, in both mature industries the share of patents created by inventors with tool and machinery experience (and hence mechanical knowledge) is much higher in Massachusetts than in other regions. Both in 1890 and 1910, Massachusetts was the only region that the tool and machinery workers accounted for more than half of shoe and textile patents. In contrast, the South was the region with the lowest proportions of textile inventions awarded to individuals with experience in tools and machinery.[23]

Also of interest are the regional shares of patents in each type of invention: product and process related; semi-machinery; and machinery. If the divergences between the shares of patents and those of employment arose from the geographic clustering of individuals with mechanical knowledge, regions with high concentrations of such individuals would generate relatively more semi-machinery and machinery inventions (where we would expect mechanical knowledge to be vital to carry out inventive activity). Table 6 suggests that this seems to be the case. Massachusetts patentees stand out for their major contributions in semi-machinery and machinery inventions, not in product and process related inventions (where we would expect production involvement to be more crucial), whereas the South's contribution in semi-machinery and machinery inventions was extremely modest as compared to other regions.

These findings from the two mature industries in terms of work experience and type of invention highlight the limited explanatory power provided by the learning-by-producing hypothesis. The location of invention seems to be more closely associated with where individuals with mechanical knowledge were located than with where there was a high concentration of production. Was this also the case for newly emerging industries such as the electric industry?

---

[23] Although the concentration of individuals with mechanical knowledge in Southern New England was comparable to Massachusetts, its shares of inventions made by individuals with tool and machinery were much smaller than those of Massachusetts. This might arise from specialization within the tool and machinery sector. That is, Massachusetts' larger shoe production volume led to its more specialization in shoe machinery than other Southern New England states.

THE GEOGRAPHY OF ELECTRIC INVENTION

Individuals with advanced technical knowledge were even more responsible for inventive activity in the electric industry than in the two mature industries. The great majority of inventions in the electric industry came from individuals who had experience in the industry (Table 7) and were highly specialized at invention.[24] Approximately three-fourth and one-half of these inventors with work experience in the industry received at least six patents within a seven-year period in 1890 and 1910 respectively (Table 8).[25] However, such inventors with work experience in the industry did not seem to be directly involved in production and were instead primarily distinguished by their distinct technical skills. In 1890 and 1910, more than two-thirds of them had worked as electricians or electrical engineers, positions that seem unlikely to have been directly involved in production, but required technical knowledge specific to the electric industry.[26] These electricians or electrical engineers played a critical role in the early development of the electric industry.

For example, Elihu Thomson, the co-founder of the Thomson-Houston Electric Company, began his career as an assistant professor of chemistry at the Philadelphia Central High School in 1870. While teaching at the Central High School, Thomson developed several inventions. He received his first patent in 1873 for an improvement in the manufacture of sulphuric acid. Later he became interested in electric technology. By January 1880, Thomson had already been awarded 9 electric patents. Shortly after, a lawyer named Frederick H. Churchill recruited Thomson as an electrician to form the American Electric Company in New Britain, Connecticut. In 1883, the company was moved to Lynn, Massachusetts, renamed to the Thomson-Houston Electric Company, and in 1892 it merged with the Edison General Electric Company to form the General Electric Company. After the merger, Thomson became the chief engineer of the consolidated firm. Throughout his career, Thomson devoted himself to improving electric technology. By the time of his death, Thomson had received more than 600 electric patents.[27]

How did these electricians and electrical engineers acquire their skills? Electric technologies were radically different from those underlying the steam- and water-powered machinery of the shoe and textile industries. They were quite abstract, requiring knowledge on how to interpret and make sophisticated technical diagrams and scientific calculations, unlike mechanical or other technologies that were possible to master by physical observation or construction. Therefore, it would be more difficult for knowledge of electric technologies to be acquired through physical construction of electrical products or through apprenticeship programs in the tool and machinery sector.

Because of the novelty of the electric technology, individuals with electric knowledge were scarce during the early year of the industry and no region had a historical legacy of such

---

[24] 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. Nevertheless, the distribution of the positions they had held (reported in Table 8) does give us some hints on whether these inventors were directly involved in production.

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

[26] Having designed electrical products, these inventors were likely to have better ideas on how to construct the products, and hence they might be involved in production. Nonetheless, their primary jobs were not in production. See, for example Passer, *Electrical Manufacturers* and Institute of Electrical and Electronics Engineers, Inc., "IEEE History Center" for more details on famous electric inventors.

[27] Institute of Electrical and Electronics Engineers, Inc., "IEEE History Center," Passer, *Electrical Manufacturers*, pp. 22-26 and LexisNexis, "U.S. Patents."

human capital. An individual who was trained at an institution of higher learning would therefore have an advantage over others in understanding the electric technologies. The biographical information of famous electric inventors provides an insight into how they acquired appropriate human capital and later became prolific inventors in electric. To name a few, Frank J. Sprague, the founder of the Sprague Electric Railway and Motor Company, graduated from the Naval Academy in 1878. Benjamin G. Lamme, a recipient of the American Institute of Electrical Engineers' Edison Medal, obtained his degree in mechanical engineering from the Ohio State University in 1888. Ernst F. W. Alexanderson, another recipient of the Edison Medal, received his engineering degree from the Royal Technical University in Stockholm in 1900.[28]

A quantitative examination of the educational background of inventors across industries also corroborates the notion that electric inventors tended to be relatively highly educated. As reported in Table 9, electric inventors, whether relatively productive or unproductive at invention, were often highly educated, as compared to the general population in the late 19th century, or even the technologically creative inventors focused on shoes and textiles. Based on the inventors sampled from 1890 and 1910 for whom inferences about educational attainment can be drawn from census materials (only about 20 percent of the total), roughly one-half of electric patentees went to college, as compared to less than 10 percent for shoe and textile inventors.[29]

Given the fact that familiarity with, if not mastery of, the scientific basis of electricity was an enormous advantage in making contributions at the frontiers of electric technology, and that those who attended engineering schools were likely more capable of dealing with technical diagrams, carrying out the necessary calculations and measurements, as well as applying the relatively abstract principles involved in electric technology, we would expect patenting rates in this industry to be higher in regions where engineering schools (or education institutions offering training in related sciences) were clustered. The results in Table 10 and Figure 2 seem to support this conjecture. Regions known for engineering schools (East North Central, Massachusetts, New York, New Jersey and Pennsylvania) generally had higher concentration of engineers and larger shares of electric patents in 1890 and 1910.[30, 31]

---

[28] Institute of Electrical and Electronics Engineers, Inc., "IEEE History Center," and Passer, *Electrical Manufacturers*.

