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1 Inventors, Firms, and the Market for Technology in the Late Nineteenth and Early Twentieth Centuries

Naomi R. Lamoreaux and Kenneth L. Sokoloff

Recent economic theory suggests that large firms invest in building their own R&D facilities because there are significant problems associated with contracting for new technological developments in the market. In the first place, the uncertainties associated with valuing technological information are sufficiently great that even if such knowledge could be "displayed on a shelf," sellers would have difficulty pricing it and buyers would have trouble deciding whether to purchase it. Technological information is unlikely to be displayed in this manner, however, because sellers are concerned not to reveal too much about their discoveries. As a result, trade in technological information is diffi-

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cult to conduct. Firms may hesitate to purchase new technologies without full information about how they work, but inventors may balk at providing this level of detail for fear of losing control of their intellectual property. At the same time, scholars argue, there are informational advantages to be gained from moving R&D in house. Many innovations are stimulated by knowledge gained in production and marketing activities. This kind of knowledge is largely firm-specific. It can be readily communicated through interactions among personnel responsible for different functions within a firm, but it is much less easily transmitted across organizational boundaries. According to this view, then, in-house R&D laboratories triumphed over market exchanges of technology because they made superior use of information generated within the firm and minimized the transaction costs associated with increasingly complex and expensive forms of technological change (Teece 1988; Mowery 1983, 1995; Zeckhauser 1996; Arrow 1962).

In this essay, we offer an alternative view based on our assessment of the information and contracting problems that firms actually faced at the time they began to build their R&D capabilities. In particular, we argue that scholars have overemphasized the information problems associated with contracting for new technological developments in the market. Contrary to what one might expect from the literature, the data show that an extensive trade in new technological ideas did develop over the course of the nineteenth century, supported by the patent system and by the emergence of information channels and intermediaries that facilitated the sale of patents at arm's length.

The growth of this market for technology had important implications, we suggest, for the extent to which invention was integrated with development. Early inventors, of course, typically engaged in both sets of activities—either commercializing their ideas themselves or joining with outside investors to form enterprises to exploit their patents. This combination of activities certainly continued and, indeed, even thrived where the growth of the market made it easier to gain financial backing. But the expansion of trade in technology also made possible a new division of labor, as inventors increasingly took advantage of the greater returns to specialization that accompanied this growth and focused their energies and resources on invention itself. Firms in turn responded to the expansion of this trade by developing capabilities that enabled them to learn about and assess externally generated inventions. In an environment where many inventions were protected by patents and where this kind of property right was vigorously enforced, maintaining one's competitive position often meant purchasing (or at least contracting for the right to use) patented technology. Indeed, a wrong decision about the value of a patent could mean that a competitor gained control of vital technology.[1]

1. As Steven Usselman's essay (chap. 2 in this volume) shows, well-organized industries like railroads sometimes formed patent pools to lower the risks of making wrong decisions and to prevent technological blackmail.

During the late nineteenth and early twentieth centuries, firms devoted a considerable part of their energies and resources to keeping on top of technological ideas originating outside their bounds. This strategy was particularly important for firms in the "high-tech" industries of the time—industries like electricity and telecommunications, where technologies were complex and undergoing rapid change. As time went on, however, firms in these industries increasingly turned their attention to developing their own internal inventive capabilities. The reasons for this shift are beyond the scope of this essay, but they include such developments as the rising cost of the human and physical capital required for invention (which made it difficult for inventors to continue to operate independently) and the emergence of large firms with significant market power (which made patents an increasingly important factor in oligopolistic competition).

