Lives of invention: Patenting and productivity among great inventors in the United States (1790-1930)

B.Zorina Khan *
Kenneth L.Sokoloff **

Thomas Edison is one of the most famous and productive inventors in American history. His inventive career spanned the period from the end of the Civil War through 1931: an era during which technological advances transformed everyday life. He is noted as the most prolific U.S. patentee, with a total of 1 093 U.S. patents to his credit, including improvements in telegraphy, incandescent light bulbs, the stock ticker, storage batteries, movies, the phonograph, automobiles and flying machines. Edison did not receive any formal schooling and was untrained in modern science and mathematics. His methods were empirical and based on thousands of meticulously documented experiments. In his famous statement, Edison attributed much of his lifelong productivity to application rather than inspiration, and noted that "genius is hard work, stick-to-it-iveness, and common sense"[1]. Besides being a celebrated inventor, Edison was a successful and wealthy entrepreneur who founded numerous companies throughout the world to exploit his inventions.

What were the factors that contributed to Edison's success and how typical was he relative to other inventors of his time? Many historians have followed a biographical approach that focuses on the attainments of one or a few outstanding individuals, whereas economists favor a more systematic assessment of central tendencies. The historical and economic methods each have their advantages and drawbacks, so here we combine both approaches and examine the biographies of some 420 "great inventors" from the United States. Other economic historians have used biographical information to explore the patterns and sources of important and exceptional innovation. For example, in his studies of painters, novelists and Nobel prize winners in

---

* Bowdoin College and NBER.
** University of California, Los Angeles and NBER.

1 Dyer F.L. and Thomas Martin T.C., *Edison, his life and inventions*, New York, Harper Bros, 1929.

economics, David Galenson has proposed a life cycle approach to creativity, and discerns two different types of innovators: "conceptual artists" or theorists who primarily make their most significant discoveries early in their careers; whereas "experimental artists" or empiricists are those whose "genius" emerges later in the life-cycle after a long gestation period during which they accumulate the skills and knowledge to realize better and better contributions or creations[2]. This sort of work raises fundamental questions about the nature of human capital, what knowledge, skills, and other personal characteristics are conducive to extraordinary creativity, and how those factors vary over time and with the field of endeavor. However, we extend the investigation beyond life cycle factors to explore the role of a number of other factors in explaining creativity or productivity at invention.

Our study assesses where and under what conditions important new technological knowledge is generated. A primary issue is how to identify what is important new technological knowledge or, in other words, how to gauge the productivity of individual inventors. Patents are the most conveniently available measure, but patents differ enormously in terms of the commercial value or technical significance of the underlying invention. Moreover, not all inventions are patented, and the propensity to patent an invention may vary across time or industry. We attempt to overcome such problems by considering a variety of indicators of productivity at generating new technological knowledge. Our study is, of course, grounded on the presumption that our sample of inventors, who have been recognized by historians as important or "great inventors", were indeed highly productive at invention. We also employ information on whether the inventor obtained patents; the total number of patents granted to an inventor over his/her lifetime; whether patents were assigned (an index of commercial value); citations to individual patents and individual inventors (an index of technical value); and on whether patents were litigated. We then explore whether there are systematic patterns to how such indexes of productivity at invention vary across the characteristics or circumstances of the "great inventors" and whether and how these patterns changed over the course of the nineteenth and early twentieth centuries.

In the second section of the paper, we discuss the construction of our complete data set and present some summary statistics about the backgrounds and careers of the "great inventors" sampled. The remainder of the paper focuses, however, on the subset of 260 inventors who were born between 1820

---

2 To gauge the significance of contributions, Galenson employs measures such as prices of paintings at auction and the number and character of citations. See, for example, Galenson D.W., *Painting outside the lines: patterns of creativity in Modern Art*, Cambridge (Mass.), Harvard University Press, 2001; EysenckH., *Genius: the natural history of creativity*, Cambridge, Cambridge University Press, 1995; the many monographs by Simonton D.K., including *Genius and creativity: selected papers*, Greenwich (CT), Ablex Publishing Corp, 1997; and Lehman H.C., *Age and achievement*, Princeton, Princeton University Press, 1953.

and 1885. In the third section, we treat the question of how the productivity of these inventors varied over their life cycle and whether the pattern changed over time (by birth cohort). In the fourth section, we explore the influence of education and formal technical qualifications on technological productivity, as well as variation in productivity at patenting across industries and regions. Finally, we analyze the entrepreneurship of the great inventors in terms of their attempts to extract returns from income and litigation. Our conclusion highlights the role of patent institutions in encouraging or enabling technologically creative individuals from humble or ordinary backgrounds to make important contributions to knowledge of technology.

