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The Case of Cleveland, Ohio

Naomi R. Lamoreaux
Yale University
National Bureau of Economic Research

Margaret Levenstein
University of Michigan

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Naomi R. Lamoreaux, Yale University and NBER

Margaret Levenstein, University of Michigan

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Patenting in an Entrepreneurial Region during the Great Depression:

The Case of Cleveland, Ohio

This paper investigates the effect of a major macroeconomic shock, the Great Depression, on patenting in an innovative region. Cleveland, Ohio, was a vibrant industrial city as late as the 1920s, a hotbed of inventive activity in such important Second Industrial Revolution industries as open-hearth steel, electrical equipment, chemicals, machines tools, and automobiles. At a time when large-scale enterprises were coming to dominate both production and innovation in the Middle Atlantic, technological innovation in the East North Central region remained the province of small-scale enterprises and independent inventors (Lamoreaux, Sokoloff, and Sutthiphisal 2011). Cleveland epitomized this regional dynamic. Much like Silicon Valley today, its success was based on networks of entrepreneurs and financiers that funneled investment into new firms and technologies. Although some of city's manufacturing firms had grown into (or become part of) large national corporations by the 1920s, the average size of firms in the city remained small relative to other manufacturing centers, and startup enterprises continued to be an important means of exploiting new technological discoveries.

Patenting is generally thought to be a pro-cyclical activity. The expected returns from commercializing a new technology fall when demand and incomes decline, and so one might expect there to be less incentive to invest in technological discovery during downturns (Schmookler 1966). In addition, invention and patenting are costly endeavors that are likely to be more difficult to finance in periods when revenues, incomes, and prices are falling. One might expect, therefore, that a shock of the magnitude of the Great Depression would have taken a serious toll on patenting rates and that the shock would have been particularly severe in a region such as Cleveland's, where there were so many small, networked firms dependent on external finance. As Figure 1 shows, the evidence is generally consistent with these expectations. Patenting rates dropped everywhere in the U.S. during the great depression, but they fell longer and farther in the East North Central region than in the Middle Atlantic. Unfortunately, we do not have a separate time series for patenting in the Cleveland area, but we can see that the fall was deeper in Ohio than in the East North Central region as a whole.

These general patterns do not, however, tell us much about the mechanisms at work in the decline. We know from David Mowery and Nathan Rosenberg's analysis of the surveys of industrial research laboratories conducted by National Research Council (NRC) during the 1930s that large firms' investments in R&D facilities and personnel actually rose during the depression. That increase in turn might explain why patenting dropped less in the Middle Atlantic than elsewhere (Mowery and Rosenberg 1989). But we have no comparable studies of firms that organized technological discovery more informally, and we have no direct information about how patenting by inventors in different kinds of enterprises and settings was affected by the macroeconomic shock.

The purpose of this paper is to begin to fill this gap in our knowledge by examining the patenting record of two different samples of inventors in the Cleveland region during the Great Depression. The first sample consists of active inventors, some of whom were employees in established firms with R&D labs and others of whom were principals in startups. Comparing the patenting behavior of these inventors with those from an earlier cohort at comparable ages and stages of their careers, we find little or no effect of the depression. To the contrary, our results indicate that inventors maintained to a remarkable extent their commitment to patenting during the depression, even though this strategy must have taken a toll on the resources of their enterprises. The second sample consists of potential inventors—graduates of the Case School of Applied Sciences from the 1920s and 1930s. We find that the record of the 1920s graduates looks much like that of the established inventors in the sense that the depression does not seem to have negatively impacted their patenting. The 1930s graduates were a different story. Not only did their patenting activity suffer during the depression, but the shock seems to have had a long-term negative effect on their careers. We draw two main conclusions from these findings. First, patenting was such an important part of firms' business strategy that they were willing to incur great sacrifices in order to keep it going during the depression. Second, the main negative effect of the Great Depression on patenting was to prevent the next generation of inventors from forming. We hypothesize that this generational effect was much greater for economies like Cleveland's that depended on networks and the formation of new enterprises and that it may have contributed to this regional center's subsequent decline.

Data Sources

In order to examine the effect of the Great Depression on Cleveland's inventors and their enterprises, we analyze data on two groups of inventors. The first consists of two cohorts of "frequent inventors": all inventors resident in Cuyahoga County who obtained at least three patents during the years 1928-30; and, for comparative purposes, all inventors resident in Cuyahoga County who received at least three patents during the years 1910-12. Whereas the first cohort suffered through a long debilitating depression in the years immediately following the sample years, the second experienced a boom when the outbreak of war in Europe stimulated American industrial production. For both cohorts of inventors, we collected additional data on occupations, patenting careers, and other personal characteristics, as well as information on the companies to which they assigned their patents.

More specifically, using Google Patent, LexisNexis, and the U. S. Patent and Trademark Office (USPTO) website, we identified every patent issued to an inventor resident in Cuyahoga County and every patent assigned to an individual or firm located in Cuyahoga County during the years 1910-12 and 1928-1930. We then selected the patentees who received at least three patents during these years. For these frequent inventors, we collected (from the same sources) all the patents they obtained over their lifetimes. The patent records provided us with the name and city of residence of the patentee(s), as well as the name and location of any individuals or companies to which the inventor(s) assigned the patent at the time of issue. We then searched for additional information on the patentees and assignees in a variety of other sources, including the manuscript U.S. Decennial Census of Population, military draft records, and social security death records available at Ancestry.com, Cleveland (and other) city directories, the surveys of industrial research laboratories published in the *Bulletin* of the National Research Council (NRC), the *Commercial and Financial Chronicle*, *Poor's* and *Moody's* manuals, issues of the R. G. Dun's *Mercantile Agency Reference Book*, incorporation records, company annual reports, newspapers and magazines, and a large variety of secondary sources. We exploit as well manuscript collections that are extant for a number of Cleveland firms and financial institutions, including the records of the Cleveland Stock Exchange.

The resulting dataset allows us to categorize the relationship between inventors and the companies to which they assigned their patents and determine whether the patentee was an employee of the assignee or a principal (proprietor, partner, officer) in the business, or whether the relationship between the patentee and the assignee was arms' length. It also enables us to follow the careers of the patentees (for example, their migration decisions and their movements into and out of employment positions and into and out of their own businesses) and the histories of companies that acquired their patents (when they were founded and dissolved or otherwise disappeared, their growth and credit ratings over time, how they created or acquired new technologies, including whether they built in-house R&D laboratories, their sources of capital, and whether and where their securities traded). We compare of the careers and the patenting records of the 1910-12 cohort of inventors with that of 1928-30 cohort in order to isolate the impact of the macroeconomic shock of the Great Depression on the latter's patenting activity.

The second group for which we collected data consists of graduates of the Case School of Applied Science from 1920 to 1939. Members of this group had the requisite technical skills and social capital to become inventors, but only some did. Of the 2,401 graduates receiving a Bachelor of Science degree during this period, 622 obtained a patent at some point during their lifetimes. We are interested in comparing the propensity to invent of graduates who came of age during the Great Depression with those who finished their degrees earlier. As we did for the "frequent inventor" sample, we collected all patents issued to these graduates over their lifetimes, as well as occupational and other information from the sources described above. We supplemented this data with information from Case commencement programs, including information on the graduates' majors, thesis topics, and honors, and an Alumni Directory that Case compiled in 1958 that reported graduates' place of employment and residence.

Cleveland's Rise as a Center of Manufacturing and Invention

Located on Lake Erie at the terminus of the Ohio Canal, Cleveland had long been the commercial center of northeastern Ohio. The city's rise as a manufacturing center was largely a post-Civil War phenomenon, however (Miller and Wheeler 1990). As late as 1870 Cuyahoga County, where Cleveland is located, ranked number twenty-two in manufacturing output among counties nationwide; by 1920 it had risen to fourth place.

Many of the firms founded in Cleveland during the late nineteenth and early twentieth centuries were in industries at the heart of the Second Industrial Revolution. Cleveland's location gave it convenient access to Lake Superior iron ore, so it is not surprising that iron and steel ranked among the city's leading industries (see Table 1). Machine-tools, another industry that was important throughout the period, gave rise to automobiles, one of the city's top three industries by 1910. Electrical machinery acquired a similar prominence by the late 1920s, and chemical products, such as paints and varnishes and oil refining, though not listed among the top group until 1947, long had a major presence in the area.

These important manufacturing industries concentrated in the Cleveland area because the city was an important center for the development of leading-edge technologies. In 1900 Cleveland ranked eighth out of all U.S. cities in the total number of patents granted to residents, and if the calculation is limited to patents deemed by official examiners to have made a significant contribution to the industrial art of the period, Cleveland was the fifth most technologically important city in the country at that time (Fogarty, Garofalo, and Hammack n.d.). The success of local firms primarily rested on technologies developed in the area. For example, more than 90 percent of the patents acquired by Cuyahoga County firms during the three years

1910 to 1912 were awarded to inventors resident in the county, and in 1928-30 the proportion was almost the same (Tables 2A and B).

In previous work (Lamoreaux, Levenstein, and Sokoloff 2006 and 2007a and b), we demonstrated that the story of Cleveland's emergence as a center of innovation bears a strong resemblance to the histories of regions like Silicon Valley, where local networks of firms and complementary technological and financial institutions helped to initiate and sustain waves of start-up enterprises.[1] In Cleveland, one of the most important early startups, the Brush Electric Company, played a role in the region's development analogous to that of Fairchild Semiconductor in California.[2] The manager of the Telegraph Supply Company of Cleveland, an even earlier startup, had encouraged inventor Charles F. Brush to work on arc-lighting technology in the company's shops. When Brush succeeded in developing a workable system, the firm's officers (all prominent local businessmen) arranged for a public demonstration and in 1880 launched a new company with an authorized capital of $3 million, an enormous amount for the time. The Brush Electric Company dominated the world market for arc lighting until the mid-1880s and then began to lose ground to competitors. By the end of the decade its major shareholders decided to cash out by selling their stock to a competing firm, the Thomson-Houston Electric Company, which joined the General Electric merger in 1891. The new owners shut down the Brush factory in 1896.

During its lifetime the Brush enterprise became the hub of large network of inventors and financiers that persisted beyond the company's demise. The inventors in the network included Brush employees who obtained valuable technological training on the job, learned about

[1] On Silicon Valley, see Saxenian 1994; Castilla 2000; Kenney and Florida 2000; Hyde 2003; Lécuyer 2006.

[2] See Saxenian 1994. The remainder of this section is based on Lamoreaux, Levenstein, and Sokoloff 2006 and 2007a. See those articles for the sources underpinning this discussion.

opportunities for spinoff enterprises, and launched their own companies. Brush foreman W. H. Bolton, for example, realized that the growth of arc lighting meant there would be rising demand for the carbon electrodes that produced the light. He left Brush to form the Bolton Carbon Company which grew into National Carbon (later one of the main constituents of Union Carbide, now a subsidiary of the Dow Chemical Company). Another Brush employee, John C. Lincoln, left to form a business manufacturing electric motors. After a couple of false starts, Lincoln's enterprise grew and prospered, splitting into two companies: Reliant Electric, which specialized in electric motors; and Lincoln Electric, a pioneering supplier of electric arc-welding equipment.

The inventors in the network also included creative individuals who were not Brush employees but who were invited to work inside the Brush factory so they could develop technologies that were complementary to the firm's main dynamo and lighting businesses. Sidney Short, for instance, moved to Cleveland and to Brush in order to supervise the building of custom generators he needed for his electric streetcar invention. He stayed and for a time ran the Short Electric Railway Company out of the Brush factory. The location enabled Short to find collaborators with appropriate human capital, such as Brush employee John C. Lincoln. Alfred and Eugene Cowles similarly benefitted from building their experimental electric aluminum smelting furnace at Brush. Brush had originally scoffed at their ideas, dismissing their smelting process as just an expensive way to burn coal, but after they built their furnace at the factory he became a believer and used their aluminum to manufacture his dynamos.