[29] Perhaps more strikingly, about 37 percent of "unproductive" electric inventors (receiving less than 6 patents in 7 years) went to college, while less than 12 percent of "productive" shoe and textile inventors (receiving at least 6 patents in 7 years) did so. A few 1890 electric inventors did not go to college. They gained a fair amount of scientific knowledge prior to their first invention by reading scientific journals (for example, Thomas Edison) or working as an apprentice for famous inventors (for instance, William Stanley, Jr. who dropped out of Yale Law program to work for Hiram Maxim). Nonetheless, they accounted for only a small fraction of electric inventors in 1890 and 1910. One might also argue that emerging industries would attract more young individuals than maturing industries, presumably because the former are more likely to offer high returns. Since the younger population would be more inclined to attend college, it is natural to observe more electric inventors who were educated in college. However, Sutthiphisal, "Geography of Invention," Chapter 6 shows that controlling for age, more electric inventors went to college than shoe and textile inventors.

[30] By the late 1880s, several U.S. institutions had started offering electrical engineering programs. Cornell University offered its first electrical engineering courses in 1883. Massachusetts Institute of Technology offered a course in electrical engineering in 1882 and awarded its first engineering degrees in 1885.

[31] The statistics on number of engineers in each region also include mining engineers because the census of manufactures reports did not make a distinction among different types of engineers. This would likely contribute to the West's large number of engineers per capita.

In contrast, where production took place does not seem to have had a powerful impact on where inventive activity in the electric industry was carried out (also shown in Figure 2). In fact, the divergence between invention and production is even more apparent in the newly emerging electric industry than in the maturing shoe and textile industries.[32] In 1890, although Massachusetts and New York had the highest shares of electric patents, their patent shares were smaller than their employment shares. Between 1890 and 1910, Massachusetts experienced a considerable drop in both electric invention and production, but a far more significant decline in invention. On the other hand, New York, which had an even more substantial decline in employment, maintained its high patent share. As for other regions, their patent shares in 1890 were rather different from their employment shares in the same year but appeared to mirror their employment shares in 1910. This phenomenon seems to imply that the clustering of invention preceded that of production in these regions.[33]

CONCLUSIONS

To investigate the influence of the location of production on the location of invention, 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

---

[32] Measurement errors associated with patent and employment data might also result in part of the divergence between production and invention observed in the electric industry. However, the impact of these errors should not be significant. Cautious readers might argue that inventors who had close ties with multi-state firms, especially those in the electric industry, might use their business addresses to apply for patents instead of their actual place of residence. However, among inventors that I match to the census manuscripts, their addresses seemed to be where they actually lived (inferred from their children's birth places). Furthermore, the U.S. Bureau of Census reported all electric related production in one single category: electrical apparatus and supply in the Census of Manufactures. This category includes products that are not selected for my electric patent sample (e.g. electric transportation equipment). The electric employment statistics reported by the Bureau are therefore different from the employment levels of electric products classified into electric patents for this paper. However, I do not expect the difference to be significant because many large electric companies during that time such as General Electric and Westinghouse were not specialized in producing just one class of electrical products. Indeed, they produced a wide spectrum of electrical goods within the same state. Consequently, the statistics in the Census of Manufactures should still be a reasonable measure of employment in the electric industry for the purposes of this paper.

[33] Another distinct feature of the geographic patterns of electric invention is that electric invention was less clustered than that in shoes and textiles at the regional level. This finding, at first, 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, the finding that electric invention was scattered 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. In Sutthiphisal, "Geography of Invention," Chapter 5, I examine the geographic patterns at a civil division smaller than a state and show that electric invention was, indeed, much more concentrated in urban areas than shoe and textile invention.

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 an 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 tool and machinery sector in that state (and in Southern New England more generally) since the early- and mid-19th century. It was individuals with technical knowledge 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 geographic patterns of invention in the new technology industry offer a striking contrast with those in shoes and textiles, in that the former was characterized by greater variability over time in the locations of high rates of invention. Again, however, 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 generators of 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 or automatically from an increase in production. Even if these countries undertake policies aimed at promoting human capital formation, not only will the process likely take many years, but there are many issues surrounding the formation of human capital that developing countries have to resolve as well. For example, policymakers in developing countries must take into account the fact that institutions facilitating human capital accumulation may vary with the level of technological development. While colleges seem to promote knowledge diffusion in industries which are more science-based such as the electric industry, technical schools or apprenticeship programs can perhaps provide effective support to industries which employ more mature technology.

Additionally, in many ways the difficulties facing follower countries that seek to jump 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 (for example, 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.[34]

APPENDIX 1. CLASSIFICATION SCHEMES

A. 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.

B. Work Experience: The index for work experience is drawn from inventor's occupation at the previous or current census (or city directory). In other words, the index is obtained from his occupational title within ten year prior to the time he received the patent. (a) The production category is only applicable to shoe and textile inventors. Inventors classified into this category are those with occupational titles implying experience in the production and trading of goods in the industry. Last makers and loom fixers are included in this category. (b) The tool and machinery category is applicable to all three industries. Unless they were specifically listed as workers in some other manufacturing industry, shoe and textile inventors classified into this category include all those with occupations such as machinists, draftsmen, mechanical engineers, toolmakers, as well as model and pattern makers. Textile inventors who were millwrights, shuttle makers, and needle makers are also included in this category. On the other hand, electric inventors classified into this category are only those with experience in general tool and machine works (not those works for electric machinery firms). (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

---

[34] The examples of Taiwan and South Korea give confidence that the case for optimism is based on more than mere hope. Among countries that received U.S. utility patents in 2001, Taiwan ranks fourth and South Korea eighth, comparable to countries that are traditionally more technologically advanced such as the United Kingdom and France. (See U.S. Patent and Trademark Office, *Technology Assessment*.)

electrical goods and equipment, except those related to electrical transportation and communication and equipments. An inventor is classified as having electrically related experience if he was involved in electrical transportation and 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.