What we can and do argue in this essay, however, is that the shift was unlikely to have been driven by firms' desire to take advantage of the lower transaction costs associated with in-house R&D compared to market purchases of technology. During the late nineteenth and early twentieth centuries there already existed a well-functioning market for invention. By contrast, when firms decided to invest in internal R&D facilities, they faced significant new information and contracting problems—problems that scholars have failed to appreciate. In order, for example, to reap the fruits that might be derived from bringing inventors within the enterprise, firms had to learn how to manage creative individuals so as to elicit their loyalty and enhance their productivity. Entrepreneurially oriented inventors initially moved in and out of employment positions and, even worse from the standpoint of firms, often tried to exploit personally inventions that they devised on company time. Before firms could capture the gains from their investments in R&D, therefore, they had to learn how to tighten up their contractual relations with employee inventors and how to convince such personnel that advancement within the enterprise was an attractive alternative to self-employment. These were not easy lessons to master. It took twenty or thirty years just for firms to work out standard employment contracts giving them property rights to inventions developed in their facilities; other problems associated with managing creative people were never completely resolved. Hence where recent scholarship has emphasized the difficulties of contracting for technology in the market and the relative ease of integrating invention and production within the firm, we reverse the story. During the late nineteenth and early twentieth centuries there was a well-functioning market for invention, but significant organizational learning had to occur before firms could productively focus on in-house R&D.

1.1 The Patent System and the Market for Technology

The patent system provided the institutional framework within which trade in technology evolved over the course of the nineteenth century. Consciously

designed with the aim of encouraging inventive activity—and thus technological progress—the U.S. system provided the first and true inventor of a device with an exclusive property right for a fixed term of years. One important feature of the law was that inventors had to be individual men or women; firms could not receive patents directly for ideas developed in their shops. These individual inventors then had the option of exploiting their property rights themselves, or they could sell (assign) or lease (license) them to others, whether individuals or firms. Of course, inventors' ability to find buyers or licensees for their patents depended on the security of these property rights. From the beginning, responsibility for enforcing patent rights was left to the federal courts, and as Zorina Khan has shown, judges quickly evolved an effective set of principles for protecting the rights of patentees and of those who purchased or licensed patented technologies. As a result, not only did thousands of inventors pay rather substantial fees to obtain patents, but large numbers of individuals and firms paid even greater amounts to purchase or license patent rights (Khan 1995).

Although one purpose of the patent system was to stimulate invention by granting creative individuals secure rights to their intellectual property, another was to promote the diffusion of technological knowledge. The law required all patentees to provide the Patent Office with detailed specifications for their inventions (including, where appropriate, working models), and the result was a central storehouse of information that was open to all. Anyone could journey to Washington and research others' inventions in the Patent Office files. In addition, more convenient means of tapping this rich source of information soon developed. The Patent Office itself published an annual list of patents issued, and private journals, many of them issued by the leading patent agencies of the day, emerged by the middle of the nineteenth century to improve upon this service. One of the most important was *Scientific American,* published by Munn and Company, the largest patent agency of the nineteenth century. Others included the *American Artisan,* published by Brown, Coombs and Company; the *American Inventor,* by the American Patent Agency; and the *Patent Right Gazette,* by the United States Patent Right Association (which, despite its name, functioned as a general patent agency). Aimed at national readerships, these journals featured articles about major technological improvements, printed complete lists of patents issued sometimes on a weekly basis, and offered to provide readers with copies of full patent specifications for a small fee. They also included a variety of advertisements that disseminated information about inventions (or how to profit from them), placed by patent agents and lawyers soliciting clients, detective agencies specializing in patent issues, inventors seeking partners with capital to invest, patent holders hoping to sell or license rights to their technologies, and producers of patented products trying to increase their sales. Over time, moreover, specialized trade journals also emerged in industry after industry to keep producers informed

about patents of interest. The *Journal of the Society of Glass Technology,* for example, provided detailed descriptions of all patents taken out in the United States and Britain that were relevant to the manufacture of glass.

As individuals, patent agents and lawyers also became important channels through which people and firms far from Washington could exploit the information in Patent Office files. Their numbers began to mushroom in the 1840s, first in the vicinity of Washington and then in other urban centers, especially in the Northeast. By the mid-1880s, there were about 550 such agents registered to practice before the Patent Office, with almost a quarter located in the District of Columbia, slightly more than half in New England and the Middle Atlantic states, another fifth in the Midwest, and the rest scattered among a few southern and western locations. Solicitors in different cities linked themselves in chains of correspondent relations (similar to those that characterized the banking system at the same time), thereby providing their local clients with access to agents in Washington and information on patenting activity across the country.[2]