The great inventors data set

This study examines the histories of 420 "great inventors" and their inventions between 1790 and 1930. The sample consists of individuals recognized in leading biographical dictionaries, such as the *Dictionary of American Biography*, as important inventors and we obtained information for each of these inventors on the patents they received, the citations to their patents, whether their patents were litigated, as well as extensive biographical information such as their level of formal schooling and whether and how they sought to extract material returns from their discoveries[3]. The overwhelming majority of the great inventors were prolific patentees: only 13 failed to patent their inventions and nearly all of these nonpatentees were born before 1820. Of the roughly 16900 patents awarded to these great inventors, we have collected detailed information on 4500 of them. These data allow us to trace changes over time in the backgrounds and behavior of the individuals who were responsible for important technological discoveries.

In previous work, we described the results for 160 great inventors who filed their first patents by 1846[4]. Our findings highlighted the democratic nature of significant inventions in the early nineteenth century. The majority of the great inventors had little or no formal education and many of those who attended college were trained in nontechnical fields. Instead of machinists or engineers, most were from the commercial, artisanal or professional classes. We argued that many of their inventions were the outcome of persistent trial and experimentation that had been inspired by technical problems they had

3 The major source of biographical information was the *Dictionary of American Biography*, New York, Charles Scribner's Sons, 1928-1936 [*DAB*]. Patent citations and assignments at issue relate to patents in the sample. Litigation information was obtained from U.S. federal court records through searches by inventors' names.

4 Khan B.Z. and Sokoloff K.L., "Schemes of practical utility: entrepreneurship and innovation among great inventors during early American industrialization, 1790-1865", *Journal of economic history*, 53 (2), 1993, p289-307. Also Khan B.Z. and Sokoloff K.L., "Entrepreneurship and technological change in historical perspective: a study of great inventors during early industrialization", *Advances in the study of entrepreneurship, innovation, and economic growth*, 6, 1993, p.37-66.

encountered or become familiar with, through work experience. Indeed, individuals with a minimum of schooling or technical training and from ordinary backgrounds were responsible for the great majority of patented inventions. Their rate of patenting was pro-cyclical, tending to increase (decrease) when the economy was expanding (contracting), as was that of the general population. This and other evidence suggested that great inventors were responding to expected profit opportunities, which were enhanced by access to broader markets. The great inventors were heavily concentrated in major centers of manufacturing and invention, both because individuals that were born in such districts were more likely to develop into great inventors and because those who were born elsewhere disproportionately migrated to New York, Southern New England and the rapidly growing Midwest. Overall, we were impressed with the entrepreneurial activities of these individuals, who rapidly changed locations and occupations to take advantage of their discoveries, founded enterprises to produce their inventions and sold or licensed the rights to their patents.

Some scholars question the relevance of pragmatic experimentalists in explaining technological change after the Civil War. They posit that major inventions during this period tended to originate from corporate research and development laboratories whose employees were formally trained in science and engineering. Edison's biography highlights the ambiguities of such a model in explaining inventive activity at the turn of the 20th century. From 1876 through 1886 Edison worked at Menlo Park and in 1887 he established the West Orange Laboratory, both of which are regarded as the precursors to the modern age of team invention in research and development laboratories. The Edison laboratory undoubtedly attracted a large number of brilliant young scientists, machinists and engineers; however, Edison's own background and the methods of his assistants were more in keeping with the earlier cohort of experimentalists. These trial and error methods were only gradually updated after inventors began to apply their formal theoretical knowledge to test scientifically based hypotheses. For instance, Charles Kettering's lab at General Motors tried over 33000 different chemical compounds in the quest to create an anti-knock fuel, before Thomas Midgley decided to use his knowledge of the periodic arrangement of chemical elements to predict the correct solution to the problem. A key feature of the current data set is that we are able to address such issues by examining the careers of the great inventors born during the late nineteenth century, some of whom were still active in the 1950s.