C. Invention Type: The index for invention type is inferred from detailed descriptions of invention that include patent drawing, specification and claims. The classification scheme for the shoe and textile industries is as follows. (a) The product and process category refers to inventions that were goods or means to produce such goods in the respective industries. Shoe heels, shoe peg, new shoe construction methods, chemical treatment of clothes and new weaving methods are included in this category. (b) The semi-machinery category refers to inventions that were incremental improvement of existing tool and machinery such as mechanisms and work supports as well as new hand tools or apparatus such as shoe knives, lasts, shuttles, bobbins, knitting machine needles and dyeing apparatus. (c) The machinery category refers to inventions that are new machinery, not just its part. (d) The other category are inventions that were not part of the industry core such as boot blacking apparatus, shoeboxes, shoe brushes and ribbon holder for retail stores.

APPENDIX 2. NOTES ON MISSING INVENTOR BIOGRAPHICAL INFORMATION

Biographical information (especially occupational titles at some points during the inventor's life) is missing for some patentees in the sample because of several reasons. First, during the period that I construct the sample, the on-line resources do not allow me to search for an individual in some census years unless he was the head of household. Furthermore, even if the inventor was the head of household in that census year, I occasionally cannot obtain his information from these on-line resources because either his name was not recorded correctly into the on-line databases or there were too many individuals with the same name living in the same county.

Because young, single, and foreign-born individuals are less likely to be heads of household and because urban areas tend to have more individuals with the same name, the biographical information of inventors in the sample would be biased to some extent. However, there is no reason to believe that this bias is systematic across regions or toward certain types of occupation.

REFERENCES

Alchian, Armen. "Reliability of Progress Curves in Airframe Production." *Econometrica* 31 (1963): 679-693.

Arora, Ashish, Andrea Fosfuri, and Alfonso Gambardella. "Specialized Technology Suppliers, International Spillovers and Investments: Evidence from the Chemical Industry." *Journal of Development Economics* 65, No. 1 (2001): 31-54.

Arrow, Kenneth J. "The Economic Implication of Learning by producing." *Review of Economic Studies* 29, No. 3 (1962): 155-173.

Audretsch, David B., and Maryann P. Feldman. "R&D Spillovers and the geography of Innovation and Production." *American Economic Review* 86, No. 3 (1996): pp. 630-640.

Copeland, Melvin T. "Technical Development in Cotton Manufacturing since 1860." *Quarterly Journal of Economics* 24, No. 1 (1909): 109-159.

Dumais, Guy, Glenn Ellison, and Edward Glaeser. "Geographic Concentration as a Dynamic Process." *Review of Economics and Statistics* 114, No. 2 (2002): 389-432.

Feldman, Maryann P., and Richard Florida. "The Geographic Sources of Innovation: Technological Infrastructure and Product Innovation in the United States." *Annals of the Association of American Geographers* 84 (1994), No. 2: 210-229.

Griliches, Zvi. "Patent Statistics as Economic Indicators: A Survey." *Journal of Economic Literature* 28, No. 4 (1990): 1661-1707.

Hekman, John S. "The Product Cycle and New England Textiles." *Quarterly Journal of Economics* 94, No. 4 (1980): 697-717.

Hounshell, David A. *From the American System to Mass Production 1800-1932.* Baltimore, MD: Johns Hopkins University Press, 1984.

Institute of Electrical and Electronics Engineers, Inc. "IEEE History Center," *www.ieee.org,* April 2003-July 2004.

Irwin, Doublas A., and Peter J. Klenow. "Learning-by-Doing Spillovers in the Semiconductor Industry." *Journal of Political Economy* 102, No. 6 (1994): 1200-1227.

Jaffe, Adam B., Manuel Trajtenberg, and Rebecca Henderson. "Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations." *Quarterly Journal of Economics* 108 (1993): 577-598.

Kane, Nancy Frances. *Textiles in Transition: Technology, Wages, and Industry Relocation in the U.S. Textile Industry, 1880-1930.* Westport, CT: Greenwood Press, 1988.

Keller, Wolfgang. "International Technology Diffusion." *Journal of Economic Literature*, forthcoming (2004).

Kim, Sukkoo. "Expansion of Markets and the Geographic Distribution of Economic Activities: The Trends in U.S. Regional Manufacturing Structure, 1860-1897." *Quarterly Journal of Economics* 110, No. 4 (1995): 881-908.

Krugman, Paul. *Geography and Trade.* Cambridge, MA: MIT Press, 1991.

Lamoreaux, Naomi R., and Kenneth L. Sokoloff. "The Geography of Invention in the American Glass Industry, 1870-1925." *Journal of Economic History* 60, No. 3 (2000): 700-729.

LexisNexis. "U.S. Patents." *www.lexisnexis.com*, March 2005.

My Family.com Inc. "Ancestry World Tree." *www.ancestry.com*, February 2003-July 2004.

_______. "Biographies of Notable Americans, 1904." *www.ancestry.com* (February 2003-July 2004).

_______. "Directories and Member Lists." *www.ancestry.com* (February 2003-July 2004).

_______. "U.S. Census Collection." *www.genealogy.com* (February 2003-July 2004).

_______. "U.S. Federal Census Images." *www.ancestry.com* (February 2003-July 2004).

Myrdal, David R. *Economic Theory and Under-developed Regions.* London: Duckworth, 1957.

Passer, Harold C. *The Electrical Manufacturers, 1875-1900.* Cambridge, MA: Harvard University Press, 1953.

Rosenberg, Nathan. "Technological Change in the Machine Tool Industry, 1840-1910." *Journal of Economic History* 23, No. 4 (1963): 414-443.

Saxenian, AnnaLee. *Regional Advantage: Culture and Competition in Silicon Valley and Route 128.* Cambridge, MA: Harvard University Press, 1994.

Schmookler, Jacob. *Inventions and Economic Growth.* Cambridge, MA: Harvard University Press, 1966.

_______. *Patents, Invention, and Economic Change: Data and Selected Essays.* Edited by Zvi Griliches and Leonid Hurwicz. Cambridge, MA: Harvard University Press, 1972.