There is plenty of anecdotal evidence to suggest that all these channels of information made possible by the patent system worked effectively to diffuse technological knowledge. Inventors scanned patent lists in search of developments in their fields and subscribed to periodicals relevant to their interests. For example, Elias E. Reis reported that, when he read in the *Official Gazette of the United States Patent Office* in 1886 about a patent issued to Elihu Thomson for a method of electrical welding, there "immediately opened up to my mind a field of new applications to which I saw I could apply my system of producing heat in large quantities."[3] Charles H. Roth, an inventor of bicycle tires, subscribed to two papers, *Bicycling World* and *Bearings,* in order to keep abreast of technological developments related to cycling. He also "read other papers at the bicycle stores and at the Crescent Wheel Club Rooms, of which club I was a member."[4] To give a different kind of example, the journals of Wright, Brown, Quinby and May, patent solicitors, were filled with notations of payments received from clients for searches of Patent Office records. For instance, when the officers of the Waltham Watch Company decided to explore the possibility of producing self-winding clocks and watches, they asked Wright, Brown, Quinby and May to conduct a search for them so they could

2. The growth and geographic spread of patent agents and solicitors can be followed through city directories and through the U.S. Patent Office's *Roster of Registered Attorneys Entitled to Practice before the United States Patent Office.* For insight into the correspondent relations of these agents, see Wright, Brown, Quinby & May Correspondence Files, Waltham Watch Company, 1854–1929, MSS 598, case 2, Baker Library, Harvard Graduate School of Business Administration.

3. See "Record of Elias E. Reis," 8, *Thomson v. Reis,* case 13,971, box 1,845, Interference Case Files, 1836–1905, Records of the Patent Office, Record Group 241, National Archives.

4. "Record of Roth," 6, *Roth v. Brown & Stillman,* case 17,930, box 2,488, Interference Case Files, 1836–1905.

learn about techniques already in use and reduce the risk of being sued for infringement.[5]

Even more interesting for our purposes, these various channels of information were also used by patentees to market their inventions. Advice manuals recommended that, "if the inventor can afford it, it is well to have the invention illustrated and described in one or more of the scientific and mechanical publications of the day." This announcement might then, if necessary (and the manuals claimed that further advertisement often would not be necessary), "be followed up by ordinary advertising . . . in the paper or papers which are designed to meet the eye of the class or classes of persons to whom the invention is of special interest." Advertisements in trade papers in turn might be followed by personal solicitations to potential buyers, whose names could be obtained from "men in New York and other large cities, who make it their business to furnish, for a reasonable consideration, full and complete lists of all parties engaged in any particular trade, occupation, profession, or manufacture throughout the country" (Simonds 1871, 19, 24–26).

Patentees who did not feel able or willing to devote so much of their time to marketing their inventions could turn to intermediaries for assistance. Virtually any businessman could perform this function, as records of patents offered for sale to important firms show.[6] But it was common for patent solicitors and agents to play the role of middleman. Although the original function of these specialists was to shepherd applications for patents through the official review process and (in the case of the lawyers) to defend previously issued patents in interference and infringement proceedings, as time went on they acquired additional functions and often began to serve as intermediaries in the sale of technology. There appears to have been some disagreement among solicitors about whether such activity was proper, but many moved in this direction, advertising their willingness to sell patents on commission.[7] Some solicitors, in

5. The example is from a letter from the Waltham Watch Company to Wright, Brown, Quinby & May, 25 January 1915, Wright, Brown, Quinby & May Correspondence Files, Waltham Watch Company, 1854–1929, case 2. For numerous other instances, see Journal 1, Wright, Brown, Quinby & May, 1881–1950, MSS 831, Baker Library, Harvard Graduate School of Business Administration.

6. For example, the Nicholson File Company was offered the opportunity to buy a patent for a rasp by a manufacturer of engine governors who had acquired it for resale. Similarly, intermediaries with main businesses as diverse as textile manufacturing and engineering consulting submitted inventions for sale to AT&T. See correspondence between the Nicholson File Company and Stillman B. Allen, 1873–75, Patent Records from Trunk, Nicholson File Co., MSS 587, Rhode Island Historical Society Manuscript Collections; and T. D. Lockwood, Reports of Inventions (Not Approved), 1904–8, box 1383, AT&T Corporate Archives.