For Short, the Cowles brothers, and other developers of new technology, the Brush facility provided a workspace and a community of like-minded inventors with whom they could discuss technological ideas. But it also provided a channel that enhanced their ability to tap local sources of investment. Financiers with ties to the network could "listen in" on the conversations inventors had about each other's discoveries—which ones were likely to work, which to prove economically valuable—and thus gain the information they needed to decide where to invest their funds. Short was able through this Brush-centered network to find financial backing for his street-car enterprise. Similarly, once Brush became convinced of the value of the Cowles brothers' innovation, he and other observers at the factory helped them raise capital.

Intriguingly, the Brush factory continued to function as an important gathering place and information center even after the enterprise was acquired by Thomson-Houston and production at the factory was shut down. When inventor Elmer Sperry accepted the invitation of a group of financiers to come to Cleveland in the mid-1890s to develop an electric streetcar system, he set up shop in the old Brush factory. He stayed on there until the turn of the century to work on other inventions, most notably an electric car and a related system of storage batteries which he sold respectively to the American Bicycle Company and the National Battery Company. Walter C. Baker developed his electric car around the same time in the same building, and Alexander Winton worked on his gasoline-powered automobile there as well. Each of these inventions led to the formation of companies bearing the inventors' names.

Other Cleveland enterprises played a similar role in incubating new firms. The network that formed around the White Sewing Machine Company, for example, either spawned directly, or facilitated the formation of, companies that ranged from the machine tool firm of Warner and Swasey to the White Motor Company, a producer of automobiles and trucks. The Brown Hoisting Machine Company and the Wellman Seaver Engineering Company seem also to have functioned in this way, spawning startups and spinoffs in industries related to their core businesses, though our research on these companies is not as complete. As in other cities, moreover, telegraph facilities and hardware stores functioned as gathering places for inventors and, as such, facilitated similar conversations and information flows.

In addition to these informal networks, Cleveland boasted an increasing number of more formal institutions that served as ongoing supports for innovation. On the educational front the most important was the Case School of Applied Science, which played a role in its region much like that of Stanford University in Silicon Valley more recently.[3] Founded in 1880, Case provided training to a number of important Cleveland inventors and had close connections to local entrepreneurs. For example, its first president, Cady Staley, took a personal interest in undergraduate Herbert Dow and served as a member of the board of directors of the Dow Chemical Company from its founding in 1897. Case's second president, Charles S. Howe, was closely associated with two of Cleveland's most important inventor-entrepreneurs, Worcester Warner and Ambrose Swasey. Both Warner and Swasey served on Case's board, and their donations to Case financed its astronomy building (and a state of the art telescope built by Warner and Swasey), the Warner Mechanics and Hydraulics Building, and an endowed chair in physics. As we will show, many Case students found employment in many of the region's high-tech enterprises and some like Walter C. Baker founded important start-up enterprises.

Local engineering societies also provided forums at which inventors could discuss technical problems and assess the merits of new technologies. In 1880 a small group of engineers who had been debating whether the country should adopt the metric system and other controversial topics organized the Civil Engineers Club of Cleveland. By 1908 the club had transformed itself into the Cleveland Engineering Society, which published a journal intermixing reports on the doings of local engineers, minutes of the organization's bimonthly meetings, and

[3] On Standford's role in Silicon Valley, see Leslie and Kargon 1996; Lowen 1997; Adams 2003 and 2005; and Gillmor 2004.

serious articles on topics such as "The Electric Furnace and its Use," "Some Recent Improvements in Electric Motor Control," "The Manufacture of Iron and Steel," and "Modern Machine Shop Milling Processes."[4] The city's growing numbers of patent attorneys also provided advice and technical expertise and sometimes helped to match inventors with buyers for their patents or round up investors for entrepreneurial ventures.[5]

On the financial front, Cleveland was home to an increasing number of banks and other similar financial institutions, many organized by the same men who founded startup companies. In 1870 the city had five banks and one savings institution. By 1920 there were thirty-eight banks, savings institutions, and trust companies with total deposits amounting to more than $800 million. Trading in local securities and the number of local brokerage houses also grew during the late nineteenth century, leading in 1900 to the formal organization of the Cleveland Stock Exchange (CSE). From early on the listings on the CSE included relatively more industrials than did its much larger counterpart in New York, and the number of manufacturing firms whose securities were traded on the CSE continued to grow, more than doubling between 1910 and 1914, for example. The newly listed manufacturers included some of the most successful of the innovative firms formed during the previous several decades, including National Carbon, Brown Hoisting Machine, Wellman-Seaver-Morgan (formerly, Wellman-Seaver Engineering), and the White Motor Company.

Although some of the region's startup enterprises had grown large by the 1920s and traded on the exchange, the average size of firms in the local economy remained relatively low.

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[4] See the Society's webpage for a history of the organization: http://www.cesnet.org/about.asp, accessed on 8 December 2013. The articles are from, respectively, the *Journal of the Cleveland Engineering Society*, 3 (Sept. 1910): 12-27; 4 (Sept. 1911): and 17-27 and 46-64; 4 and (March 1912): 145-62.

[5] One of the organizers of the Brush Electric Company was a patent attorney and former U.S. Commissioner of Patents. For a more general discussion of patent attorneys' role as intermediaries in the market for technology, see Lamoreaux, Sokoloff, and Sutthisphisal 2013.

In 1870 the county ranked sixty-sixth among the hundred largest manufacturing counties in terms of the average number of workers per establishment.[6] In 1920 its rank on this scale was still only fifty-two. Certainly, the region's older, more established enterprises accounted for a large fraction of the patents assigned at issue at issue to Cuyahoga firms on the eve of the Great Depression (compare Tables 3A and 3B), but as we will show, the growing presence of these firms in the region's economy does not seem to have choked off opportunities for new innovative enterprises, which continued to form and many of them to prosper.

Cleveland on the Eve of the Great Depression

There is no question that Cleveland's economy was changing during the 1920s. Some of the innovative enterprises founded during earlier periods had successfully established themselves and hired staffs of inventors, and some of these more established firms had even built their own in-house R&D laboratories. In 1920 the NRC began to survey firms to find out whether they had R&D facilities and, if so, where the labs were located and how many researchers they employed. Table 4 shows that a growing number of firms reported having laboratories in Cleveland. Most of these firms were headquartered locally, but a few were large national companies that also had facilities elsewhere. The most important example was General Electric, whose main laboratory was in Schenectady, New York, but which operated the National Electric Lamp Association (NELA) research facility in Cleveland.

The growth of large firms and the spread of industrial R&D laboratories meant that an increasing fraction of the county's inventors were employees. Nonetheless, inventors who

[6] U.S. Bureau of the Census, Historical Census Browser, retrieved 28 July 2006 from the University of Virginia, Geospatial and Statistical Data Center, http://fisher.lib.virginia.edu/collections/stats/histcensus/index.html.

operated independently or who were principals in companies formed to exploit their technological discoveries continued to generate large numbers of patents. In 1910-12 employees and principals each accounted for about the same proportion of patents (45.4 percent for employees and 46.5 percent for principals), and most of the rest went to independent inventors or patent attorneys (Table 5A). By 1928-30 the fraction going to employee- inventors had increased to 52.8 percent (Table 5B), but that meant that nearly half of all patents were still going to principals (38.2 percent) and independents/patent attorneys (8.2 percent). Table 6 sets these patterns in long-run context by comparing the 1928-30 and 1910-12 data to samples of Cleveland inventors that we took for earlier periods. When we combine principals and independents (excluding patent attorneys), we find, as one might expect, that their proportion of both patentees and patents peaked around the turn of the century and then fell off with the rise of large-scale manufacturing and industrial R&D in the twentieth century. Nonetheless, the share of inventive activity attributable to these two categories of patentees remained substantial, both in absolute terms and relative to their historic highs.

As was the case nationally (see Lamoreaux and Sokoloff 1999), the proportion of patents assigned, and the proportion of assignments that went to companies, increased dramatically in the Cleveland area over time (see Table 7). Employees often had contracts that obligated them to turn over their inventions to their employers, so their patents were more likely than those of other inventors to be assigned at issue (Fisk 1998). In 1910-12, for example, the employees in our frequent inventors sample assigned two thirds (66.4 percent) of their patents at issue, but principals assigned only 43.2 percent (and independents and patent attorneys only 36.1 percent) (Table 5A). Over time, however, the gap between employees and other inventors narrowed, perhaps because principals faced more pressure from investors to transfer their technology or perhaps because companies generally attached more importance to controlling patented technology.[7] Employees assigned almost 90 percent of their patents at issue in 1928-30. For principals the figure was 82.5 percent and for independents and patent attorneys, 84.6 percent (Table 5B). Interestingly, however, for both principals and employees the average number of assignees increased between the two cohorts from 1.03 to 1.25 for employees and from 1.19 to 1.48 for principals, suggesting that neither group of inventors was automatically assigning their inventions to the firms with which they were associated, even as their tendency to assign patents by the time of issue increased.[8] Indeed, as late as 1928-30, employees transferred to their employers only 60.8 percent of the patents they assigned at issue, and principals transferred to their companies only about 47.5 percent (of the lower proportion) of patents they assigned at issue.

Although some employees pursued careers in established firms, increasingly as researchers in R&D labs, others used jobs as stepping stones to start their own businesses. This path from employee to employer seems to have become somewhat more difficult to navigate by the 1920s. Although the age distribution of employees and principals was very similar in the 1910-12 cohort, employee-inventors in the 1928-30 cohort were younger on average than the principal-inventors (Tables 8A and 8B). This change suggests that either the probability of employees starting their own businesses was dropping and/or entry into principal status was occurring later in inventors' careers. It was certainly still possible in the 1920s to make the transition from employee to principal. For example, Wilbur Burke was listed in the 1920 U.S. Census as the manager of an electrical company, but by 1926 he was president of the Electric

[7] Tom Nicholas (2007) has shown that intellectual property played a dramatically more important role in market evaluations of companies in the 1920s than it had in the preceding decade.

[8] This trend rise might reflect entrepreneurial behavior, but it could also reflect increased mobility across firms or movement in and out of employment and self-employment.

Vulcanizing Rubber Co, a newly formed Cleveland company. Lee Chadwick was a mechanical engineer working in an auto works company in 1910, but president of the Cleveland Metal Products Company in 1923. Anthony Fricker was a machinery salesman in 1910, but president of the A. Fricker Manufacturing Company in 1923. Inventor-entrepreneurs were not disappearing—nearly half of the 1928-30 frequent inventors were principals or independents/patent attorneys and about 20 percent were under age 40—but it is clear that they were aging relative to employees.

There was a similar change over time in the proportion of principals and employees who came from outside the region. In the 1910-12 cohort, principals and employees were equally likely to be born outside of Ohio, suggesting that the local networks that helped inventors get a start in business were relatively welcoming to newcomers (Table 8A). By the1928-30 cohort, however, principals were more likely than employees to be from Ohio, and it seems that inventors without local connections had a harder time finding support to start a business, particularly in the early stages of their careers. In both periods, moreover, principals were less likely than employees to come from foreign countries, perhaps because immigrants were less likely to have the skills or relationships necessary to establish a firm (Tables 8A and 8B).

The Cleveland region nonetheless remained a magnet for migrants at least through the 1920s. Although there was decline between the 1910-12 and 1928-30 cohorts in the proportion of inventors born abroad (Tables 8A and 8B), this trend is consistent with overall patterns of migration during the Teens and Twenties. Moreover, the decline in foreign migrants was largely offset by an influx of inventors born in other regions of the U.S., a flow that continued during the 1920s. Over 50 percent of the American-born inventors in the 1928-30 cohort who came from outside Ohio were first observed in the state in the ten preceding years, about the same proportion as in the 1910-12 sample (Table 9A and 9B).