Sokoloff, Kenneth L. "Inventive Activity in Early Industrial America: Evidence from Patent Records, 1790-1846," *Journal of Economic History* 48, No. 4 (1988): 813-850.

Sutthiphisal, Dhanoos. "The Geography of Invention in High- and Low-Technology Industries: Evidence from the Second Industrial Revolution." PhD diss., University of California, Los Angeles, 2004.

Temin, Peter. "Manufacturing." In *American Economic Growth,* edited by Lance E. Davis. New York, NY: Harper & Row, 1972.

The Church of Jesus Christ of Latter-day Saints. "Ancestral File." *www.familysearch.org,* February 2003-July 2004.

_______. "Census Records." *www.familysearch.org,* February 2003-July 2004.

_______. "Pedigree Resource File." *www.familysearch.org,* February 2003-July 2004.

Thomson, Ross. *The Path to Mechanized Shoe Production in the United States.* Chapel Hill, NC: The University of North Carolina Press, 1989.

U.S. Bureau of the Census. *Census of Population, Reported by States.* Washington, DC: GPO, various years.

_______. *Census of Manufactures, Reported by States.* Washington, DC: GPO, various years.

_______. *Census of Manufactures, Reported by Industries.* Washington, DC: GPO, various years.

U.S. Census Bureau. *Measuring America: The Decennial Censuses From 1790 to 2000.* Series POL/02-MA. Washington, DC: GPO, 2002.

U.S. Patent and Trademark Office. "Full-Page Images." *www.uspto.gov,* October 2001-July 2004.

_______. "Patent Classification," *www.uspto.gov* (October 2001-July 2004).

_______. *Technology Assessment and Forecast Report: Patent Counts by Country/State and Year – Utility Patents, January 1, 1963 – December 31, 2001.* Washington, DC: GPO, 2001.

U.S. Patent Office. *Annual Reports of the Commissioner of Patents.* Washington, DC: GPO, various years.

_______. *Official Gazette of the United States Patent Office.* Washington, DC: GPO, various years.

U.S. Technical Committee on Industrial Classification. *Standard Industrial Classification Manual.* Revision of the 1945 ed. of manufacturing industries and the 1949 ed. of nonmanufacturing industries. Washington, DC: Executive Office of the President, Bureau of the Budget, 1957.

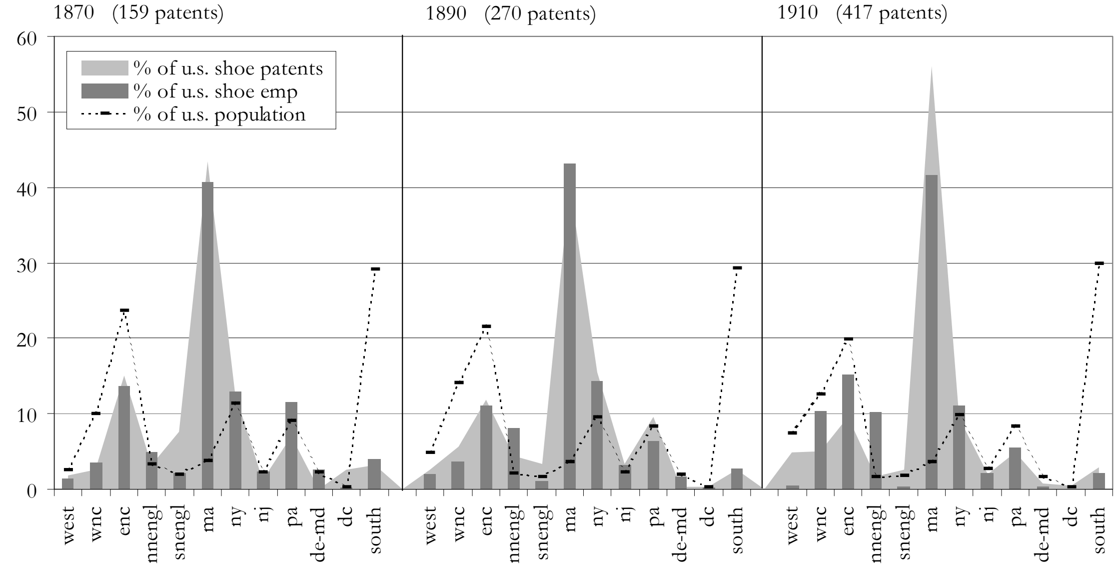
Weld, L. D. H. "Specialization in the Woolen and Worsted Industry." *Quarterly Journal of Economics* 27, No. 1 (1912): 67-94.

Wright, Gavin. "Cheap Labor and Southern Textiles, 1880-1930." *Quarterly Journal of Economics* 96, No. 4 (1981): 605-629.

Young, Alwyn. "Learning by Doing and the Dynamic Effects of International Trade." *Quarterly Journal of Economics* 106, No. 2 (1991): 369-405.