7. H. W. Boardman and Company (1869, 13), solicitors of American and European patents, stated unequivocally that the firm rigidly adhered to a rule "never to take contingent interests in applications for Patents, nor to negotiate sales of Patent rights, or become the owners in whole or in part of them. We deem all such to be deviations from that rigid professional course necessary to insure the strictest honor and integrity toward a client." Simonds (1871, 7–9) took a similar position, advising patentees to sell their inventions themselves and not be seduced by the promises of such agents. See also Hutchinson and Criswell (1899, 161–62); Cresee (1907, 41–43).

fact, became known for this service, and inventors would seek them out to find buyers for their patents. For example, a party with an interest in a "Patent Self Oiler" for railroad cars wrote an agent named Lemuel Jenks to solicit his assistance in marketing their device: "We intend to sell it to one person for the six New England States and I therefore wish you would give me your opinion in that matter: to viz what price you think we should ask; what would we have to pay you for your assistance in carrying and effecting a sale."[8] The records of important concerns such as the American Telephone and Telegraph Company (AT&T) contain numerous letters from inventors offering their own patents for sale, but also a nearly equivalent number of approaches from patent agents and solicitors marketing inventions on behalf of their patentee clients.[9]

1.2 A Quantitative Picture of the Market

The extent to which the market for patented technology was already well established by 1870, especially in the northeastern regions of the country, can be seen from table 1.1, which reports descriptive statistics for a sample of assignment contracts.[10] In order for the sale of a patent to be legally binding, a copy of the contract had to be deposited with the Patent Office in Washington. These contracts are now stored at the National Archives, and our sample consists of all the approximately 4,600 contracts filed during the months of January 1871, January 1891, and January 1911. Although the number of assignment contracts increased dramatically over this period, more than doubling between 1871 and 1911, the number of patents filed increased even more rapidly. As a result, the ratio of assignments in our sample to the total number of patents issued actually peaked by the beginning of our period, declining from 0.83 in 1870–71 to 0.71 in 1890–91 and 1910–11.[11]

The high volume by 1870 of contracts relative to patents is a strong indication that trade in rights to patented technology was already well developed. In addition, the high proportion early on of what we are calling "geographic assignments"—that is, sales of patent rights that were restricted to some (often distant) subregion of the United States—suggests that a significant amount of arm's-length trading was already occurring by midcentury. Although the

8. Letter of 30 April 1870 from Aug. H. Fick (last name not completely legible) to Jenks, Lemuel Jenks, 1844–1879, MSS 867, box 3, folder 59, Baker Library, Harvard Graduate School of Business Administration.

9. See T. D. Lockwood, Reports of Inventions (Not Approved), 1904–8.

10. In this paper we focus on national aggregates. In other work (Lamoreaux and Sokoloff 1996) we deal with the issue of why the market for technology did not develop uniformly across the nation.

11. It is important to note that these ratios are not measures of the proportion of patents that were ever assigned, which we cannot calculate, but instead are estimates of the volume of assignment activity relative to patenting activity. One cannot infer from the fall in these ratios that the proportion of patents ever assigned also declined after 1870–71. The drop over time in the proportion of secondary and geographic assignments might have reduced the estimated ratios, even if the overall proportion of patents ever assigned continued to rise.