As the continued importance of principals in the population of inventors suggests, the growing presence of large firms in the region's economy does not seem to have choked off entrepreneurial opportunities. The proportion of patents accounted for by more established enterprises rose over time, but this pattern is exactly what one might expect to find in an innovative region that had been generating new firms for an extended period of time. Some of the startups from previous periods succeeded and hired staffs of inventors, and their employees accounted for an increasing share of the patents produced in the region. But migrants continued to flow into the region, new firms continued to form, and the inventors who were principals of startups still accounted for a large proportion of the area's output of patents.

The Effect of the Great Depression on Cleveland's Inventors and their Enterprises

To assess how the Great Depression affected Cleveland's still vibrant inventive community, we estimate the probability that patentees in our 1910-12 and 1928-30 frequent-inventor samples obtained a patent in each year of their patenting careers and then compare the patenting of the 1928-30 inventors during the Great Depression with the patenting of the1910-12 inventors during the equivalent time period in their careers.[9] This comparison enables us to control for changes in the probability of patenting over the life cycle and hence to ask whether inventors patented less than one might otherwise expect during the Great Depression. For each cohort of inventors, we compare the probability of patenting in three-year time intervals before and after the selection period, controlling for age. We also check to see whether the probability

[9] We also ran estimates on the number of patents obtained in each year with very similar results.

of patenting was higher for inventors who were principals in companies, or who were independents and patent attorneys, relative to those who were employees. Tables 10A and 10B report the descriptive statistics.

Because we selected the frequent inventors on the basis of their having received at least three patents during the sample years, including the patents from these (high patenting) years in the analysis might bias our results and make it easier to find that patenting for the 1928-30 group declined during the Great Depression. We deal with this selection problem in three ways. First, although we chose the sample on the basis of the year the patents were *issued*, the estimates are computed on the basis of the year the inventor *applied* for the patent. The year of application corresponds much more closely to the time in which the patentee was engaged in the inventive activity. Second, we run the estimates both with and without the patents from the selection years so as to obtain what are effectively upper and lower bound estimates for the coefficients on adjacent periods. Most patent applications were submitted two to three years before they were issued (2.19 years on average for the 1910-12 patents; 3.32 years on average for the 1928-30 patents). Not surprisingly, therefore, the coefficients on the period just before the selection years (1907-09 for the 1910-12 group and 1925-27 for the 1928-30 group) change most in magnitude when we exclude these patents. Finally, the effect of the selection bias on the two cohorts should have been much the same, so the change in patenting by the 1928-30 group during the depression years relative to the change in patenting by 1910-12 group during the comparison period will still be informative.

Tables 11A and B present Logit estimates of the probability that a member of the 1910-12 and 1928-30 cohorts would apply (successfully) for at least one patent in any given year. In each table, Column 1 reports the probability of obtaining a patent in each year as a function of the inventor's age. For both cohorts, patenting increased with age until about the time the inventor turned 46 and then declined. This relationship between patenting and age was stable across all the specifications and also across cohorts. It does not seem, therefore, that there were any large changes in the life cycle pattern of inventing in the interval between the two samples. The third column in each table adds dummies for the various three-year time intervals, with the omitted category being 1901-03 for the 1910-12 sample and 1919-21 for the 1928-30 sample.[10] Columns 1 through 5 in each table include the sampled patents; columns 6 through 9 exclude them. If one focuses on the estimates for the 1928-30 cohort (Table 11B), one sees that the inventors' probability of patenting, controlling for age, was significantly higher during the period 1928-30 than during the base years and then tailed off, as might be expected, during the depression. What is striking, however, is how minimal the drop in patenting was during the depression years. Indeed, the coefficient on 1931-33 is positive and is statistically significant if one excludes the patents on which the same was selected. Although the point estimates turn negative during the later years of the downturn, the probability of patenting is not statistically different from in the base years. By contrast, for the 1910-12 group (Table 11B), the decline over comparable intervals was much steeper, the coefficients are all negative, and in most cases the coefficients are statistically significant. In other words, it appears that the 1910-12 inventors fared much worse after the sample selection period than the 1928-30 inventors, even though they faced more favorable macroeconomic conditions.

Columns 4 and 8 of each table highlight an important difference between the two cohorts. Among the 1910-12 group, principals and independent inventors had significantly higher probabilities of patenting over their careers than employees, but the differences among types of

[10] The omitted periods were chosen to be as close as possible to the sample years without including many of the patents on which the sample was selected.

inventors largely disappear by 1928-30. These results underscore the changes in Cleveland's economy that we discussed in the previous section. Although the inventor-entrepreneurs who drove Cleveland's early growth continued to have a strong incentive to invent and patent, their relative position in the local economy had slipped. Controlling for occupation does not, however, change the time pattern of patenting for either cohort. Although there are undoubtedly other differences between the two cohorts, and also between the time periods in which they were active—differences that should make us cautious about the precision of these comparisons—the relatively minimal impact of the Great Depression nonetheless comes through with striking clarity.

The Graduates of Case School of Applied Science, 1920-39

If the Great Depression did not dramatically dampen the patenting activity of Cuyahoga County's established inventors, it may nonetheless have made it more difficult for young would-be inventors to pursue careers in the region that gave them scope for technological creativity. In order to explore this possibility we collected information about the patenting activity of a set of young men whom we know started their careers with the human capital necessary to engage in technological discovery—the 2,480 students who graduated with Bachelor of Science degrees from the Case School of Applied Science between 1920 and 1939. Located in Cleveland, Ohio and founded in 1880 by local businessmen interested in promoting the study of engineering, Case trained a number of significant inventor-entrepreneurs and worked closely with the firms they started, supplying them with both research and scientifically trained employees (Cramer 1980).

As Table 12 shows, about a quarter of the Case graduates from these two decades obtained at least one patent during their lifetimes, and many of these inventors were quite prolific. Inventing was not evenly distributed among graduates from different fields of study (Table 13). Among the Case patentees, the average number of lifetime patents was 5.45, but physicists patented at almost twice that average (9.38 lifetime patents) and civil engineers only about half (2.81). Nor was patenting evenly distributed by occupation. For this part of the analysis we rely on the decennial censuses of 1930 and 1940, which classified heads of household alternatively as workers, employers, or people who labored on their "own account." Although these groupings roughly correspond to the categories of employee, principal, and independent inventor that we used for the frequent inventors samples, it is clear that the Census counted many principals and entrepreneurs as "workers" because they drew salaries from their companies. We were able to locate about two-thirds of the Case graduates in the 1940 Census (Table 14A). About 96 percent of those for whom we were able to identify an occupational category were classified as workers. Workers had more patents on average than employers or those operating on their "own account."[11]

As we did for the samples of frequent inventors, we estimated the probability that members of the Case graduating classes obtained a patent in each year of their careers. Table 15 reports summary statistics and Tables 16A and B Logit estimates (for the 1920s and 1930s classes respectively) of the probability that a Case graduate obtained a patent in a particular year.

[11] Intriguingly, the Case patentees whom we were not able to locate in the Census had high patenting rates. This result is particularly surprising as patenting often provides us with a city of residence that assists in locating an individual in the Census. There are two possible reasons for this pattern of missing inventors: more prolific inventors may have come from ethnic groups that had common names and thus are more difficult to identify, and more prolific inventors may have been more mobile, particularly in 1939 as the United States began the buildup for World War II.

Controlling for age, we find the familiar inverted u-shaped relationship between age and patenting, with maximum inventiveness at about the age of 40 years.

In order to examine the impact of the Great Depression on the patenting of these highly trained and technically competent potential patentees, we include dummy variables for successive three-year intervals. Looking first at the 1920s graduates, we find that, controlling for age, Case alumni were more likely to patent during the Great Depression than they were in other years. This effect appears stronger for the early years of the catastrophe (the coefficients on the years 1931-33 are positive and highly significant) than for the later years of the depression. The coefficients for the 1934-36 and 1937-39 periods are positive but smaller in magnitude, and the one for 1934-36 is only marginally significant. There was no significant difference in patenting by occupation—not surprising, given the small number of inventors classified by the census as non-workers. However, residence in Cuyahoga County in 1940 was negatively and significantly associated with patenting. Students who left the Cleveland area after they graduated had higher probabilities of patenting on average over their careers than those who stayed behind.

1930s graduates that remained in the county also had significantly lower patenting rates than those that migrated elsewhere, but in other respects their situation was completely different. Those that managed to become employers had marginally greater probabilities of patenting than those who were employees or worked on their own account. But regardless of occupation patenting activity for these cohorts during the depression was below what one would expect it to be, controlling for graduates' ages. The coefficients on the dummies for the depression years are all negative, though not significant. More striking evidence that the depression mattered for these students comes from an alternative specification (in the last column of each table) using dummies for graduation years. For the 1920s graduates there was a positive and in some cases statistically significant association between their year of graduation and their probability of patenting over their careers. Those who obtained their degrees during the years 1931-33 and 1934-36 were significantly less likely to patent over their entire careers than those who graduated later in the 1930s, when economic conditions were better. For the Case students who graduated before 1937, the depression not only reduced their patenting activity during the years of the downturn but had negative consequences for their patenting careers over the long term.

As Tables 16A and B show, Case graduates who remained in Cleveland had lower probabilities of patenting over their careers than those who moved in search of greener pastures. Figure 2 depicts the residence of those graduates who could be located in the 1930 and 1940 censuses and in a 1958 alumni directory. As might be expected, the proportion of graduates from any particular class who resided in Cuyahoga County fell over time. Graduates who obtained their degrees during the 1920s were more likely to live in the county in 1930 than graduates from the 1930s were in 1940. But relatively more of the former had left the area by 1940. The close spacing of the 1940 and 1958 lines indicates that most of the movement out of the area occurred during the depression. The two lines were especially close together for the 1930s graduates, suggesting that those who remained had few opportunities to migrate later on. Given the patenting penalty associated with residence in the city in 1940, this pattern provides further evidence of the negative impact of the depression on the careers those who came of age during its depths.

Hard Times

The results from our two data exercises suggest that the Great Depression had a much more detrimental effect on the patenting behavior of inventors just starting out during the 1930s than on those who established themselves the decade before. Inventors who had already demonstrated their technological creativity were able largely to maintain their commitment to patenting despite the downturn, and as a result came through the catastrophe remarkably well. We are in process of compiling full biographies for the frequent inventors in our 1928-30 cohort. Thus far we have completed about a half, and it is striking how well those who lived out the depression were situated in 1940. The vast majority of the employees in the group were working in 1940 for the same company that employed them in 1930. The principals changed companies a bit more (and since they were older to begin with, a greater proportion of them died), but most of the survivors ended the decade still principals and still relatively well off. The 1940 Census includes data on income that was top-coded at a level of $5,000 a year. The modal (and median) income for the frequent inventors we have coded thus far was above this threshhold.

Of course, there are contrary accounts of failure or bad fortune. Inventor Anthony Fricker founded Universal Specialties in 1929 but by 1935 was living on a farm in Pennsylvania and in 1940 reported little or no income. Harold D. Church, vice president of the White Motor Company, lost his position after a strike during the late 1930s. James W. Howell worked as an employee at White when the downturn began, but then started an auto repair shop during the 1930s, perhaps because he was laid off from his job. He reported no income or property in 1940.