_______. "Invention and Bounded Learning by Doing." *Journal of Political Economy* 101, No. 3 (1993): 443-472.

Panel A: Shoes



Panel B: Textiles

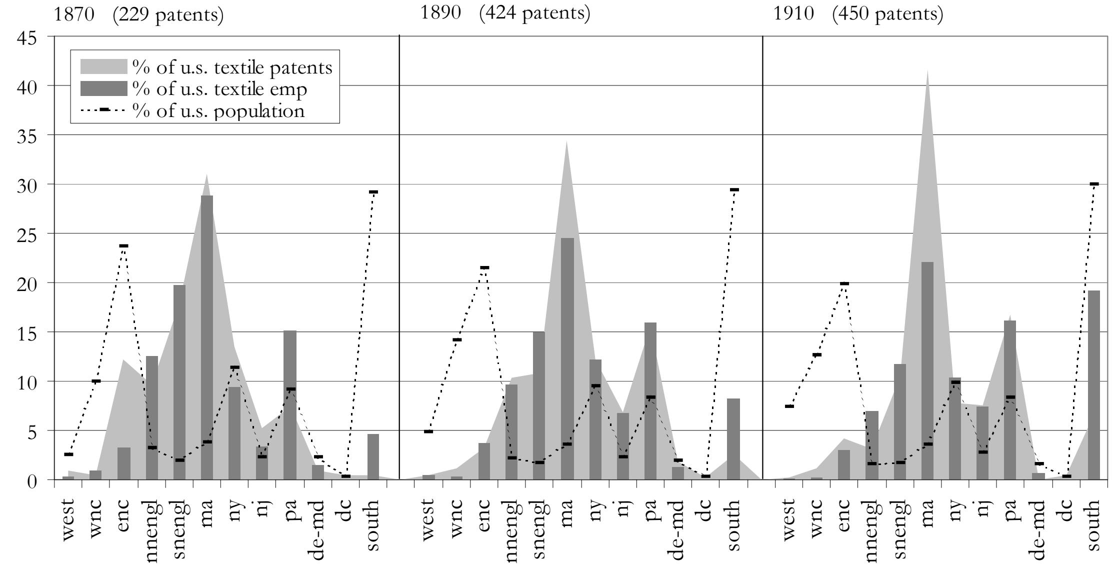


FIGURE 1
REGIONAL SHARES OF EMPLOYMENT AND PATENTS

Sources and Notes: *Annual Reports of the Commissioner of Patents*, 1870, 1890 and 1910; *U.S. Census of Manufactures Reports*, 1870, 1890 and 1910; *U.S. Census of Population Reports*, 1870, 1890 and 1910. WNC = West North Central, ENC = East North Central, NNENGL = Northern New England, SNENGL = Southern New England. See Appendix 1-A for the geographic classification scheme.

TABLE 1
SHARES OF PATENTS CREATED BY INVENTORS WITH EXPERIENCE IN SHOE AND TEXTILE PRODUCTION, TOOLS AND MACHINERY, AND OTHER SECTORS

Year	No. of patents	Patentee's work experience distribution (normalized percent): Production	Tools & machinery	Other	Percent with unknown work experience	Number of patents an inventor received within 7 years (median): Production	Tools & machinery
Panel A: Shoes							
1870	159	52.5	23.3	24.2	24.5	2	3
1890	270	40.4	40.4	19.1	30.4	1	4
1910	417	41.7	40.6	17.7	17.3	2	5
Panel B: Textiles							
1870	229	42.8	42.8	14.5	24.5	1	2.5
1890	424	42.1	47.6	10.4	27.1	2	4
1910	450	40.2	50.8	9.0	18.7	1.5	4

Sources and Notes: *Annual Reports of the Commissioner of Patents*, 1867-73, 1887-93 and 1907-13; *U.S. Census of Population Manuscripts*, 1850, 1860, 1870, 1880, 1900, 1910, 1920 and 1930; *Ancestry.com* (U.S. City Directories, mostly in 1890). The index for work experience is inferred from inventor's occupation 10 years before and up to the time of invention. To obtain the work experience distribution, I omit patents with missing inventor information and normalized the reported shares so that all other categories add up to one. See Appendix 1-B for more details on work experience classification and Appendix 2 for the reasons why work experience may be unknown.

TABLE 2
DISTRIBUTION OF PATENTEE'S WORK EXPERIENCE BY EACH TYPE OF SHOE AND TEXTILE INVENTION

Year	Type of invention	No. of patents	Share of patents (percent)	Patentee's work experience distribution (normalized percent)			Percent with missing experience information
				Production	Tools & machinery	Other	
			Panel A: Shoes				
1870	Product & process	81	50.9	60.3	13.8	25.9	28.4
	Semi-machinery	37	23.3	48.4	29.0	22.6	16.2
	Machinery	33	20.8	50.0	45.8	4.2	27.3
	All types of invention	159	100.0	52.5	23.3	24.2	24.5
1890	Product & process	108	40.0	63.5	12.2	24.3	31.5
	Semi-machinery	44	16.3	55.9	38.2	5.9	22.7
	Machinery	106	39.3	12.5	75.0	12.5	32.1
	All types of invention	270	100.0	40.4	40.4	19.1	30.4
1910	Product & process	138	33.1	47.8	10.9	41.3	33.3
	Semi-machinery	98	23.5	56.7	42.2	1.1	8.2
	Machinery	141	33.8	31.6	66.9	1.5	5.7
	All types of invention	417	100.0	41.7	40.6	17.7	17.3
			Panel B: Textiles				
1870	Product & process	25	10.9	72.2	0.0	27.8	28.0
	Semi-machinery	111	48.5	40.4	49.4	10.1	19.8
	Machinery	87	38.0	36.9	46.2	16.9	25.3
	All types of invention	229	100.0	42.8	42.8	14.5	24.5
1890	Product & process	58	13.7	76.7	14.0	9.3	25.9
	Semi-machinery	223	52.6	36.2	51.5	12.3	26.9
	Machinery	141	33.3	36.3	55.9	7.8	27.7
	All types of invention	424	100.0	42.1	47.6	10.4	27.1
1910	Product & process	48	10.7	51.5	42.4	6.1	31.3
	Semi-machinery	270	60.0	42.0	49.1	8.9	17.0
	Machinery	131	29.1	33.3	57.4	9.3	17.6
	All types of invention	450	100.0	40.2	50.8	9.0	18.7

Sources and Notes: *Annual Reports of the Commissioner of Patents*, 1870, 1890 and 1910; *U.S. Census of Population Manuscripts*, 1850, 1860, 1870, 1880, 1900, 1910, 1920 and 1930; *Ancestry.com* (U.S. City Directories, mostly in 1890). For the work experience distribution, I omit patents with missing inventor information and normalized the reported shares so that all other categories add up to one. See Appendix 1-B and 1-C for more details on the classification of work experience and invention type.