Table 1.1 **Descriptive Statistics on Assignments Made before and after Issue of Patents**

	1870–71	1890–91	1910–11
New England			
Assignment to patenting index	115.1	109.5	132.4
% assigned after issue	70.4	31.2	30.1
% secondary assignments	26.6	14.8	12.0
% geographic assignments	17.1	0.8	0.0
Middle Atlantic			
Assignment to patenting index	100.7	94.8	116.3
% assigned after issue	70.9	44.4	37.9
% secondary assignments	33.3	16.4	11.0
% geographic assignments	19.1	1.9	0.7
East North Central			
Assignment to patenting index	96.3	118.1	104.9
% assigned after issue	77.7	48.5	32.8
% secondary assignments	18.1	18.4	11.8
% geographic assignments	34.3	5.7	1.8
West North Central			
Assignment to patenting index	90.7	110.1	73.5
% assigned after issue	77.4	48.6	42.6
% secondary assignments	32.3	19.2	11.0
% geographic assignments	41.9	13.0	2.6
South			
Assignment to patenting index	60.0	68.9	68.0
% assigned after issue	74.4	42.3	48.2
% secondary assignments	27.9	11.3	19.1
% geographic assignments	20.9	6.2	2.5
West			
Assignment to patenting index	150.0	67.2	81.5
% assigned after issue	59.1	57.4	36.0
% secondary assignments	22.7	11.4	10.4
% geographic assignments	18.2	7.4	1.2
Total domestic			
Assignment to patenting index	100.0	100.0	100.0
% assigned after issue	72.3	44.1	36.5
% secondary assignments	27.8	16.4	12.0
% geographic assignments	22.8	4.6	1.2
Assignments to patents ratio	0.83	0.71	0.71
Number of contracts	794	1,373	1,869

Source: Our sample consists of all assignment contracts filed with the Patent Office during the months of January 1871, January 1891, and January 1911. These contracts are recorded in "Liber" volumes stored at the National Archives.

Notes: There are a total of about 4,600 contracts in our sample. Only those involving assignors that resided in the United States are included in this table. The assignment-to-patenting index is based on the ratio of assignments originating in the respective regions (given by the residence of the assignor) to the number of patents filed from that region in 1870, 1890, and 1910 respectively. In each year the index has been set so that the national average equals 100. The percentage of secondary assignments refers to the proportion of assignments where the assignor was neither the patentee nor a relative of the patentee. The percentage of geographic patent assignments refers to the proportion of assignments where the right transferred was for a geographic unit smaller than the nation.

proportion of geographic assignments dropped dramatically between 1870–71 and 1910–11, this change did not mean that market trade in technology was falling off. Rather the decline should be seen as a consequence of the growth of national product markets. Once manufacturers in a single location could retail their products nationally, it made less sense to try to sell geographically exclusive rights to producers in different parts of the country. Producers were now more interested in purchasing full national rights that would give them a competitive edge over rivals elsewhere.[12]

Two related changes are also apparent in the table. In 1870–71, secondary assignments—that is, sales of patents where the assigner was neither the patentee nor a relative of the patentee—accounted for more than a quarter of total sales. By 1910–11, the figure had fallen to 12 percent. In other words, there was less reselling of patents as time went on; an increasingly large proportion of sales were being made directly by the patentee.[13] More important, the proportion of assignments that occurred after the date the patent was issued dropped from 72.3 percent of the total in 1870–71 to 36.5 percent in 1910–11. That is, as time went on patentees were able to sell their inventions earlier and earlier—often before their patents were actually issued.[14]

For the subset of inventions assigned at or before the date the patent was issued, we can get a more precise sense of the magnitude and direction of change over time. Table 1.2 is based on three random cross-sectional samples of patents drawn from the *Annual Report of the Commissioner of Patents* for the years 1870–71, 1890–91, and 1910–11. These documents report for all patents issued during the year the names of the patentees as well as the names of any assignees who were granted property rights to the patents at the time of

12. In addition, the marketing of geographic assignments had always posed information problems that could be avoided once it became possible to dispose of national rights in one fell swoop. For example, the relationship between inventors and the itinerant agents who sometimes marketed their patents in other parts of the country was open to opportunism and even outright fraud, and disreputable agents were accused of a variety of crimes—from misrepresenting the value of patents, to collecting commissions on bogus sales, to embezzling funds rightfully due inventors. Further, contemporary writers claimed that patentees who disposed of their rights piecemeal risked the possibility that familiarity with the device would stimulate some other inventor to patent a substitute or an improvement that would reduce the value of the original patent and therefore the proceeds from later sales. For this reason they advised inventors to dispose of a patent in its entirety "as soon as possible after its issue" (Simonds 1871, 28–29; An Experienced and Successful Inventor 1901, 58–59; Cresee 1907, 26–27, 61).