Our analysis in this paper is primarily based on the patenting activity of 260 inventors born between 1820 and 1885, many of whom contributed to the so-called "Second Industrial Revolution"of the early 20th century. A valid concern is the extent to which the biographical sample and their patents capture truly important inventions, since some might argue that patents tend to reflect only minor incremental improvements or that inventors differ greatly in terms of true significance. Moreover, the reputations of inventors vary over time, so their inclusion in a biographical dictionary of the 1930s might not accurately reflect the significance of their contributions to technology as judged from a long-run perspective. We grant the legitimacy of these concerns, but have sought to be extremely careful in our assessments of productivity at invention. In addition to using simple patent counts, we gauged the relative importance of inventors by the amount of apace allotted to them in the biographical dictionaries[5]. Second, we have compiled the number of two types of citations to the inventions of our great inventors: one which provides an index of technological significance during the lifetime of the inventor and the other which provides an index of how significant the invention is from a modern perspective (since the mid-1970s). Taken together, these measures allow us to follow Galton's 1869 definition of genius in terms of "the opinion of contemporaries, revised by posterity"[6].

Table 1.A. indicates that the great inventors born during or after 1820 were quite different from their earlier counterparts. They were, in particular, much more likely to have technical occupations, such as engineers, machinists or full-time inventors, rather than as artisans, and had many more years of formal schooling (and in courses of study such as natural science or engineering). There was also an increase over time in the proportion of the great inventors who were children of inventors or of other individuals from technical or science-based occupations. As might be expected, more specialization at invention over time is evident, both in higher numbers of patents granted as well as in the number of years between first patent and last

---

5 The *DAB* assessment of importance of inventors can arguably be proxied by the space allotted to each individual, ranging from 444 column lines to Alexander G.Bell, to 40 lines for Moses S.Beach. We created an index that measured the space for a particular inventor relative to the average of 94 lines.

6 Quoted in EysenckH. , *op. cit.*, note 2, p.19. Inventor citations comprise a count of patents that mentioned a great inventor's name in the patent specifications and the majority of these "inventor citations" are contemporary with the great inventor's own cohort. The second metric counts the number of citations that a specific patent in our sample received from patentees who filed patents after 1975. These "long-term patent citations" in part indicate inventions that patentees today regard as still germane to their technical field. Patent citations explained 32% of the variation in historical importance for technical inventors, but only 14% for nontechnical inventors. Correlations of career patents with inventor citations (0, 7) and patent citations (0, 7) imply that the quantity of patents is related to quality. Commercially valuable inventions (as measured by patent assignments) are significantly correlated with technically valuable inventions, as shown by the correlation coefficients of assignments with inventor citations (0, 6), and patent citations (0, 7). Assignments are positively related to career patents (0, 8). Inventor citation has a lower but significant correlation with patent citation (0, 5), which in part reflect changes in technological fields of interest over time. The *DAB* index is correlated with number of patents (0, 5), inventor citations (0, 5), patent citations (0, 4), and assignments (0, 3). The relatively low correlation for assignments suggests that entry in the *DAB* was not simply due to commercial success. All correlation coefficients are statistically significant ($p <.0001$).

patent. Edison of course is an outlier, but other important inventors who were just as specialized in their interests include Carleton Ellis (753 patents), Elihu Thomson (696), Henry A.W. Wood (440), Walter V.Turner (343) and George Westinghouse (306)[7]. Of those great inventors born before 1820, the average received his first patent at the age of 34 (28, 2% received their first patent after age 40) and was granted 12 patents over a 25-year period. For those born later, the first patent came at age 32 (with only 16, 5% receiving their first patent after 40) and on average 57 patents would be obtained over a career that lasted almost 32 years. Great inventors were increasingly mobile, in geographic terms, with an increase in both the proportion born abroad as well as in states other than where patents were received. The next section of the paper examines these summary statistics in greater detail.