TABLE 3
SKILL DISTRIBUTION OF SHOE AND TEXTILE INVENTORS FOR EACH WORK EXPERIENCE CATEGORY

Year	Work experience	No. of inventors	Percent inventors received more than 6 patents in seven years	Skill distribution (unnormalized percent) Machinists	Draftsmen & engineers	Electricians & electrical engineers	Others	Unknown skills
			Panel A: Shoes					
1870	Production	54	16.7	1.9	0.0	0.0	83.3	14.8
	Tools & machinery	19	36.8	57.9	21.1	0.0	15.8	5.3
	All experience	136	22.1	8.8	3.7	0.0	52.9	34.6
1890	Production	72	9.7	2.8	0.0	0.0	61.1	36.1
	Tools & machinery	52	36.5	65.4	7.7	0.0	9.6	17.3
	All experience	228	18.9	17.5	3.1	0.0	32.9	46.5
1910	Production	85	16.5	7.1	1.2	0.0	68.2	23.5
	Tools & machinery	64	48.4	46.9	20.3	0.0	7.8	25.0
	All experience	278	20.5	13.3	5.8	0.4	39.2	41.4
			Panel B: Textiles					
1870	Production	67	7.5	7.5	3.0	0.0	70.1	19.4
	Tools & machinery	66	18.2	71.2	1.5	0.0	9.1	18.2
	All experience	200	13.0	26.0	2.5	0.0	37.0	34.5
1890	Production	109	16.5	6.4	0.9	0.0	49.5	43.1
	Tools & machinery	97	36.1	72.2	5.2	0.0	4.1	18.6
	All experience	339	19.8	23.3	2.4	0.0	23.9	50.4
1910	Production	124	10.5	5.6	0.8	0.0	37.9	55.6
	Tools & machinery	105	42.9	44.8	17.1	1.9	9.5	26.7
	All experience	329	21.3	17.0	6.4	0.9	24.3	51.4

Sources and Notes: *Annual Report of the Commissioner of Patents*, 1867-73, 1887-93 and 1907-13; *U.S. Census of Population Manuscripts*, 1850, 1860, 1870, 1880, 1900, 1910, 1920 and 1930; *Ancestry.com* (U.S. City Directories, mostly in 1890). The index for work experience is inferred from inventor's occupation ten years before and up to the time of invention, whereas that for skills is from his occupation history up to the cross-section year.

TABLE 4
SHARES OF MACHINISTS AND MACHINISTS PER CAPITA BY REGIONS

	Share of U.S. machinists (percent)				Machinists per capita (normalized)			
Region	1850	1870	1890	1910	1850	1870	1890	1910
West	0.5	0.9	5.0	6.2	0.14	0.37	1.03	0.84
WNC	0.1	3.5	7.2	6.4	0.17	0.35	0.51	0.50
ENC	7.0	17.9	23.1	30.0	0.36	0.76	1.07	1.51
NNengl	8.2	5.0	2.6	1.9	1.57	1.52	1.18	1.14
SNengl	10.6	9.2	6.8	5.0	4.72	4.72	3.87	2.78
MA	21.8	15.1	10.6	8.0	5.08	4.00	2.97	2.18
NY	21.4	20.8	14.5	13.6	1.60	1.83	1.51	1.37
NJ	5.0	3.2	5.1	4.8	2.36	1.38	2.22	1.73
PA	16.1	15.1	13.8	13.1	1.62	1.65	1.65	1.57
DE-MD	4.0	2.3	2.1	1.5	1.38	0.98	1.07	0.91
DC	0.2	0.6	0.4	0.5	0.99	1.75	1.09	1.40
South	4.9	6.2	8.8	9.1	0.14	0.21	0.30	0.30

Sources and Notes: *U.S. Census of Population Reports*, 1850, 1870, 1890 and 1910; *U.S. Census of Manufactures Reports*, 1850, 1870, 1890 and 1910. Machinists include those who were apprentices to machinists. Normalized machinists per capita are equal to the share of machinists divided by the share of population.

Table 5
Shares of Patents created by Inventors with Experience in Shoe and Textile Production, Tools and Machinery, and Other Sectors

Year	Region	Share of employment (percent)	Share of patents (percent)	No. of patents	Patentee's work experience distribution (percent, normalized)			% with missing experience information
					Production	Tools & machinery	Other	
				Panel A: Shoes				
1870	MA	40.7	43.4	69	54.9	41.2	3.9	26.1
	SNengl	2.2	7.5	12	50.0	8.3	41.7	0.0
	NY-PA	24.5	19.5	31	47.6	19.0	33.3	32.3
	ENC	13.7	15.1	24	60.0	0.0	40.0	16.7
	Other	18.9	14.5	23	43.8	12.5	43.8	30.4
1890	MA	43.2	40.4	109	40.7	51.2	8.1	21.1
	SNengl	1.1	3.3	9	50.0	37.5	12.5	11.1
	NY-PA	20.6	25.2	68	43.8	29.2	27.1	29.4
	ENC	11.1	11.9	32	16.7	38.9	44.4	43.8
	Other	24.1	19.3	52	46.4	28.6	25.0	46.2
1910	MA	41.7	56.1	234	38.1	59.6	2.3	6.8
	SNengl	0.3	2.6	11	62.5	0.0	37.5	27.3
	NY-PA	16.6	14.1	59	60.0	7.5	32.5	32.2
	ENC	15.2	9.6	40	59.3	11.1	29.6	32.5
	Other	26.2	17.5	73	30.8	7.7	61.5	28.8
				Panel B: Textiles				
1870	MA	28.8	31.0	71	34.5	56.4	9.1	22.5
	SNengl	19.8	17.9	41	54.3	34.3	11.4	14.6
	NY-PA	24.6	21.0	48	57.7	30.8	11.5	45.8
	South	4.7	0.4	1	0.0	0.0	100.0	0.0
	Other	22.1	29.7	68	37.5	41.1	21.4	17.6
1890	MA	24.5	34.4	146	34.1	60.3	5.6	13.7
	SNengl	15.0	10.8	46	50.0	41.2	8.8	26.1
	NY-PA	28.1	27.8	118	58.6	37.1	4.3	40.7
	South	8.3	2.6	11	57.1	0.0	42.9	36.4
	Other	24.1	24.3	103	34.7	43.1	22.2	30.1
1910	MA	22.1	41.6	187	31.1	65.3	3.6	10.7
	SNengl	11.8	10.5	47	44.4	47.2	8.3	23.4
	NY-PA	26.5	24.5	110	39.2	45.6	15.2	28.2
	South	19.2	6.7	30	68.0	12.0	20.0	16.7
	Other	20.4	16.7	76	52.5	35.6	11.9	22.4

Sources and Notes: *Annual Reports of the Commissioner of Patents*, 1870, 1890 and 1910; *U.S. Census of Population Manuscripts*, 1850, 1860, 1870, 1880, 1900, 1910, 1920 and 1930; *Ancestry.com* (U.S. City Directories, mostly in 1890). For shoes, other = West, WNC, Northern New England, NJ, MD-DE, DC and South. For textiles, other = West, WNC, ENC, Northern New England, NJ, MD-DE and DC. See Table 1 for more details on work experience distribution.