What is most striking, however, is how few such stories we are turning up in our biographical research. Only when we have archival records that allow us actually to see what was going on inside firms during this time period do we get a sense of the financial pressure the city's enterprises faced and the enormous risks that owners took in order to maintain their commitment to technological innovation during the depression. The Lees-Bradner Company, developer of machines to manufacture gears for automobiles, was in such bad shape in the early years of the depression that it was down to three employees by 1934, the year it developed an innovative rotary hobbing machine. Bradner, who owned the majority owner of the company's shares, voted himself the power "to invest the funds of this Company in such stocks, bonds and other securities as he, in his sole discretion, shall deem advisable," and essentially gambled with the company's remaining funds in a desperate effort to keep the company afloat. He succeeded, and the company survived the depression to make about half of the thread milling machines used by the Allies during World War II.[12]

The Towmotor Company, inventor of fork lifts, did a similarly booming business during the Second World War, acquired other companies during the post-war expansion, and ultimately merged with the Caterpillar Tractor Company in 1963. During the depression, however, the company barely managed to keep going. The company's officers took pay cuts, pleaded with shareholders to buy more of the company's shares or lend it money, and ultimately took on a sales manager (who proved unsatisfactory) because he would lend the enterprise $4,000. The company managed to bring out new models of "towmotors," despite the stringency, but in the end the shareholders lost faith and dissolved the company. The inventor-entrepreneurs behind continued to run it as a partnership from 1937 to 1942, when thanks to wartime demand for its products, it was able once again to find investors and reorganize as a corporation.[13]

We conclude this section with an extended example: the history of the Brush Beryllium Company. If any startup was well connected to the networks that had sustained Cleveland's innovative economy, it was this one, for the firm was a spinoff of Brush Laboratories, a company

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[12] Resolution adopted at the Directors' meeting of 2 June 1933, Container 1, Folder 4—Corporate Proceedings, Lees-Bradner Company Records, 1906-1992, Ms. 4653, Western Reserve History Society Library; "Lees-Bradner Co.," *Encyclopedia of Cleveland History*, http://ech.case.edu/cgi/article.pl?id=LC2, accessed 21 Jan. 2014.

[13] Towmotor Corporation Records, Mss. 4593, Western Reserve Historical Society Library. See especially the documents in Container 1, Folder 2.

founded in 1921 by Charles Brush, Jr. with backing from his father, the arc lighting pioneer.[14] Brush Laboratories' mission was to invent or acquire new technologies, commercialize them, and then spin off the resulting businesses. By the end of the decade researchers at the company had developed several promising technologies which they thought could form the basis for new companies. One of these involved the production of beryllium compounds as well as a very pure form of the metal. Beryllium had properties that made it particularly valuable in a variety of high-tech industries of the time, including x-rays, electronics, and aviation. In the form of an oxide, it was a superior material out of which to make refractories and other similar devices. In combination with copper, it made a bronze that had the strength of steel.

The untimely death of Brush, Jr. in 1927, followed by the death of Brush, Sr. in 1929 disrupted the financing for these projects. Formal financial institutions had not been important sources of venture capital, even during the technology boom of the late 1920s. Now, however, the Cleveland Trust Company had charge of the Brush estates, and, as the labs' officers well understood, that control was a potential source of trouble. The company's president, Charles Baldwin Sawyer, warned directors in early October, 1929 that though "at present the prospects are bright enough, … should things go amiss, it would be very difficult to convince bankers of the desirability of continuing."[15] Of course, things in the larger economy did go terribly amiss, and by late 1930 the Cleveland Trust Company was declining to invest additional funds from the

[14] Articles of Incorporation of the Brush Laboratories Company, 29 October 1921, Charles Baldwin Sawyer Collection, Brush Laboratories, Series II, Box 1, Folder 1, Special Collections, Kelvin Smith Library, Case Western Reserve University.
[15] President's Report [to the Directors of the Brush Laboratories Company], 10 Oct. 1929, Charles Baldwin Sawyer Collection, Brush Laboratories, Series II, Box 1, Folder 6.

Brush estate in beryllium research. Determined to keep the project going, the directors launched a new corporation, the Brush Beryllium Company, in January, 1931.[16]

Financial conditions made it difficult to raise funds, but members of the Brush and Sawyer extended families came through with subscriptions for $35,000 of the firm's $50,000 in capital stock.[17] Charles Baldwin Sawyer served as president of the Beryllium Company as well of Brush Laboratories, and when he wrote stockholders in July of 1932 to thank them for sending in the final installment, he acknowledged the payments "with much appreciation of the difficulties involved." The company faced a number of technological challenges, however, and found it harder and harder to raise the funds it needed to surmount them. The company had to learn how to produce beryllium oxide of sufficient purity to satisfy its customers. It also suffered repeated damage to its equipment because beryllium chloride expanded dramatically when heated, which was a necessary step in the production of pure beryllium. When researchers finally solved this second problem, they found that another company beat them to patenting the process. They came up with an alternative solution that turned out to be advantageous for other reasons but in the process burned through most of their research funds.[18]

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[16] The Trust Company forced the Laboratories to hire Union Carbide to study the beryllium project's prospects. The report in effect recommended that the project was at too early a stage for the Trust Company to continue its investment. President's Report to Stockholders [of the Brush Laboratories Company], 19 Jan, 1931, Charles Baldwin Sawyer Collection, Brush Laboratories, Series II, Box 1, Folder 6; and letter from R. T. Sayer to I. F. Frieberger and A. R. Horr of the Cleveland Trust Company, 29 Nov. 1930, Box 14, Folder 2. The company began operations with a paid-in capital of only $500. See the "Articles of Incorporation of the Brush Beryllium Company." We received a copy of the articles from the company's successor, Brush Engineered Materials.

[17] See the letters from Charles Baldwin Sawyer to Roger G. Perkins on 6 July 1931, 4 Dec. 1931, and 13 July 1932, Charles Baldwin Sawyer Collection, Brush Laboratories, Series II, Box11, Folder 2; the letters from Sawyer to Roselyn Weir on the same dates, Box 12, Folder 7; and the letter to Dorothy H. Dick, 25 May 1933, Box 14, Folder 5.

[18] Letter from Sawyer to Perkins, 13 July 1932, Charles Baldwin Sawyer Collection, Brush Laboratories, Series II, Box 11, Folder 2.

To conserve cash Sawyer agreed to take his salary in stock.[19] All of the company's employees agreed to pay cuts, its patent attorney accepted stock for a substantial part of his compensation, and other outside contractors made similar arrangements.[20] Nonetheless, with sales of the company's products "in these times … disappointing,"[21] the company had to let most of its employees go. By December 1932, it was down to two key researchers and had only $2000 left in the bank, enough to continue with the patent work and keep the men employed for about two months.[22]

Sawyer and other company officials pressed shareholders to increase their investment and, at the same time, conducted a desperate effort to "interest outside capital." "Because of the extreme times," however, money was difficult to raise.[23] The Cleveland Trust Company was unrelenting,[24] and other potential investors were too pressed themselves to be of assistance. For example, a family named "[t]he Boks were favorably impressed and anxious to be of help," but their financial condition was "depressed." Curtis Bok promised to "scrape around the dead leaves and see if he could send us a little," but there is no evidence that he was able to invest

[19] Letter from Charles Baldwin Sawyer to Roger G. Perkins, 28 July 1931, Charles Baldwin Sawyer Collection, Brush Laboratories, Series II, Box 11, Folder 2.
[20]Letter from Sawyer to Perkins, 13 July 1932, Charles Baldwin Sawyer Collection, Brush Laboratories, Series II, Box 11, Folder 2.
[21] Letters from Sawyer to Perkins, 13 July 1932 and 8 Dec. 1932, Charles Baldwin Sawyer Collection, Brush Laboratories, Series II, Box 11, Folder 2.
[22] Letter from Sawyer to Perkins, 8 Dec. 1932, Charles Baldwin Sawyer Collection, Brush Laboratories, Series II, Box 11, Folder 2.
[23] Letter from Sawyer to Perkins, 8 Dec. 1932, Charles Baldwin Sawyer Collection, Brush Laboratories, Series II, Box 11, Folder 2; letter from Sawyer to Charles Brush Perkins, 30 Jan 1933, Box 11, Folder 1; letters from Sawyer to R. T. Sawyer, 31 Jan. 1933, 3 Feb 1933, and 8 Feb. 1933, Box 11, Folder 6; and letter from R. T. Sawyer to Sawyer, 8 Feb. 1933.
[24] Letter from Sawyer to R. T. Sawyer, 14 Feb. 1933, Charles Baldwin Sawyer Collection, Brush Laboratories, Series II, Box 11, Folder 6; letter from I. F. Freiberger to Sawyer, 10 Feb. 1933, Box 14, Folder 2. Cleveland Trust did, however, allow the Brush estate to lend $3,000 to Brush Laboratories in 1933. See letter from G. F. Karch to Sawyer, 11 Jan. 1933, Box 14, Folder 2.

anything in the end.[25] Sawyer's correspondence shows him following up all potential leads, even those that took him outside the networks that had previously financed the region's innovative economy. For example, when Sawyer learned that a Brush family member was "a great friend of Frank Vanderlip of New York, son of the big financier" and that Vanderlip, Sr. was interested in beryllium, he worked that connection (and others) and managed to meet with the financier on a trip to the region. Nothing came of the meeting, however, in part because the financier insisted on taking his cue from officers of the Cleveland Trust Company.[26]

The company would probably have gone under if Roger G. Perkins, a stockholder who belonged to the Brush extended family, had not come through in February 1933 with a modest additional investment of $1,500 from himself and another member of the family (he invested another $2000 in August). This infusion, which came at "a most opportune moment," tided the company over.[27] During the next few months, Sawyer turned to Perkins several times for small amounts (installments on the new investment) to allow the Beryllium Company to buy ore and pay its bills.[28] The correspondence with Perkins reveals the financial pressure that potential investors were under as a result of the severe banking crisis of early 1933. Perkins was a stockholder in the Union Trust Company, which federal examiners declared insolvent and would not allow to reopen after the bank holiday. Stockholders bore double liability for their

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[25] Letter from Sawyer to R. T. Sawyer, 3 Feb. 1933, Charles Baldwin Sawyer Collection, Brush Laboratories, Series II, Box 11, Folder 6. Sawyer tried unsuccessfully to move outside the network and solicit an investment from Frank Vanderlip of New York. See letter from Sawyer to I. F. Freiberger, 7 Mar. 1933, Box 14, Folder 2.

[26] Letter from William H. Weir to Sawyer, 8 Jan. 1932, Charles Baldwin Sawyer Collection, Brush Laboratories, Series II, Box 12, Folder 7; letters from Sawyer to R. T. Sawyer, 31 Jan. 1933, Box 11, Folder 6; letter from Sawyer to I. F. Freiberger, 7 Mar. 1933, Box 14, Folder 2; letter from Sawyer to R. E. Larsen, 1 Feb. 1934, Box 10, Folder 3.

[27] Letter from Sawyer to Maurice Perkins, 8 Feb. 1933, Charles Baldwin Sawyer Collection, Brush Laboratories, Series II, Box 11, Folder 1; letter from Sawyer to R. T. Sawyer, 8 Feb. 1933, Box 11, Folder 6; letter from Sawyer to I. F. Freiberger, 8 Feb. 1933, Box 14, Folder 2; letter from Roger G. Perkins to Sawyer, 5 Aug. 1933, Box 11, Folder 2.

[28] Letters from Sawyer to Perkins, 15 Mar 1933; 11 Apr. 1933; 9 May 1933, Charles Baldwin Sawyer Collection, Brush Laboratories, Series II, Box 11, Folder 2.

investments in many such institutions, and Perkins worried that, in addition to the money he had had lost in the collapse, he would be financially crippled by assessments on this liability.[29]

In April, 1934, the company managed to secure an investment of $2,000 from Roy E. Larsen, an executive at Time, Inc., which Sawyer immediately used to buy ore.[30] It was still strapped for cash, however, and Sawyer sent shareholders another round of begging letters that do not seem to have generated any new funds.[31] In August the company landed an investment of $5,000 from John Sherwin and his brother Francis, a Cleveland financier, for the express purpose of supporting "further work on the metal." While waiting for these funds, Sawyer asked Larsen to in put in another $1,500 to make it possible to purchase more ore.[32]

Somehow, in this hand to mouth way, the company survived the worst years of the depression. Sales increased beginning in 1934, and the resulting revenues gave the company the funds it needed to commercialize its process of refining pure beryllium, putting it in a position later on to win important contracts from the federal government's Manhattan Project. The company prospered with the growth of the aviation industry during the Second World War and afterwards, and it survives to the present day. Now called Brush Engineered Materials it

[29] See letter from Sawyer to R. G. Perkins, 1 Aug. 1933, Charles Baldwin Sawyer Collection, Brush Laboratories, Series II, Box 11, Folder 2.