Life cycle patterns of great inventors

This section considers variation in productivity over the life-cycle of important U.S. inventors who were born between 1820 and 1885. The notion that inventors' peak productivity occurs when they are young is based on common perceptions that genius manifests itself early in life because of innate abilities or theoretical expertise. Some researchers have found that important achievements in the physical sciences, such as the work of Nobel Prize winners, were generally completed before the age of forty[8]. Indeed, Carleton Ellis fits the profile of the theoretically motivated genius. Ellis, who was born in 1876, a generation after Edison, created his first invention while still a chemistry student at the Massachusetts Institute of Technology. Approximately half of Ellis's 753 patents were granted during the first two decades of his career and more than 70% of his long-term citations refer to work he completed before he was forty. Similarly, Elihu Thomson, whose company later merged with Edison General to form General Electric, obtained more than forty percent of all of the patents he ever received while still in his thirties. Thomson had taught physics and chemistry and, unlike Edison, his work was based on a thorough understanding of the scientific principles underlying his inventions. Scientist William Channing, while collaborating with Moses G.Farmer to improve electric telegraphs, was able to achieve enough within a space of three years to earn himself an entry in the *Dictionary of American Biography* as a great inventor.

---

7 Although inventors with longer careers and larger numbers of patents were probably more likely to be viewed as great inventors, this was not necessarily the case. For instance, John F.O'Connor, a Chicago engineer who received over 800 patents related to railroad inventions, remained obscure and is not part of our sample. O'Connor was likely an Irish immigrant who was born in 1864. His last patent was filed in 1935 and the majority were assigned to his employer, William H.Miner Company of Illinois.

8 Stephan P.E. and Levin S.G., *Striking the mother lode in science: the importance of age, place and time*, New York-Oxford, Oxford University Press, 1992.

Thomas Edison, on the other hand, was "a trial-and-error inventor [who] scorned scientific theory and mathematical study which might have saved him time"[9]. He and his assistants found a solution to the problem of producing a durable filament for the incandescent light bulb only after months of trying thousands of different fibers. Edison obtained his first patent in 1869 at the age of 22 and his last patent was granted some 63 years later. As Figure 1 indicates, Edison's productivity in terms of the numbers of patents per year peaked during his forties, but most of his patents were filed well after this period. During this lengthy career, some have argued, his best work was completed in his first decade of invention and the rest of his career lacked the creativity of his youth[10]. However, the evidence suggests that he was a productive inventor for most of his life: as Figure1(a) shows, the majority of the long-term citations (that is, citations made in patent applications filed since 1975) to his inventions refer to patents that he filed after he was fifty and this is similar to the pattern for his inventor citations (contemporary citations that occur within the descriptions of all patents ever granted). Figure1(b) traces the life cycle record of patents granted to all great inventors and suggests that their overall patenting behavior on average most closely resembled the pattern we associate with experimentalists who had long careers. The data on long-term citations are consistent, for they are disproportionately higher for patents granted to inventors later in their careers[11].

Economic models of human creativity focus on the endowment or accumulation of human capital that leads individuals to be more productive at invention or innovation. Among the well-known channels for acquiring such human capital are experience, apprenticeship and formal schooling. Such frameworks generally predict that inventors with specialized formal education in technical subjects will tend to exhibit a different pattern over the life cycle, relative to experimentalists who primarily benefit from experience or untutored empiricism. It might be expected, for example, that learning through work experience involves rather continuous additions to human capital that would be associated with a life cycle pattern of productivity that peaks later in an individual's career. Thus, if Edison was right that genius is indeed only "one percent inspiration" we should observe a life cycle pattern rather similar to Figure1 (a). On the other hand, if most of the human capital conducive to technological discovery is obtained through a formal education in science or engineering, then we should observe an earlier peak in productivity than would be the case for trial and error inventors. We might further expect technological creativity grounded in formal schooling to then dissipate over the life cycle, as the human capital that had been acquired

---

9 *DAB*, p.280.

10 *DAB*, p.279.

11 This result could be explained, however, by the likelihood that the later the patent (by anyone), the more likely it is to be cited in patent applications filed during the late-20th century.

becomes dated. Figures1(c) and 1(d) show the age distribution of both patents and citations awarded to inventors who received formal technical training in science or engineering, relative to all other inventors. The distributions for the technically qualified are quite distinct, because they are skewed towards earlier ages and fall off more rapidly, as the human capital model predicts.