TABLE 6
REGIONAL SHARES OF SHOE AND TEXTILE PATENTS FOR EACH TYPE OF INVENTION

			Share of patents for each type of invention (percent)				
Year	Region	No. of patents	Product & process	Semi-machinery	Machinery	All types	Share of employment (percent)
			Panel A: Shoes				
1870	MA	69	29.6	54.1	72.7	43.4	40.7
	SNengl	12	13.6	2.7	0.0	7.5	2.2
	NY-PA	31	22.2	10.8	18.2	19.5	24.5
	ENC	24	13.6	24.3	6.1	15.1	13.7
	Other	23	21.0	8.1	3.0	14.5	18.9
1890	MA	109	28.7	52.3	51.9	40.4	43.2
	SNengl	9	4.6	4.5	0.9	3.3	1.1
	NY-PA	68	31.5	11.4	23.6	25.2	20.6
	ENC	32	8.3	11.4	12.3	11.9	11.1
	Other	52	26.9	20.5	11.3	19.3	24.1
1910	MA	234	24.6	75.5	86.5	56.1	41.7
	SNengl	11	2.9	3.1	0.0	2.6	0.3
	NY-PA	59	28.3	6.1	5.0	14.1	16.6
	ENC	40	13.8	8.2	2.8	9.6	15.2
	Other	73	30.4	7.1	5.7	17.5	26.2
			Panel B: Textiles				
1870	MA	71	12.0	36.0	29.9	31.0	28.8
	SNengl	41	12.0	23.4	13.8	17.9	19.8
	NY-PA	48	48.0	15.3	18.4	21.0	24.6
	South	1	0.0	0.0	1.1	0.4	4.7
	Other	68	28.0	25.2	36.8	29.7	22.1
1890	MA	146	27.6	39.5	29.8	34.4	24.5
	SNengl	46	8.6	13.5	7.8	10.8	15.0
	NY-PA	118	36.2	20.6	35.5	27.8	28.1
	South	11	1.7	3.1	2.1	2.6	8.3
	Other	103	25.9	23.3	24.8	24.3	24.1
1910	MA	187	31.9	45.2	38.2	41.6	22.1
	SNengl	47	6.4	13.3	6.1	10.5	11.8
	NY-PA	110	31.9	21.5	27.5	24.5	26.5
	South	30	0.0	8.5	5.3	6.7	19.2
	Other	75	29.8	11.5	22.9	16.7	20.4

Sources and Notes: *Annual Reports of the Commissioner of Patents*, 1870, 1890 and 1910. See Appendix 1-C for more details on the classification of invention type.

Table 7
Shares of Patents created by Inventors with Experience in Electric Production, Tools and Machinery or Other Electrically-Related Industries, and Other Sectors

		Patentee's work experience distribution (normalized percent)			Percent with unknown work experience	Number of patents an inventor received within 7 years (median)	
Year	No. of patents	Electric	Tool-mach & elec-rel	Other		Electric	Tool-mach, elec-rel & other
1870	18	50.0	18.8	31.3	11.1	11	2
1890	539	76.6	12.6	10.8	29.5	10	3
1910	670	80.8	11.6	7.6	19.0	5	4

Sources and Notes: *Annual Reports of the Commissioner of Patents*, 1867-73, 1887-93 and 1907-13; *U.S. Census of Population Manuscripts*, 1850, 1860, 1870, 1880, 1900, 1910, 1920 and 1930; *Ancestry.com* (U.S. City Directories, mostly in 1890); *IEEE.org* (History Center). The index for work experience is inferred from inventor's occupation 10 years before and up to the time of invention. To obtain the work experience distribution, I omit patents with missing inventor information and normalized the reported shares so that all other categories add up to one. See Appendix B for more details on work experience classification.

Table 8
Skill Distribution of Electric Inventors for Each Work Experience Category

			Percent inventors received more than 6 patents in seven years	Skill distribution (unnormalized percent)				
Year	Work experience	No. of inventors		Machinists	Draftsmen & engineers	Electricians & electrical engineers	Others	Unknown skills
1870	Electric	2	100.0	0.0	0.0	50.0	50.0	0.0
	Mach & elec-rel	3	66.7	33.3	0.0	0.0	0.0	66.7
	All experience	10	50.0	10.0	0.0	10.0	50.0	30.0
1890	Electric	121	73.6	2.5	0.8	66.1	5.0	25.6
	Mach & elec-rel	33	36.4	30.3	9.1	15.2	33.3	12.1
	All experience	312	50.0	4.5	2.9	28.2	17.6	46.8
1910	Electric	265	49.4	3.4	3.4	74.0	3.4	15.8
	Mach & elec-rel	54	48.1	16.7	29.6	9.3	5.6	38.9
	All experience	468	41.5	4.7	7.3	45.3	7.1	35.7

Sources and Notes: *Annual Report of the Commissioner of Patents*, 1867-73, 1887-93 and 1907-13; *U.S. Census of Population Manuscripts*, 1850, 1860, 1870, 1880, 1900, 1910, 1920 and 1930; *Ancestry.com* (U.S. City Directories, mostly in 1890); *IEEE.org* (History Center). The index for work experience is inferred from inventor's occupation ten years before and up to the time of invention, whereas that for skills is from his occupation history up to the cross-section year.