[30] See the exchange of letters between Sawyer and Larsen dated 10 Apr. 1934 and 16 Apr. 1934, Charles Baldwin Sawyer Collection, Brush Laboratories, Series II, Box 10, Folder 3. Larsen was also strapped for funds. He also brought stock in another spinoff from Brush Labs, the Brush Development Company, and had to request an extension on his payments. See the exchange between Sawyer and Larsen dated 21 Apr. 1934 and 23 Apr. 1934, Box 10, Folder 3.

[31] See Letter from Sawyer to Maurice Perkins, 14 May 1934, Charles Baldwin Sawyer Collection, Brush Laboratories, Series II, Box11, Folder 1; letter from Sawyer to R. G. Perkins, 14 May 1932, Box 11, Folder 2; letter from Sawyer to Roselyn Weir, 15 May 1934, Box 12, Folder 7.

[32] Letter from Sawyer to Larsen, 21 Aug. 1934, Charles Baldwin Sawyer Collection, Brush Laboratories, Series Ii, Box 10, Folder 3. Intriguingly Francis Sherwin was at that time an officer of the Cleveland Trust Company. He later became a director of Brush Beryllium. See "Sherwin, Francis McIntosh," *Encyclopedia of Cleveland History*, http://ech.case.edu/ech-cgi/article.pl?id=SFM, accessed 26 October 2010.

continues, among other things, to produce beryllium in various forms for use in consumer electronics, aerospace, and other industries.[33]

Conclusion

When we are able to dig more deeply into the histories of individual companies such as Brush Beryllium, we can see the financial distress to which they were subject and get some sense of the extraordinary value their owners must have ascribed to patenting to be able to continue to invent and apply for patents during these difficult times. We do not have this kind of detail for most of the companies associated with the patentees in our frequent inventors sample. All we can see is that the inventors associated with them, both as principals and employees, generally were able to maintain their commitment to patenting across the depression. Often we can also see that they emerged from the catastrophe financially well off, so perhaps it is not surprising that the summaries of their careers we find in obituaries and biographical dictionaries gloss over the stringent conditions they must have faced during this critical period.[34]

The frequent inventors in our sample came through the depression remarkably unscathed, but the innovative economy that had nurtured them during the 1920s does not seem to have fared as well. Innovative economies require continuous regeneration, and our data suggests that the depression had a much more detrimental effect on the next generation—the young men with appropriate human capital who came of age during its depths. In better times they might have

[33] *Seventy-Five Years of Taking Technology Where It Has Never Been Before: The History of Brush Engineered Materials Inc. and its Predecessor Companies, Brush Wellman Inc. and Brush Beryllium Company* (Cleveland: Brush Engineered Materials, 2008). See also Bengt Kjellgren, "History of the Brush Beryllium Company," Engineering Training Meeting No. 2, 31 July 1952. We received a copy of this document from the Brush Engineered Materials Company.
[34] See, for good examples, Charles Baldwin Sawyer's obituary in the *New York Times* on March 26, 1964.

spawned another wave of startups, but instead many of them left the city. Their patenting careers were stunted compared to the previous decades' graduates, and the careers of those who stayed in the region were stunted more than those who left.

Mowery and Rosenberg (1989) showed that large firms increased their investments in R&D during the depression, taking advantage of their pool of retained earnings to develop new technologies at a time when it did not make much sense to invest in production facilities. Our finding that inventors in our frequent inventors sample maintained their commitment to patenting over the same years is consistent with Mowery and Rosenberg's view but extends it by suggesting that R&D was also a critical part of business strategies of smaller, more entrepreneurial, more financially constrained firms—so much so that they kept it going despite the great sacrifices it entailed. In the end, however, it is likely that the depression helped to shift the locus of inventive activity in favor of the large firms Mowery and Rosenberg studied. As young would-be inventors left innovative regions like Cleveland's in search of jobs, they would find them disproportionately in the R&D labs that large firms were building and expanding at such a rapid pace. Cleveland's factories would experience a resurgence in demand during the boom years that followed World War II, but what was missing in the postwar prosperity was the next wave of startups that those migrating might have founded—startups that could have carried the region through the next technological transformation.

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TABLE 1.
CLEVELAND'S LARGEST INDUSTRIES, 1870-1947
(RANKED BY AVERAGE EMPLOYMENT)

Industry Rank	1870	1880	1890	1900	1910	1920	1929	1947
1	Coal, rectified	Iron and steel	Iron and steel	Iron and steel	Iron and steel, steel works, and rolling mills	Auto	Foundry and machine tools	Foundry and machine tools
2	Iron, forged and rolled	Slaught-ering and meat-packing	Foundry and machine-shop products	Foundry and machine-shop products	Foundry and machine-shop products	Foundry and machine tools	Auto	Auto
3	Flour-mill products	Foundry and machine-shop products	Petroleum Refining	Slaught-ering and meat-packing, wholesale	Auto-mobiles	Iron and steel	Electrical machinery	Electrical machinery
4	Meat, packed pork	Clothing, men's	Slaught-ering and meat-packing, wholesale	Clothing, women's factory product	Slaught-ering and meat-packing	Electrical machinery	Iron and steel	Chemicals
5	Iron, castings (not specified)	Liquors, malt	Carpen-tering	Liquors, malt	Clothing, women's	Clothing, women's	Printing and publishing	Iron and steel

Note: The 1870 and 1930 data are for Cuyahoga County. The 1947 data are for the Cleveland metropolitan area, consisting of Cuyahoga and Lake Counties. All other years are for the city of Cleveland.

Sources: U.S. Census Office, *Census of the United States*, 1850-1910; U.S. Bureau of the Census, *Census of the United States*, 1920; U.S. Bureau of the Census, *Census of Manufactures: 1929*; U.S. Bureau of the Census, *Census of Manufactures: 1947*.

TABLE 2A.
RESIDENCE OF INVENTORS ASSIGNING PATENTS TO CUYAHOGA FIRMS, 1910-12

	Percent of inventors	Percent of patents
Located in Cleveland	86.2	87.7
Located in Cuyahoga County	4.6	6.5
Located in Ohio	3.9	2.4
Other U.S.	5.3	3.5
Foreign Countries	0	0
Total number	*282*	*547*

TABLE 2B.
RESIDENCE OF INVENTORS ASSIGNING PATENTS TO CUYAHOGA FIRMS, 1928-30

	Percent of inventors	Percent of patents
Located in Cleveland	81.2	87.2
Located in Cuyahoga County	3.4	2.1
Located in Ohio	4.0	3.5
Other U.S.	10.0	6.3
Foreign Countries	1.3	0.8
Total number	*670*	*1246*

Notes: The inventor's residence is at the time of application for the patent. Only patents assigned at issue to companies located in Cuyahoga County are included in the table. Patents awarded to multiple inventors are divided by the number of inventors. For example, if two inventors jointly applied for a patent, each inventor is counted as receiving 0.5 patents. We exclude design patents from this analysis.

Sources: We searched Google Patent, LexisNexis, and the USPTO website for all patents assigned at issue during these years to companies located in Cuyahoga County.

TABLE 3A.
AGE OF CUYAHOGA COUNTY FIRMS OBTAINING PATENT ASSIGNMENTS IN 1910-12

Age Definition	Year established		First year sighted		First year using previous (acquired) firm's info if it is formed earlier	
	Percent of Firms	Percent of Patents	Percent of Firms	Percent of Patents	Percent of Firms	Percent of Patents
Prior to 1883	25.5	36.6	10.1	22.5	10.8	22.7
1883-1892	9.8	8.6	9.5	8.4	10.8	9.3
1893-1902	33.3	34.8	21.6	36.0	21.6	40.6
1903-1912	31.4	20.0	58.8	33.1	56.8	27.4
Total number for which firm age could be established	*51*	*325*	*148*	*547*	*148*	*547*
All Cuyahoga County firms receiving patent assignments	*148*	*547*	*148*	*547*	*148*	*547*

TABLE 3B.
AGE OF CUYAHOGA COUNTY FIRMS OBTAINING PATENT ASSIGNMENTS IN 1928-30

Age Definition	Year established		First year sighted		First year using previous (acquired) firm's info if it is formed earlier	
	Percent of Firms	Percent of Patents	Percent of Firms	Percent of Patents	Percent of Firms	Percent of Patents
Prior to 1901	39.4	42.1	21.9	31.5	26.5	38.7
1901-1910	25.0	18.1	19.2	21.6	18.5	22.1
1911-1920	19.2	25.0	26.2	25.0	24.2	20.5
1921-1930	16.4	14.8	32.7	21.9	30.8	18.7
Total number for which firm age could be established	*104*	*745*	*260*	*1246*	*260*	*1246*
All Cuyahoga County firms receiving patent assignments	*260*	*1246*	*260*	*1246*	*260*	*1246*

Notes and Sources: See Tables 2A and 2B. Where possible, we determined the year the current firm was established using Cleveland city directories, the annual reports of incorporations issued by the Ohio Secretary of State, company histories, financial statements, and newspaper articles. For firms whose year of establishment could not be determined, we calculate "first sighted" as the first year for which we have a record of the firm's existence, based on city directories, reports of stock trades or quotations, patent assignments, or other mentions of the firm's existence. Although there is no missing data for "first sighted," this measure underestimates the age of firms. "Year established," by contrast, suffers from missing data and also overstates average age, because firms with short life spans are more likely to be missing.

TABLE 4.
NUMBER OF FIRMS LOCATED IN CLEVELAND WITH INDUSTRIAL RESEARCH LABORATORIES

Year	Number of Firms	Average Number of Research Lab Employees	Average Employees, excluding GE
1920	5	53.4	10.5
1921	7	95.0	22.5
1927	23	68.4	39.1
1931	38	74.5	39.5
1933	38	68.9	41.8
1938	42	93.1	57.9
1940	53	98.2	67.0
1946	45	174.6	174.6

Source: *Bulletin of the National Research Council*, 1920, 1921, 1927, 1931, 1933, 1938, 1940 and 1946.

Note: In most cases where a firm, such as General Electric, had research laboratories in more than one location, the number reported here reflects research laboratory employment for the entire firm, not just Cleveland. In 1946, General Electric's research employment was not reported, so excluding it does not change the average. The 1946 number is inflated, however, by the inclusion of firms such as Dow Chemical Company, Radio Corporation of America, and B. F. Goodrich, all of which had substantial research employment outside Cleveland.