It is perhaps not surprising that formal schooling and especially courses of study in science or engineering at an institution of higher learning, came to be much more important over time for an individual to make a substantial contribution to new technological knowledge. The majority of great inventors active through the middle of the 19^{th} century had no more (if that) than a primary school education and seem to have relied on apprenticeships or work experience to accumulate the skills and background knowledge they needed to be productive at invention. As technology progressed and became more complex and capital intensive, however, would-be inventors increasingly opted for (or were required to obtain) more formal training to operate on the technological frontiers. College-educated individuals (and most of these had pursued programs in the natural sciences or engineering) accounted for a growing proportion of great inventors over time and by the final cohort nearly all enjoyed this level of education. Inventors with such a technical education in science or engineering received only 8% of all patents ever awarded to those born between 1820 and 1839 and they accounted for even smaller proportions of patents that were assigned or cited. In contrast, among the inventors in the cohort born between 1860 and 1885, those with a scientific or engineering education accounted for 45,1% of all patents ever awarded, 52,1% of all patents assigned, 40,4% of all long-term citations and 60,9% of inventor citations. Moreover, the inventors schooled in science or engineering increased their relative productivity (as compared to the other great inventors) over time, as judged by lifetime patents, rates of assignment and rates of citation.

Geographical and industrial patterns

This section explores the distribution of inventors and their patents across regions and industries. It is perhaps expected that the great inventors and their inventive activity would be concentrated in newly emerging industries. Pioneering inventions not only are the sort that earn individuals the status of a great inventor, but the most technologically creative individuals were probably drawn to newly emerging industries because of their high rates of return on inventive activity. Throughout the nineteenth century agriculture was still the largest source of employment in the economy, but it attracted little attention from patentees in general and less from great inventors. The early birth cohort of great inventors, those born before 1840, was focused largely on breakthrough technologies in manufacturing and transportation. For example, Allen B.Wilson, born in 1824, was responsible for a number of significant improvements to sewing machines. Wilson was able to finance the costs for his first patent application by selling off a share of his potential patent rights. He later formed a partnership with another great inventor, Nathaniel

Wheeler, which became the fourth largest sewing-machine manufacturing establishment in the country. Another famous great inventor partnership of the time, George Babcock and Stephen Wilcox, focused on the manufacture of steam engines and boilers. Still other great inventors of this era made their reputation through their contributions to the technologies involved in steam ships.

By the second birth cohort, both commercial interests and great inventors shifted increasingly toward the pursuit of the profit opportunities available in the burgeoning electrical industry. The early 20th century was renowned as "a new era" of the most rapid aggregate productivity growth in American economic history, in part because of the diffusion of innovations related to electricity[12]. The foundations for the surge in productivity were laid in the second half of the 19th century, with the development of telegraphy, underwater cables, arc lights and long-distance power generation. These enterprises involved numerous great inventors, including George Westinghouse, Moses G.Farmer, Stephen D.Field and Nikola Tesla. Electrical inventions comprised the single largest industry in terms of patents and assignments. The enormous enthusiasm about the potential for electricity is reminiscent of the modern dot-com phenomenon. As inventive activity became more technically demanding, it is likely that the returns to technological specialization increased, as well as the benefits to belonging to the cohort with the most recent training. Patterns by age and cohort suggest that the technological contributions to the "new economy" were disproportionately by specialized younger inventors, whereas the patentees of inventions in other fields of technology were likely to be older. Like the modern dot-com boom, inventions and investments in electrical discoveries generated large fortunes and readily attracted flows of venture capital for speculative research and development. Patentees were able to parlay their property rights in promising inventions into part ownership in numerous companies on advantageous terms that included retention of patent rights and royalties. Edison attracted capital from prominent investment bankers and financiers, as well as from investors in the several hundred public corporations with which he was associated[13]. However, he was not atypical in this regard, for investors were eager to fund start-ups allied with other great inventors.