13. Although assignment contracts had to be filed with the Patent Office in order to be legally binding, there was no similar legal requirement to file licensing agreements. Our sample of assignment contracts does contain some licensing agreements, but they are very few in number, and anecdotal evidence suggests that those recorded in this manner were a declining proportion of the total of such agreements over time. It is likely, therefore, that the decrease in secondary assignments was more than compensated for by an increase in licenses, and that our figures understate this important (and growing) dimension of the market for patented technology.

14. At least part of the rise in the fraction of assignments that occurred before issue resulted from an increase in the length of time consumed by the application process. In order to get a rough idea of the extent of the increase, we compared two samples of 125 patents each drawn from the October 1874 and October 1911 issues of the *Official Gazette of the United States Patent Office.* In 1874, the median time between application and issue was 4 months and the mean 5.8 months. In 1911, the median was 12 months and the mean 18.2 months.

Table 1.2 Assignment of Patents at Issue, 1870–1911

	1870–71	1890–91	1910–11
Number of patents	1,563	2,031	2,512
% of patents assigned	18.4	29.3	31.1
% of assignments to group including patentee	52.1	41.5	25.4
% of assignments in which patentee assigned away all rights to unrelated individuals	24.7	11.1	10.4
% of assignments in which patentee assigned away all rights to a company	23.6	47.1	64.2
% of assignments in which patentee assigned away all rights to a company with the same name as the patentee	5.6	11.8	9.2
% of patents in which patentee maintained stake (did not assign or assigned to group including patentee or assigned to company with the same name)	92.2	86.3	79.7

Sources: The table is based on three random cross-sectional samples of patents drawn from the *Annual Report of the Commissioner of Patents* for the years 1870–71, 1890–91, 1910–11.

Notes: The three samples total slightly under 6,600 patents, including those granted to foreigners. The table includes only patents awarded to residents of the United States. The category "% of assignments to group including patentee" consists of patents assigned to one or more individuals including the patentee, an individual with the same family name as the patentee, or an individual specifically designated as an agent for the patentee. Patents assigned to companies with the same last name as the patentee were included in the general category of patents assigned to companies, as well as in the particular category of companies with the same name as the patentee. It is, of course, also possible that patentees had an ownership stake in companies that did not bear their name.

issue. Table 1.2 reports the frequency with which patents in these samples were assigned at issue, as well as the frequency of various types of assignments, including the proportion that went to companies. The table also provides a summary measure of the extent to which patentees retained a stake in their inventions—that is, the total number of patents not assigned at the time of issue plus the number of those assigned that went to groups including the patentee or to companies with the same name as the patentee.

When combined with the information from table 1.1, the figures in table 1.2 suggest a progression over time. Initially, inventors not only came up with new technological ideas but also developed and commercialized them, sometimes by starting their own businesses, sometimes by selling partial rights to their ideas to producers in different geographic markets, and sometimes by doing both. As the market for technology expanded and matured, inventors seem to have employed it to facilitate these kinds of business activities. For example, during the early 1870s assignments at issue typically involved the sale of shares of patent rights to groups of individuals who were not coinventors, but who generally resided in the vicinity of the patentee, and it is likely that these partial assignments compensated local partners for advances of capital to support the development and commercialization of the inventions. Over time, however, a

Table 1.3 **Distribution of Patents by Patentee Commitment to Patenting, 1790–1930**

	Number of "Career" Patents by Patentee (%)					
	1 Patent	2 Patents	3 Patents	4–5 Patents	6–9 Patents	10+ Patents
1790–1811	51.0	19.0	12.0	7.6	7.0	3.5
1812–29	57.5	17.4	7.1	7.6	5.5	4.9
1830–42	57.4	16.5	8.1	8.0	5.6	4.4
1870–71	21.1	12.5	9.9	15.8	11.8	28.9
1890–91	19.5	10.3	10.3	10.3	13.8	35.9
1910–11	33.2	14.3	8.2	9.8	9.4	25.0