TABLE 5A.
PATENTS AND ASSIGNMENTS BY OCCUPATIONAL CATEGORY OF 1910-12 FREQUENT INVENTORS

	Employees	Principals	Independent Inventors & Patent Attorneys	Unknown/ Deceased/ No Occupation
Number of patentees	56	55	12	1
Percent of patentees	45.2	44.4	9.7	08
Distribution of patents by occupational category	45.4	46.5	7.5	0.6
Distribution of high-tech patents by occupational category (20.9% of all patents)	39.5	50.1	10.4	0.0
Distribution of assignments by occupational category	56.9	38.0	5.1	0.0
Out of all patents in each category				
Percent of patents assigned	66.4	43.2	36.1	0.0
Percent assigned to company where patentee is principal		32.2		
Percent assigned to company where patentee is employee	31.0			
Average number of different assignees for inventors who assigned at least two patents	1.03	1.19	1.50	
Average age in 1911	44.7	45.2	48.5	63

TABLE 5B.
PATENTS AND ASSIGNMENTS BY OCCUPATIONAL CATEGORY OF 1928- 1930 FREQUENT INVENTORS

	Employees	Principals	Independent Inventors & Patent Attorneys	Unknown/ Deceased/ No Occupation
Number of patentees	101	63	13	3
Percent of patentees	56.1	35.0	7.2	1.7
Percent of patents	52.8	38.2	8.2	0.8
Distribution of high-tech patents by occupational category (18.6% of all patents)	44.9	41.5	13.0	0.6
Distribution of assignments by occupational category	54.8	36.5	8.0	0.7
Out of all patents in each category				
Percent of patents assigned	89.7	82.5	84.6	73.3
Percent assigned to company where patentee is principal		47.5		
Percent assigned to company where patentee is employee	60.8			
Average number of different assignees for inventors who assigned at least two patents	1.25	1.48	2.33	1.00
Average age in 1929	43.7	48.5	44.0	65.0

Sources: Using Google Patent, LexisNexis, and the USPTO website, we identified every patent issued to an inventor resident in Cuyahoga County during the years 1910-12 and 1928-1930. We then selected the patentees who received at least three patents during these years. The 1910-12 panel includes 124 inventors and 656 patents, and the 1928-30 includes 180 inventors and 989 patents. The patent records provided the name and city of residence of the patentee(s), as well as the name and location of any individuals or companies to which the inventor(s) assigned the patent at the time of issue. We then searched for additional information on the patentees and assignees in a variety of other sources, including the manuscript records of U.S. Decennial Census of Population available at Ancestry.com, directories for Cleveland and other cities, the surveys of industrial research laboratories published in the Bulletin of the National Research Council (NRC), the Commercial and Financial Chronicle, Poor's and Moody's manuals, issues of the R. G. Dun's Mercantile Agency Reference Book, incorporation records, company annual reports, newspapers and magazines, and a large variety of other primary and secondary sources.

Notes: Assignments include only assignments made at the time the patent issued. An inventor is considered a principal of a firm if he was ever a principal of that firm. He is considered an employee of the firm if he was ever an employee and was never a principal of that firm. This protocol was adopted because we do not have annual observations of employment in most cases. It is also often the case that a person whom we classify as a principal because he was the founder or officer of a firm was also sometimes reported to be an employee. This procedure does treat as principals those employees who began their careers as employee-inventors but moved into the executive offices of the company and therefore does somewhat overstate the importance of principals in this sample. Patents awarded to multiple inventors are divided by the number of inventors. High-tech patents are patents are defined as those in USPTO patent classes corresponding to Chemical/ Computers & Communications/ Drugs & Medical/ Electrical & Electronic Industries, based on "Classification of patent classes into technological categories and sub-categories" Appendix 1, Hall, Jaffe and Trajtenberg (2001).

TABLE 6.
PRINCIPALS AND INDEPENDENTS AS A SHARE OF ALL FREQUENT INVENTORS AND PATENTS, 1884-1930

	1884-86 Cleveland sample	1898-1902 Cleveland sample	1910-12 Cuyahoga sample	1928-30 Cuyahoga sample
Percent of Patentees Who Were Principals and Independents	45.2	54.3	53.2	37.2
Percent of Patents Awarded to Principles and Independents	55.6	58.4	47.6	36.0
Total Number of Patentees	*42*	*36*	*124*	*180*
Total Number of Patents	*394*	*839*	*656*	*989*
Number of Years in Sample	*7*	*18*	*3*	*3*

Sources and Notes: The comparisons over time must be made with caution because these samples were collected in different ways. See Table 5 for a description of the 1910-12 and 1928-30 samples. Note that the 1910-12 and 1928-30 samples differ from the earlier ones in that, in order to take account of increased suburbanization, they encompass the whole of Cuyahoga County, rather than just the city of Cleveland. For the 1884-86 sample, we selected the 42 patentees who were Cleveland residents and who received three or more patents in 1884, 1885, and 1886 (we excluded John Walker because his name was too common for us to make precise matches) and then collected all of the patents they were awarded in those three years and also in 1881, 1882, 1888, and 1889. The 36 patentees in the 1898-1902 sample include Cleveland residents who obtained a patent in 1900 and had a total of at least three patents in 1898, 1900, and 1902. They also include several inventors resident in Cleveland who were prominent enough to be profiled in the *Dictionary of America Biography*. We collected all the patents these patentees received in 1892 through 1912, except for the years 1895, 1901, and 1904. For more information, see Lamoreaux et al. (2006 and 2007a). For the purposes of this table, we do not count patent attorneys but only independent inventors. We also do not apportion patents with multiple inventors. If at least one of the co-inventors was a principal or an independent inventor, then the patent is counted in that category.

TABLE 7.
ASSIGNMENT PATTERNS OF PATENTS OBTAINED BY CLEVELAND AREA
FREQUENT INVENTORS, 1884 TO 1930

Assignment Information	1884-86 Cleveland sample	1898-1902 Cleveland sample	1910-12 Cuyahoga sample	1928-30 Cuyahoga sample
Assignments at Issue				
Percent of Patents	22.3	52.9	52.9	86.7
Assigned to Companies				
Percent of Patents	14.0	49.3	48.6	84.4
Percent of Assignments	62.5	93.2	91.9	97.4
Total Number of Patentees	*42*	*36*	*124*	*180*
Total Number of Patents	*394*	*839*	*656*	*989*
Number of Years in Sample	*7*	*18*	*3*	*3*

Notes and Sources: See Table 6.

TABLE 8A.
AGE AND PLACE OF BIRTH BY OCCUPATIONAL CATEGORY, 1910-12 FREQUENT INVENTORS
(PERCENT)

	Employees	Principals	Independent Inventors and Patent Attorneys	All inventors
Place of birth				
Ohio	39.3	40.0	8.3	36.3
Other ENC	8.9	5.5	16.7	8.1
Other US	19.6	29.1	50.0	26.6
Foreign	26.8	20.0	25.0	24.2
Age Group in 1911				
39 or less	32.1	32.7	25.0	31.4
40-49	35.9	36.5	25.0	34.8
50 or more	32.1	30.8	50.0	33.9

TABLE 8B.
AGE AND PLACE OF BIRTH BY OCCUPATIONAL CATEGORY, 1928-30 FREQUENT INVENTORS
(PERCENT)

	Employees	Principals	Independent Inventors and Patent Attorneys	All inventors
Place of birth				
Ohio	34.7	44.4	46.2	38.9
Other ENC	17.8	9.5	0.0	13.3
Other US	30.4	33.3	53.9	32.8
Foreign	16.8	12.7	0.0	14.4
Age Group				
39 or less	28.7	20.6	38.5	25.1
40-49	55.5	33.3	23.1	44.7
50 or more	17.8	46.0	38.5	30.2

Notes: "All inventors" includes inventors in the "unknown" occupational category. Other ENC (East North Central) includes anyone born in the states Illinois, Indiana, Michigan, and Wisconsin. Other US includes anyone born in a US state outside the ENC region. The year and place of birth are unknown for six of the frequent inventors in the 1910-12 cohort and one in the 1928-30 cohort.

Sources: See Table 5.

TABLE 9A.
IN-MIGRATION OF 1910-12 FREQUENT INVENTORS: YEAR FIRST OBSERVED IN OHIO
(PERCENT)

Date first known to be living in Ohio	Born in Other State than Ohio	Born in Foreign Country
Before 1880	7.0	23.3
1880-1889	9.3	23.3
1890-1899	30.2	33.3
1900-1909	53.5	20.0
Total number	43	30

TABLE 9B.
IN-MIGRATION OF 1928-30 FREQUENT INVENTORS: YEAR FIRST OBSERVED IN OHIO
(PERCENT)

Date first known to be living in Ohio	Born in Other State than Ohio	Born in Foreign Country
Before 1898	3.5	4.4
1898-1907	22.1	21.7
1908-1917	23.3	34.8
1918-1927	51.2	39.1
Total number	86	23

Sources and Notes: See Tables 5 and 8A and 8B.

TABLE 10A.
SUMMARY STATISTICS FOR THE PROBABILITY THAT A FREQUENT INVENTOR WOULD PATENT IN EACH YEAR, 1910-12 SAMPLE

Variable name	Definition	Mean	Standard Deviation	Minimum	Maximum
Patenting1	= 1 if an inventor applied for a successful patent	0.217	0.413	0	1
Patenting2	= 1 if an inventor applied for a successful patent, excluding patents issued in the years 1910-12	0.185	0.388	0	1
Age	= Year minus year of birth	46.407	17.526	18	95
Principal	= 1 if inventor was a principal in 1910-12	0.437	0.496	0	1
Independent or Patent Attorney	= 1 if inventor was an independent inventor or patent attorney in 1910-12	0.109	0.312	0	1
Year		1911.7	19.847	1860	1970
Years before 1895		0.210	0.407	0	1
Year 1895-97		0.050	0.218	0	1
Year 1898-00		0.053	0.224	0	1
Year 1901-03		0.054	0.226	0	1
Year 1904-06		0.054	0.226	0	1
Year 1907-09		0.054	0.226	0	1
Year 1910-12		0.054	0.226	0	1
Year 1913-15		0.053	0.225	0	1
Year 1916-18		0.051	0.220	0	1
Year 1919-21		0.050	0.218	0	1
Year after 1921		0.318	0.466	0	1

Table 10B.
SUMMARY STATISTICS FOR THE PROBABILITY THAT A FREQUENT INVENTOR WOULD PATENT IN EACH YEAR, 1928-30 SAMPLE

Variable name	Definition	Mean	Standard Deviation	Minimum	Maximum
Patenting1	= 1 if an inventor applied for a successful patent	0.215	0.411	0	1
Patenting2	= 1 if an inventor applied for a successful patent, excluding patents issued in the years 1910-12	0.185	0.388	0	1
Age	= Year minus year of birth	46.671	17.495	18	95
Principal	= 1 if inventor was a principal in 1928-30	0.343	0.475	0	1
Independent or Patent Attorney	= 1 if inventor was an independent inventor or patent attorney in 1928-30	0.069	0.254	0	1
Year		1929.8	19.349	1874	1970
Years before 1913		0.209	0.407	0	1
Year 1913-15		0.050	0.219	0	1
Year 1916-18		0.052	0.221	0	1
Year 1919-21		0.052	0.223	0	1
Year 1922-24		0.053	0.224	0	1
Year 1925-27		0.053	0.224	0	1
Year 1928-30		0.052	0.222	0	1
Year 1931-33		0.051	0.221	0	1
Year 1934-36		0.050	0.218	0	1
Year 1937-39		0.048	0.214	0	1
Years after 1939		0.330	0.470	0	1

Sources and Notes: See Table 5. For this analysis, we collected all the patents that each of the 1910-12 and 1928-30 frequent inventors obtained over their lifetimes from Google Patent and the LexisNexis patent database. We consider each inventor to be "at risk" for patenting from the year in which he turned 18 until his death. Where birth year was missing, it was imputed as the average year of birth for inventors in that sample. Where death year was missing, it was imputed as 75 or the last year in which a patent application was submitted, whichever was greater. For the 1910-12 group, 6 people were missing year of birth and 59 were missing year of death. For the 1928-30 group, one person was missing date of birth and 56 were missing date of death. Year indicates the date of application for the patent. The mean values for the year dummies indicate the proportion of observations (inventor x year). Inventors are counted only when they are over 18 and alive.