---

12 According to the *Wall Street Journal*, March 14, 1918, p.6, "the electro-chemical industry of the United States has been so developed as now to make it certain that it is about to establish a new era in American industry". In 1884, the American Institute of Electrical Engineers was founded and included three great inventors (Alexander G.Bell, Thomas A.Edison and Franklin L.Pope) among its six vice-presidents.

13 Just one of these enterprises, the Edison Electric Light Company, along with Drexel, Morgan & Co., provided $150,000 to finance his R & D in the electrical field between October 1878 and March 1881.

Throughout the nineteenth century, patenting among the population of "ordinary inventors" clustered in specific regions and in urban areas. The early 19th century was marked by expanding markets, fueled both by the extension of transportation networks and increases in income, and patenting rates per capita rose rapidly in Southern New England and New York. Metropolitan counties registered the highest rates of inventive activity, but much of the rise in early patenting was due to residents of rural counties that had recently gained access to markets[14]. National markets emerged shortly after the Civil War, with the rapid expansion in access to railroads, but regional disparities in patents and assignments persisted throughout the nineteenth century. Patenting rates in the South and the West remained lower than in the Northeast while, within the Northeast, New England's importance decreased relative to the Middle Atlantic.

As Table 2 shows, such locational factors were even more pronounced among the great inventors. Patenting by great inventors was highly concentrated in the Middle Atlantic (51, 2% of patents) and New England (25, 9%), although the level of activity grew over time in the Midwest. The Middle Atlantic dominated in part because inventors were attracted to the region from other parts of the country. Henry Sargent was an extreme example, moving and receiving patents in 26 different cities between 1854 and 1893, but great inventors evinced exceptional mobility and tended to migrate to more profitable markets. Almost a quarter of the inventors were foreign-born, but migrants also dominated among the native-born. Migration to centers of invention and assignment occurred in part because of institutional factors such as ready access to venture capital, patent agents and legal counsel and networks of other inventors working on similar issues. The role of networks can be seen from the numerous partnerships or loose alliances that inventors formed with each other, ranging from employment and assignment contracts to long-term joint ownership of enterprises.

These networks were especially evident among inventors in the electric industry, where younger inventors briefly worked for established entrepreneurs such as Edison or Westinghouse, before breaking off to form their own enterprises. Westinghouse, when he wished to switch from air-brake inventions to the electrical field, purchased key patents to work on and hired the services of then-junior inventors William Stanley and Nikola Tesla. Stanley had been an assistant to Hiram Stevens Maxim and after leaving Westinghouse Electric he established his own firm, the Stanley Electric Manufacturing Company, which he eventually sold to General Electric. Such network effects accumulated, resulting in growing industrial specialization within and across regions. For the cohort of great inventors born between 1840 and 1859, 68% of New England patents and 39% of Middle Atlantic patents

---

14 See Sokoloff K.L., "Inventive activity in early industrial America: evidence from patent records, 1790-1846", *Journal of economic history*, XLVIII (4), 1988, p.813-850.

were in the electric industry. In the next cohort, however, important electrical discoveries were clustered primarily in the Middle Atlantic region. The electrical industry's share of New England patents fell to 24%, whereas the share for the Middle Atlantic increased to 42%, and this latter region accounted for 75% of all electrical patents. Similarly, great inventors in the Midwest region were increasingly specialized in transportation-related patents.

Entrepreneurship among great inventors

Our evidence does indeed suggest that the U.S. patent system, which granted well-enforced tradable property rights to a secure asset, was highly beneficial to inventors and especially to those whose wealth would not have allowed them to directly exploit their inventions through manufacturing or other business activity. The ability to obtain patents provided a means for individuals whose chief asset was technological creativity or accumulated human capital that was conducive to inventive activity, to extract a return from their talents by focusing on invention. The biographies indicate that a remarkably high proportion of the great inventors, generally near or above half, extracted much of the income from their inventions by selling or licensing off the rights to them. Moreover, it was just those groups that one would expect to be most concerned to trade their intellectual property that were indeed the most actively engaged in marketing their inventions. The great inventors with only a primary school education were most likely to realize the income from their inventions through sale or licensing, whereas those with a college education in a non-technical field were generally among the least likely to follow that strategy[15]. Inventors who chose to realize the fruits of their technological creativity through direct exploitation (a business enterprise focusing on production) might not seem to have been so affected by the patent system, but in fact even this group benefited. They were obviously helped by holding a monopoly on the use of the respective technology, but many of them were also aided in mobilizing capital for their firms by being able to report patents (or contracts committing patents granted in the future) as assets. Patent portfolios were especially useful as a signal for those who wished to attract venture capital for exceptionally innovative projects that might otherwise have seemed overly risky.