TABLE 9
DISTRIBUTION OF INVENTOR EDUCATION

			Distribution of inventor education				
			Unnormalized percent			Normalized percent	
Year	No. of patents received within seven-year period	No. of inventors	Did not go to college	Went to college	Unknown education	Did not go to college	Went to college
			Panel A: Shoes				
1870	Less than 6 patents	106	11.3	0.0	88.7	100.0	0.0
	At least 6 patents	30	16.7	0.0	83.3	100.0	0.0
	All inventors	136	12.5	0.0	87.5	100.0	0.0
1890	Less than 6 patents	185	23.2	0.5	76.2	97.7	2.3
	At least 6 patents	43	25.6	2.3	72.1	91.7	8.3
	All inventors	228	23.7	0.9	75.4	96.4	3.6
1910	Less than 6 patents	221	19.5	0.5	80.1	97.7	2.3
	At least 6 patents	57	19.3	0.0	80.7	100.0	0.0
	All inventors	278	19.4	0.4	80.2	98.2	1.8
			Panel B: Textiles				
1870	Less than 6 patents	174	14.9	0.6	84.5	96.3	3.7
	At least 6 patents	26	11.5	0.0	88.5	100.0	0.0
	All inventors	200	14.5	0.5	85.0	96.7	3.3
1890	Less than 6 patents	272	18.0	1.5	80.5	92.5	7.5
	At least 6 patents	67	17.9	0.0	82.1	100.0	0.0
	All inventors	339	18.0	1.2	80.8	93.8	6.2
1910	Less than 6 patents	259	11.6	0.8	87.6	93.8	6.3
	At least 6 patents	70	21.4	2.9	75.7	88.2	11.8
	All inventors	329	13.7	1.2	85.1	91.8	8.2
			Panel C: Electric				
1870	Less than 6 patents	5	20.0	0.0	80.0	100.0	0.0
	At least 6 patents	5	40.0	0.0	60.0	100.0	0.0
	All inventors	10	30.0	0.0	70.0	100.0	0.0
1890	Less than 6 patents	156	12.8	7.7	79.5	62.5	37.5
	At least 6 patents	156	11.5	17.3	71.2	40.0	60.0
	All inventors	312	12.2	12.5	75.3	49.4	50.6
1910	Less than 6 patents	274	7.3	4.4	88.3	62.5	37.5
	At least 6 patents	194	8.2	11.9	79.9	41.0	59.0
	All inventors	468	7.7	7.5	84.8	50.7	49.3

Sources and Notes: *Annual Report of the Commissioner of Patents*, 1867-73, 1887-93 and 1907-13; *U.S. Census of Population Manuscripts*, 1850, 1860, 1870, 1880, 1900 and 1910; *Ancestry.com* (U.S. City Directories, mostly in 1890); *IEEE.org* (History Center). The index for college education is inferred from inventor's occupation during the age of 11 to 22 as well as other sources such as the IEEE History Center and university Internet archives located by www.google.com (for example, Massachusetts Institute of Technology, Lehigh University and Stanford University). An inventor is classified as having no college education if he worked before the age of 21, or work as a laborer when he was 22; whereas an inventor is identified as having college education if he reported his education as a student at the age of 18-22.

TABLE 10
SHARES OF ENGINEERS AND ENGINEERS PER CAPITA BY REGIONS

	Share of U.S. engineers (percent)				Engineers per capita (normalized)			
Region	1850	1870	1890	1910	1850	1870	1890	1910
West	5.1	4.2	9.4	15.4	1.37	1.65	1.93	2.08
WNC	0.5	8.9	10.5	9.1	0.54	0.89	0.74	0.72
ENC	18.1	22.7	23.8	22.2	0.93	0.96	1.10	1.12
NNengl	3.2	2.0	1.9	1.4	0.61	0.61	0.85	0.87
SNengl	2.5	3.0	2.3	2.0	1.10	1.55	1.34	1.11
MA	5.9	5.2	5.4	4.8	1.38	1.39	1.52	1.30
NY	18.4	17.1	13.8	14.6	1.38	1.51	1.45	1.47
NJ	2.7	4.6	4.0	4.1	1.29	1.96	1.74	1.50
PA	19.9	16.9	12.7	10.8	2.00	1.85	1.52	1.30
DE-MD	3.2	2.5	2.0	1.6	1.09	1.06	1.01	0.98
DC	0.4	0.6	0.6	0.6	1.93	1.61	1.55	1.54
South	20.1	11.4	13.6	13.4	0.56	0.39	0.46	0.45

Sources and Notes: *U.S. Census of Population Reports*, 1850, 1870, 1890 and 1910; *U.S. Census of Manufactures Reports*, 1850, 1870, 1890 and 1910. Normalized engineers per capita are equal to the share of engineers divided by the share of population.

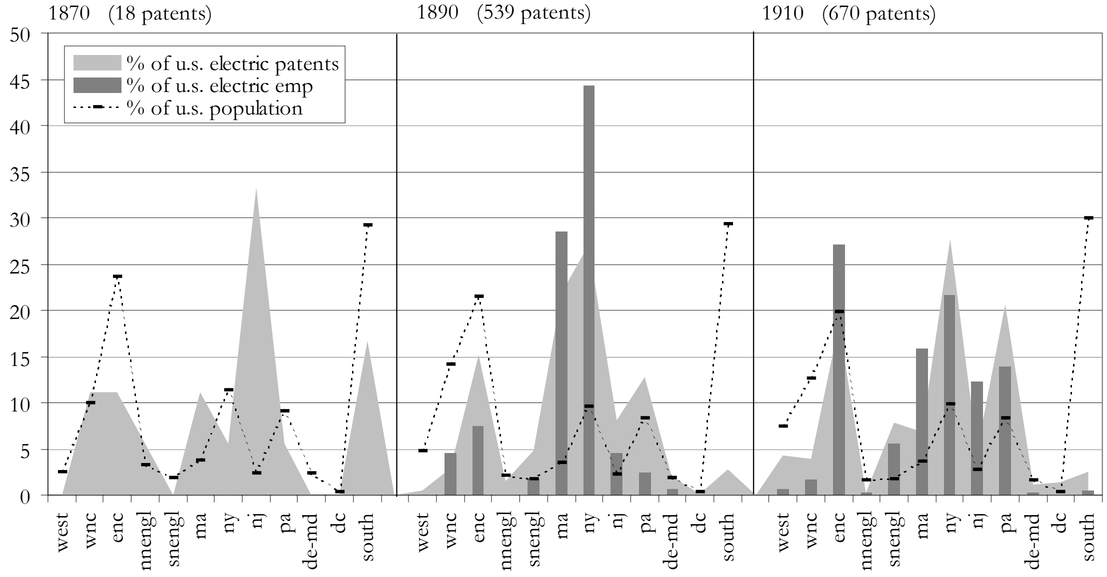


FIGURE 2
REGIONAL SHARES OF EMPLOYMENT AND PATENTS IN THE ELECTRIC INDUSTRY

Sources and Notes: See Figure 1.