TABLE 11A. LOGIT ESTIMATES OF THE PROBABILITY OF PATENTING IN EACH YEAR BY THE 1910-12 FREQUENT INVENTORS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Includes Patents Granted in 1910-12					Excludes Patents Granted in 1910-12			
Age	0.398***	0.378***	0.283***	0.399***	0.277***	0.361***	0.278***	0.362***	0.274***
	(23.32)	(21.79)	(13.67)	(23.37)	(13.65)	(20.64)	(13.29)	(20.71)	(13.39)
Age squared	-0.00429***	-0.00404***	-0.00303***	-0.00430***	-0.00301***	-0.00387***	-0.00296***	-0.00388***	-0.00296***
	(-23.41)	(-21.82)	(-15.07)	(-23.47)	(-15.10)	(-20.69)	(-14.55)	(-20.76)	(-14.66)
Years before 1895			-1.450***		-1.532***		-1.414***		-1.485***
			(-7.39)		(-8.09)		(-7.37)		(-7.91)
Year 1895-97			-0.987***		-1.021***		-0.956***		-0.981***
			(-4.69)		(-4.86)		(-4.54)		(-4.67)
Year 1898-00			-0.578**		-0.596**		-0.549**		-0.562**
			(-3.06)		(-3.15)		(-2.90)		(-2.97)
Year 1901-03			0.264		0.281		0.170		0.183
			(1.54)		(1.63)		(0.98)		(1.06)
Year 1907-09		1.743***	1.283***		1.322***		-0.333		-0.308
		(13.82)	(7.23)		(7.44)		(-1.85)		(-1.71)
Year 1910-12			0.862***		0.913***		-0.199		-0.161
			(4.76)		(5.06)		(-1.09)		(-0.88)
Year 1913-15			-0.103		-0.0426		-0.0762		-0.0252
			(-0.54)		(-0.23)		(-0.40)		(-0.13)
Year 1916-18			-0.800***		-0.729***		-0.772***		-0.712***
			(-3.78)		(-3.50)		(-3.68)		(-3.44)
Year 1919-21			-0.656**		-0.569**		-0.651**		-0.576**
			(-2.96)		(-2.63)		(-2.98)		(-2.68)
Year after 1921			-1.022***		-0.887***		-1.083***		-0.969***
			(-4.33)		(-3.92)		(-4.74)		(-4.40)
Principals				0.619***	0.591***			0.643**	0.500**
				(3.64)	(3.62)			(3.17)	(3.03)
Independents/ Patent Attorneys				0.591**	0.785***			0.644**	0.734***
				(2.88)	(3.67)			(3.07)	(3.61)
Constant	-9.605***	-9.360***	-6.802***	-10.06***	-7.110***	-9.202***	-6.853***	-9.669***	-7.107***
	(-24.96)	(-23.87)	(-12.67)	(-24.97)	(-13.72)	(-22.89)	(-13.13)	(-23.05)	(-13.56)

Observations	6921	6921	6921	6921	6921	6921	6921	6921	6921

* = p<0.05 ** = p<0.01 *** = p<0.001

Notes and sources: See Table 10. The omitted occupational categories are employees and unknowns/deceased, and the omitted years are 1901-03. These estimates use a random effects model. T-statistics are in parentheses.

TABLE 11B. LOGIT ESTIMATES OF THE PROBABILITY OF PATENTING IN EACH YEAR BY THE 1928-30 FREQUENT INVENTORS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Includes Patents Granted in 1910-12					Excludes Patents Granted in 1910-12			
Age	0.469***	0.446***	0.349***	0.470***	0.340***	0.432***	0.325***	0.432***	0.324***
	(30.31)	(28.62)	(18.16)	(30.33)	(18.01)	(27.40)	(13.92)	(27.40)	(16.90)
Age squared	-0.00509***	-0.00481***	-0.00365***	-0.00510***	-0.00362***	-0.00463***	-0.00345***	-0.00464***	-0.00347***
	(-30.48)	(-28.72)	(-20.10)	(-30.50)	(-20.08)	(-27.51)	(-17.03)	(-27.51)	(-19.01)
Years before 1913			-0.907***		-1.035***		-1.068**		-1.076***
			(-5.37)		(-6.21)		(-2.79)		(-6.18)
Year 1913-15			-0.646***		-0.692***		-0.593*		-0.583**
			(-3.62)		(-3.87)		(-2.20)		(-3.24)
Year 1916-18			-0.572***		-0.595***		-0.499*		-0.482**
			(-3.44)		(-3.58)		(-2.09)		(-2.88)
Year 1922-24			0.497***		0.518***		0.0948		0.126
			(3.39)		(3.53)		(0.51)		(0.83)
Year 1925-27		1.736***	1.502***		1.541***		-0.0870		-0.0492
		(16.21)	(9.86)		(10.09)		(-0.53)		(-0.32)
Year 1928-30			0.948***		1.010***		0.608***		0.652***
			(6.06)		(6.44)		(4.11)		(4.13)
Year 1931-33			0.229		0.315		0.404**		0.454**
			(1.39)		(1.91)		(3.00)		(2.72)
Year 1934-36			-0.350		-0.242		-0.170		-0.113
			(-1.95)		(-1.36)		(-1.32)		(-0.62)
Year 1937-39			-0.332		-0.200		-0.139		-0.0759
			(-1.73)		(-1.05)		(-1.10)		(-0.39)
Year after 1939			-1.111***		-0.916***		-0.925		-0.833***
			(-5.16)		(-4.28)		.		(-3.89)
Principals				0.288*	0.394**			0.169	0.361*
				(2.23)	(2.62)			(1.28)	(2.20)
Independents/ Patent Attorneys				0.00695	0.111			0.0554	0.149
				(0.01)	(0.34)			(0.27)	(0.72)
Constant	-11.14***	-10.87***	-8.671***	-11.26***	-8.521***	-10.76***	-8.227***	-10.82***	-8.284***

	(-31.97)	(-30.83)	(-17.80)	(-31.76)	(-17.59)	(-29.93)	(-12.57)	(-29.76)	(-17.25)
Observations	10220	10220	10220	10220	10220	10220	10220	10220	10220

* = p<0.05 ** = p<0.01 *** = p<0.001

Notes and sources: See Table 10. The omitted occupational categories are employees and unknowns/deceased, and the omitted years are 1919-21. These estimates use a random effects model. T-statistics are in parentheses

TABLE 12.
LIFETIME PATENTING BY CASE SCHOOL OF APPLIED SCIENCE GRADUATES

Year of Grad	Total Number of Graduates	Number of Patentees	Total # Patents	Avg. Patents per graduate	Avg. Patents per patentee
1920	79	16	187	2.37	11.69
1921	106	24	116	1.09	4.83
1922	139	34	161	1.16	4.74
1923	132	22	104	0.79	4.73
1924	100	16	112	1.12	7.00
1925	103	25	188	1.83	7.52
1926	116	29	97	0.84	3.34
1927	103	20	129	1.25	6.45
1928	120	27	103	0.86	3.81
1929	100	28	265	2.65	9.46
1930	114	34	265	2.32	7.79
1931	139	37	201	1.45	5.43
1932	165	48	187	1.13	3.90
1933	148	33	139	0.94	4.21
1934	146	41	167	1.14	4.07
1935	120	32	174	1.45	5.44
1936	124	31	123	0.99	3.97
1937	123	35	140	1.14	4.00
1938	132	42	254	1.92	6.05
1939	171	41	242	1.42	5.90
All years	2,480	615	3,354	1.35	5.45

Notes and Sources: The table includes graduates from the Case School of Applied Science who were awarded the degree of Bachelor of Science in the years 1920-39. We culled their names from the Case School's Annual Commencement Programs, which we obtained from the Case Western Reserve University Archives. We then searched the Google Patent database to find all the patents obtained by these graduates over their lifetimes.

TABLE 13.
PATENTING BY MAJOR, CASE GRADUATES 1920-39

Major	Number of Graduates	Number of Patentees	Average Lifetime per patentee
Civil	330	33	2.81
Mechanical	786	199	5.47
Electrical	465	119	5.03
Mining	46	7	2.86
Metallurgical	300	64	3.61
Physics	118	52	9.38
Chemical	427	141	5.93
Not Listed	8	1	2.00
Total	2,480	615	5.45

Sources: See Table 12.

TABLE 14A.
OCCUPATION AND PATENTING OF CASE GRADUATES BY YEAR OF GRADUATION, 1940 CENSUS

	Workers	Employers	Own Account	No occupational information	Not found in Census
Number of graduates	1,508	20	42	165	745
Number of patentees	389	6	9	101	110
Average patent per patentee	5.73	2.83	3.22	6.25	4.08

TABLE 14B
OCCUPATION AND PATENTING OF CASE GRADS BY YEAR OF GRADUATION, 1940 CENSUS (1920S GRADUATES ONLY)

	Workers	Employers	Own Account	No occupational information	Not found in Census
Number of graduates	668	15	33	44	337
Number of patentees	161	3	7	27	43
Average patent per patentee	6.32	2.33	2.43	9.41	6.32

TABLE 14C
OCCUPATION AND PATENTING OF CASE GRADS BY YEAR OF GRADUATION, 1930 CENSUS (1920S GRADUATES ONLY)

	Workers	Employers	Own Account	No occupational information	Not found in Census
Number of graduates	750	14	14	67	253
Number of patentees	167	4	4	24	42
Average patent per patentee	5.65	2.50	4.50	9.96	5.98

Notes and Sources: See Table 12. We obtained occupational information for the Case graduates by searching for them in the 1930 and 1940 manuscript population censuses on Ancestry.com. We had a somewhat better chance of locating graduates who patented because the patent records contained information on location.

TABLE 15.
SUMMARY STATISTICS FOR THE PROBABILITY THAT A CASE GRADUATE WOULD PATENT IN EACH YEAR

Variable name	Definition	Mean	Standard Deviation	Minimum	Maximum
Patenting	= 1 if an inventor applied for a successful patent	0.024	0.154	0	1
Age	= Year minus year of birth	38.6	9.696	20	74
Majors				0	1
Chemical		0.167	0.373	0	1
Civil		0.138	0.345	0	1
Electrical		0.191	0.393	0	1
Mechanical		0.316	0.465	0	1
Metallurgical		0.118	0.322	0	1
Mining		0.023	0.149	0	1
Physics		0.004	0.061	0	1
Not Listed	Major not listed in the commencement book	0.044	0.204	0	1
Employment in 1930					
Employer	classified as an employer in 1930 Census	0.019	0.135	0	1
Own Account	classified as own account in 1930 Census	0.018	0.132	0	1
Worker	classified as a worker in 1930 Census	0.964	0.187	0	1
Employment in 1940					
Employer	classified as an employer in 1940 Census	0.015	0.120	0	1
Own Account	classified as own account in 1940 Census	0.031	0.175	0	1
Worker	classified as a worker in 1940 Census	0.954	0.210	0	1
Living in Cuyahoga County in 1940	Graduate living in Cuyahoga county in 1940	0.530	0.499	0	1
Year		1944.8	9.548	1921	1960
Year 1920-21				0	1
Year 1922-24		0.013	0.115	0	1
Year 1925-27		0.028	0.165	0	1
Year 1928-30		0.041	0.199	0	1
Year 1931-33		0.056	0.231	0	1
Year 1934-36		0.074	0.262	0	1
Year 1937-39		0.089	0.285	0	1
Year 1940-42		0.101	0.301	0	1
Year 1943-45		0.101	0.301	0	1
Year of Graduation		1929.0	5.671	1920	1939
YoG 1922-24		0.187	0.390	0	1
YoG 1925-27		0.152	0.359	0	1
YoG 1928-30		0.141	0.348	0	1
YoG 1931-33		0.170	0.375	0	1
YoG 1934-36		0.132	0.338	0	1

Notes and Sources: See Table 14. Location in 1940 is from the 1940 Census. We consider each inventor to be "at risk" for patenting from his year of graduation until 1960. Where birth year was missing, it was imputed as the average year of birth for the class the person belongs to. Where death year was missing, it was imputed as 75. Out of 2480, 131 persons were missing date of birth and 504 were missing date of death.