The patterns of variation over educational class and time in the relative prevalence of different means employed by inventors in realizing the returns to their inventive activity and in the relative productivity or prominence of

---

15 Although a bit less striking, it is notable that the inventors who had studied engineering or a natural science were also, for a time (the middle three birth cohorts), much more inclined to rely on sales or licensing of their inventions to realize income. This pattern might be explained as due to these inventors choosing to specialize in what their human capital gave them a comparative advantage in – inventive activity – and leaving it to others to carry out the commercial exploitation.

different sub-groups at invention, are both fascinating and complex. We have highlighted the role of a revolutionary, low-cost, examination-based patent system, which encouraged a broad range of creative individuals and firms to invest more in inventive activity, but was especially crucial for those who began without much in the way of resources except for their technological creativity. A key feature of the story, however, is that much of the population possessed some familiarity with the basic elements of technology during this era. Moreover, apprenticeship or the widespread practice of leaving home during adolescence to pick up skills in a trade, a traditional social institution for the transmission and accumulation of more detailed technological knowledge, was both widely accessible and capable of adapting to many of the new developments and to the general quickening of the pace of advance over the 19th century. Technologically creative individuals without the resources to attend institutions of higher learning thus had avenues for acquiring the skills and knowledge necessary to be effective at invention and could later take advantage of the access to opportunities for inventive activity grounded in the patent system. Good things generally come to an end eventually and in this case circumstances changed over time with the evolution of technology. Formal knowledge of science became increasingly important for making significant contributions at the technological frontier, particularly with the so-called Second Industrial Revolution and the cost of carrying out inventive activity rose. Both of these developments served to narrow the range of the population that could generate important inventions, at least to the extent that technologically creative individuals from humble origins found it difficult to gain access to the programs in engineering or natural sciences which proliferated with the expansion of land-grant state universities during the late-19th century. Given the much higher costs of conducting inventive activity, those who were supplying the capital to fund such endeavors may have reasonably desired more in the way of credentials, as well as long-term commitments, from those they were supporting. This interpretation is obviously somewhat speculative, but it does seem to be consistent with the major patterns in the data.

Changes also occurred in the competitive environment, especially in terms of litigation. Lawsuits tended to arise more from aggressive commercial strategies than from weak intellectual property rights. Only 20% of the great inventors active during the first half of the 19th century were involved in litigation, but nearly half (47,2%) of the inventors in the later cohorts were party to lawsuits[16]. Patents in the newly emerging and most lucrative fields

---

[16] Note that the data on lawsuits generally comprise only a small fraction of all disputes, because many were settled before reaching trial. In 1920 great inventor Alexander McDougall brought the largest lawsuit filed in the US courts to date in terms of damages at issue, against a subsidiary of U.S. Steel. He was unsuccessful in his claim for $19million to compensate for the alleged infringement of his patent (N°822,753) of June 1906, for ore-cleaning. (See *New York Times*, August 18, 1921, p.24).

were the most likely to be litigated. Inventors involved in electricity were four times more likely than the average inventor to be involved in federal litigation and indeed were responsible for 41,4% of all cases[17]. Inventors such as Edison were alert to new discoveries made elsewhere and used the patent records as a source of information to locate promising areas for technological profit opportunities. Edison made contributions to the quadriplex telegraph, shifted to the telephone after the breakthrough patents of Alexander G.Bell and Elisha Gray and similarly changed direction throughout his career whenever a new field opened. His companies purchased the rights to numerous patents by other inventors, in order to gain a foothold in the development of new technologies and were aggressive in promoting their interests. It is therefore not surprising that he was involved in 11,3% of the 533 federal cases that concerned great inventors.