TABLE 16A.
LOGIT ESTIMATES OF THE PROBABILITY OF PATENTING IN EACH YEAR BY 1920S CASE GRADUATES

	(1)	(2)	(3)	(4)	(5)	(6) Period dummies are graduation years
	Period dummies are patenting years					
Age	0.237*** (7.41)	0.240*** (7.49)	0.248*** (6.20)	0.259*** (6.10)	0.318*** (5.30)	0.265*** (6.24)
Age squared	-0.00301*** (-7.71)	-0.00305*** (-7.76)	-0.00323*** (-6.55)	-0.00332*** (-6.38)	-0.00361*** (-5.30)	-0.00341*** (-6.54)
Chemical major		1.786*** (10.04)	2.465*** (8.80)	2.567*** (7.81)	2.556*** (7.78)	2.577*** (7.80)
Electrical major		0.849*** (4.51)	1.467*** (5.05)	1.628*** (4.80)	1.620*** (4.78)	1.619*** (4.77)
Mechanical major		1.482*** (8.57)	1.884*** (6.77)	2.085*** (6.39)	2.057*** (6.30)	2.077*** (6.36)
Metallurgical major		0.866*** (4.14)	1.539*** (4.93)	1.672*** (4.61)	1.629*** (4.48)	1.622*** (4.46)
Mining major		-0.622 (-1.31)	-0.115 (-0.18)	0.251 (0.38)	0.224 (0.34)	0.298 (0.45)
Physics major		2.915*** (15.39)	3.550*** (12.05)	3.534*** (10.27)	3.557*** (10.33)	3.554*** (10.33)
Employer in 1930			-0.000220 (-0.00)	-0.0267 (-0.08)	-0.100 (-0.29)	-0.0610 (-0.18)
Own Account in 1930			0.432 (1.39)	0.406 (1.29)	0.367 (1.16)	0.438 (1.39)
Living in Cuyahoga 1940				-0.342*** (-3.61)	-0.348*** (-3.67)	-0.393*** (-4.11)
Year 1920-21						0.541*** (3.61)
Year 1922-24					0.472 (0.88)	0.107 (0.75)
Year 1925-27					0.585 (1.46)	0.366* (2.47)
Year 1928-30					0.808* (2.49)	

Year 1931-33					1.201*** (4.50)	
Year 1934-36					0.587* (2.37)	
Year 1937-39					0.631** (2.93)	
Year 1940-42					0.457* (2.30)	
Year 1943-45					-0.0278 (-0.14)	
Constant	-8.130*** (-12.88)	-9.516*** (-14.52)	-10.15*** (-12.26)	-10.29*** (-11.48)	-12.54*** (-9.05)	-10.62*** (-11.73)
Observations	37678	37645	26769	20764	20764	20764
Pseudo R-squared	0.009	0.061	0.069	0.070	0.077	0.074

* = p<0.05 ** = p<0.01 *** = p<0.001

Notes and sources: See Table 15. The omitted categories are Civil Engineering Major, Worker in 1930, living outside Cuyahoga County in 1940, graduation in 1928-30, and all years not included in the period dummies. When the occupational class or place of residence is not known, that person's observations are excluded from the analysis. T-statistics are in parentheses.

TABLE 16B.
LOGIT ESTIMATES OF THE PROBABILITY OF PATENTING IN EACH YEAR BY 1930S CASE GRADUATES

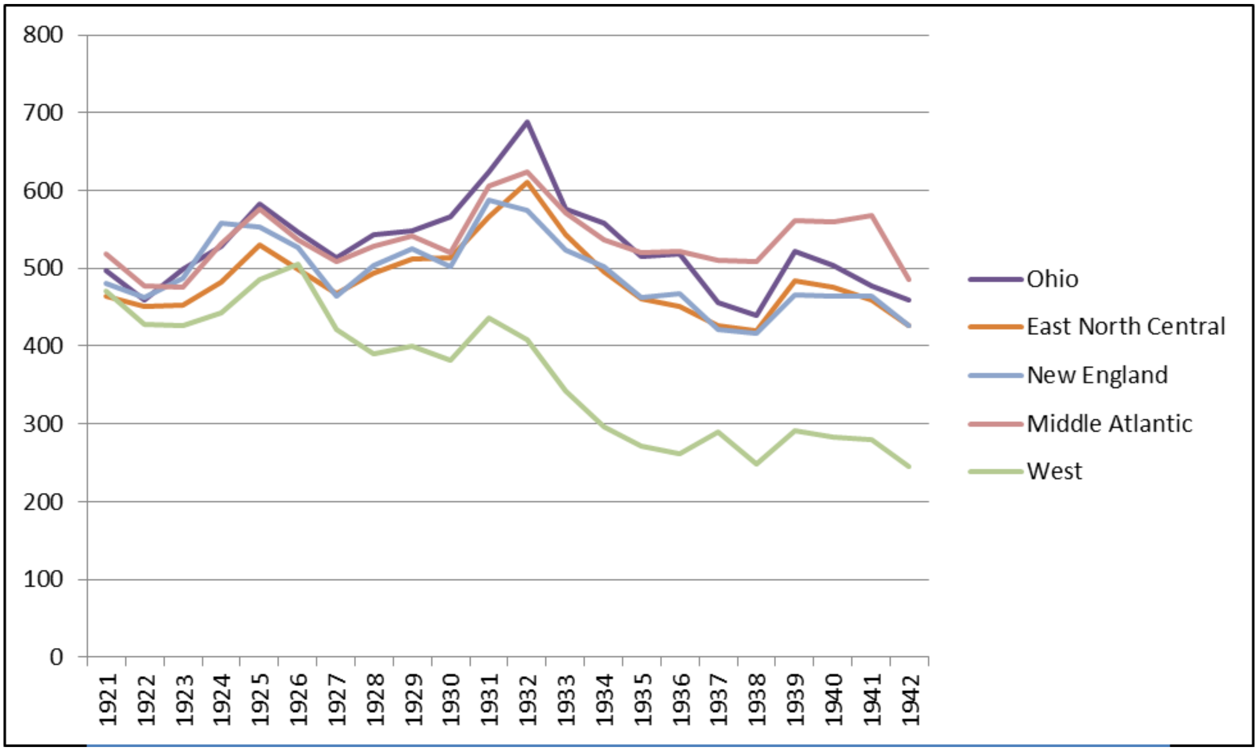
	(1)	(2)	(3)	(4)	(5)	(6) Period dummies are graduation years
	Period dummies are patenting years					
Age	0.352*** (7.39)	0.351*** (7.36)	0.318*** (5.44)	0.323*** (5.52)	0.267*** (3.58)	0.336*** (5.71)
Age squared	-0.00440*** (-6.88)	-0.00437*** (-6.82)	-0.00395*** (-5.04)	-0.00401*** (-5.12)	-0.00329*** (-3.50)	-0.00420*** (-5.32)
Chemical major		2.186*** (8.66)	2.141*** (7.36)	2.128*** (7.30)	2.123*** (7.28)	2.166*** (7.39)
Electrical major		2.168*** (8.56)	1.924*** (6.55)	1.941*** (6.59)	1.937*** (6.58)	1.984*** (6.70)
Mechanical major		1.785*** (7.11)	1.553*** (5.36)	1.540*** (5.31)	1.535*** (5.29)	1.567*** (5.37)
Metallurgical major		1.397*** (5.16)	1.420*** (4.53)	1.431*** (4.55)	1.423*** (4.52)	1.453*** (4.59)
Mining major		2.571*** (5.30)	2.420*** (4.80)	2.303*** (4.56)	2.317*** (4.58)	2.503*** (4.91)
Physics major		2.587*** (9.82)	2.904*** (9.45)	2.880*** (9.35)	2.877*** (9.34)	2.846*** (9.20)
Employer in 1940			0.954* (2.23)	0.976* (2.28)	0.973* (2.27)	0.977* (2.28)
Own Account in 1940			-0.227 (-0.50)	-0.117 (-0.26)	-0.105 (-0.23)	-0.251 (-0.55)
Living in Cuyahoga 1940				-0.370*** (-4.31)	-0.374*** (-4.34)	-0.384*** (-4.43)
Year 1928-30						0.488*** (3.44)
Year 1931-33					-0.631 (-1.13)	-0.254* (-2.20)
Year 1934-36					-0.548 (-1.57)	-0.188 (-1.56)
Year 1937-39					-0.00393 (-0.02)	

Year 1940-42					0.108 (0.57)	
Year 1943-45					0.156 (1.03)	
Constant	-10.35*** (-11.93)	-12.23*** (-13.58)	-11.46*** (-10.43)	-11.34*** (-10.31)	-10.31*** (-6.81)	-11.50*** (-10.31)
Observations	33475	33475	20830	20771	20771	20771
Pseudo R-squared	0.011	0.037	0.042	0.045	0.047	0.051

* = p<0.05 ** = p<0.01 *** = p<0.001

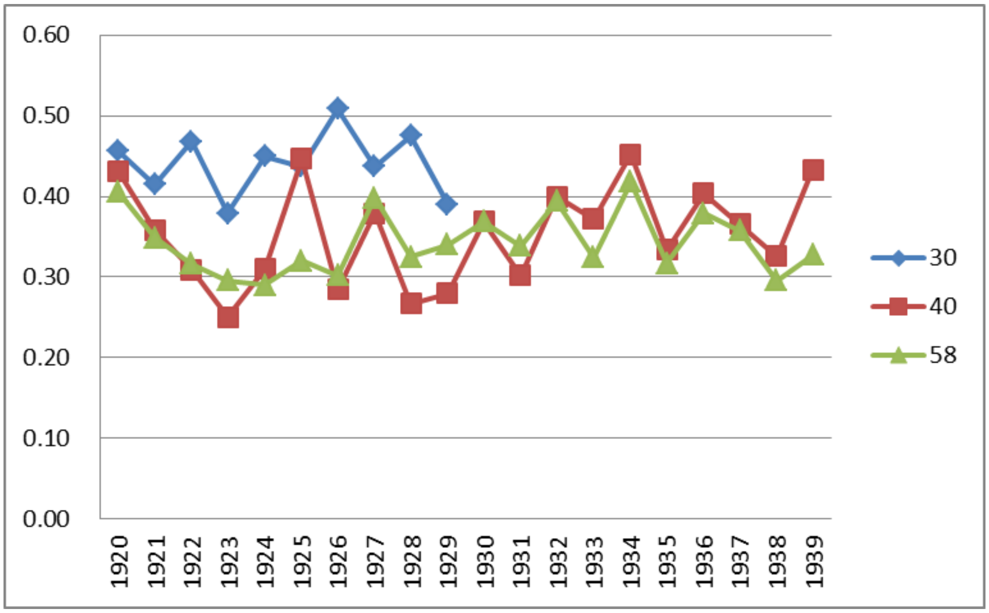
Notes and sources: See Table 15. The omitted categories are Civil Engineering Major, Worker in 1940, living outside Cuyahoga County in 1940, graduation in 1937-39, and all years not included in the period dummies. When the occupational class or place of residence is not known, that person's observations are excluded from the analysis. T-statistics are in parentheses.

FIGURE 1. PATENTING RATES PER CAPITA BY REGION, 1921 TO 1942



Notes and Sources: Patent rates are numbers of patents per million residents of the region. Patent counts come from the U.S. Commissioner of Patents, *Annual Reports*, 1921-25 and 1946. Population figures are from Carter et al. (2006), 28-29.

FIGURE 2.
PROPORTION OF CASE GRADUATES LIVING IN CUYAHOGA COUNTY,
BY GRADUATION YEAR



Sources: Case Commencement Programs, 1920-30; the manuscript 1930 and 1940 Population available at Ancestry.com; and the 1958 Case Alumni Directory.