The Supreme Court had long upheld the dictum that "in the construction of patents and the patent laws, inventors shall be fairly, even liberally, treated" so patentees had great leeway in formulating strategies[18]. Former competitors, such as Gordon McKay and Charles Goodyear, pooled patents to resolve overlapping claims. A combination even paid John Good $150000 a year *not* to manufacture rope with the superior technology covered by his key 1885 patent. A number of these lawsuits involved antitrust charges of attempts to monopolize the industry based on the advantage of patent ownership. George Eastman's firm, Eastman Kodak, was charged several times with antitrust violations[19]. In 1912 he controlled more than 75% of the entire photography market and earned 171% in profits. Eastman Kodak bought out competing patents, filed lawsuits against competitors, stipulated exclusive contracts with suppliers and required principals in acquired companies to sign agreements not to re-enter the industry. The firm joined with Edison Manufacturing Company and eight others to organize the Motion Picture Patents Company, which controlled over 70% of that industry. Although the holding company managed the pooled patents, one of its major functions was to bring patent lawsuits so as to deter competitors[20]. Then, as now, courts at times found it difficult to disentangle the legitimate entrepreneurial exploitation of patent rights from welfare-reducing monopolistic strategies, especially when the defendant was universally regarded as a public benefactor.

---

17 The top seven litigants were all in the electricity and communications industry: Nikola Tesla (14 cases); Alexander G Bell (16); Reginald A Fessenden (17); Elihu Thomson (25); Charles Van Depoele (34); George Westinghouse (36); Thomas Edison (60). The per capita rate of litigation for their industry was 8.1, compared to 2 for agriculture and food, and 1.0 for miscellaneous inventions.

18 243 U.S. 502, 1917.

19 For instance 230F 522, 1916; 183F 704, 1912; 226 F 62, 1915.

20 The pool was dissolved after antitrust charges were settled in 1916.

Sir Henry Sumner Maine was a stringent critic of democratic ideals, but even he conceded that the U.S. patent system was one of the "provisions of the Constitution of the United States which have most influenced the destinies of the American people" and was moreover responsible for the finding that the United States in 1885 was "the first in the world for the number and ingenuity of the inventors by which they have promoted the useful arts"[21]. The majority of great inventors chose to patent their key inventions. The American patent system facilitated the entry of relatively disadvantaged individuals into the field of technology, enabled them to specialize in invention, mobilize resources to fund patenting and commercialize their discoveries and enhanced the diffusion of information and inventions[22]. Patent rights comprised secure assets that were extensively traded and gave inventors with only modest resources the opportunity to appropriate private returns as well as to make valuable contributions to society.

Throughout the nineteenth century important inventions were generated by patentees from ordinary backgrounds, as gauged by their occupations and educational level. For generations, most of the great inventors in the United States, such as Thomas Edison, had acquired through apprenticeship and experimentation the aptitude they needed to make significant contributions to technical knowledge. By the early twentieth century, however, specialized training in science or engineering was becoming increasingly important for those who aimed to operate at the frontiers of technology. These patterns reflected the changing nature of invention, innovation and entrepreneurship. The acquisition of human capital through formal education increased the inventor's ability to resolve complex problems more quickly, although this type of capital also depreciated more rapidly. Formal education was also associated with more effective organizational skills, the ability to attract and train skilled employees, and the mobilization of large-scale capital through corporate equity ownership. Such expertise in innovation became more valuable as markets became national or even international. By the era of the "new economy" of the 1920s, Elihu Thomson, an immigrant scientist, was a more typical great American inventor than Edison.

---

21 Maine H.S., *Popular government*, Indianapolis, Liberty Classics, (1976 reprint of 1885), p.241-242.

22 In particular, we emphasize the role of relatively low patent fees, the award of patents to the first and true inventor (which protected poor inventors who needed to raise money to obtain a patent), the centralized examination system after 1836 (which led to economies of scale); the training of a large cadre of patent examiners unlike any other in the world; the provision of a signal that facilitated mobilization of capital; the acquisition of information not just about prior arts but also about potential new areas of interest; and increased security of property rights. There were minimal restrictions on the rights of patentees after the patent was granted (no compulsory licenses, "Crown use" or working requirements). The Patent Office itself was self-financing and independent and thus less susceptible to political corruption or arbitrary political dictates. The patent system received strong support and enforcement from federal laws and courts.