Sources: The figures from 1790 to 1842 are from Sokoloff and Khan 1990, 363–78. The figures for the later years were computed from a longitudinal data set constructed by selecting all the patentees in the cross-sectional samples (see table 1.2 for a description) whose family names began with the letter *B* and collecting information on the patents they received during the twenty-five years before and after they appeared in the samples. This data contains information of 6,057 patents granted to the 561 *B* inventors.

second pattern emerged as patentees increasingly relinquished all property rights to their inventions by the time of issue, assigning their rights in particular to companies. The shift can be seen as a drop in the proportion of patents in which the patentee retained a direct stake—from 92.2 percent in 1870–71 to 79.7 percent in 1910–11. Because many of the patents not assigned at issue were probably of limited economic value, however, the change can be seen more clearly in the fall in the proportion of assignments that went to groups that included the patentee—from 52.1 percent in 1870–71 to 25.4 percent in 1910–11.[15]

The growth of trade in patented technologies was accompanied by dramatic increases in the degree to which patentees specialized in inventive activity. This development is reflected in table 1.3, which presents estimates of how the share of patents awarded to inventors with long-term commitments to patenting changed over the course of the nineteenth century. We obtained the estimates for 1870–71, 1890–91, and 1910–11 by selecting from our three cross-sectional samples inventors whose last names began with the letter *B* and collecting information on all the patents these inventors received in the twenty-five years before and after they appeared in the respective sample. We then grouped the inventors according to the total number of patents they obtained over the fifty-year period and calculated how all the patents in each cross-section were distributed across these groups. Finally, we compared our results with data on career patenting for the period 1790–1842 compiled by Kenneth Sokoloff and Zorina Khan (1990).

The figures indicate a major shift, with the proportion of patents awarded to

15. As we will show below, however, a significant proportion of the assignments to companies involved firms in which the patentees were officers.

Table 1.4 **Average Number of Patents Awarded to Various Types of Patentees, 1870–1911**

	1870–71	1890–91	1910–11
Year total of patents for all patentees	1.92	2.29	2.00
	(1,563)	(2,031)	(2,512)
Year total of patents for patentees who did not assign	1.67	1.99	1.61
	(1,275)	(1,436)	(1,730)
Year total of patents for patentees who assigned	3.03	3.00	2.87
	(288)	(595)	(782)
Year total of patents for patentees who assigned to a group including themselves	1.75	1.79	1.60
	(150)	(247)	(199)
Year total of patents for patentees who assigned away all their rights to unrelated individuals	3.85	2.95	2.51
	(71)	(66)	(81)
Year total of patents for patentees who assigned away all their rights to companies	4.97	4.10	3.43
	(68)	(280)	(502)
Year total of patents for patentees who assigned away all their rights to companies with the same name as the patentee	3.31	5.41	4.35
	(16)	(70)	(72)

Sources: The table is based on three cross-sectional samples drawn from the *Annual Report of the Commissioner of Patents* for the years 1870–71, 1890–91, 1910–11.

Notes: For each patent in the sample, we counted all of the other patents received by that patentee in the same year. For additional information on these samples and on the definitions of the categories, see table 1.2. The number of sample observations for each cell is reported within parentheses.

individuals who received ten or more patents over their careers increasing from below 5 percent in the three early cross-sections to 25 percent or more in the three cross-sections between 1870 and 1911. The early 1800s were a relatively democratic era of invention, when a broad segment of the population was acquainted with the basic elements of the technology in use, and the typical inventor filed only one or two patents over his or her lifetime. The rapid expansion of the market for patents that occurred during the second third of the nineteenth century made it easier to extract returns from technological discoveries by selling off patent rights, and seems to have coincided with the emergence of a class of inventors who were relatively specialized at inventive activity. Occasional inventors, whose efforts at technological creativity were only one aspect of their work, continued to be significant contributors to technological change, but their share of patents fell sharply. From over 70 percent as late as the 1830s, the share of patents accounted for by individuals with only one or two career patents declined to less than 35 percent by the 1870s.

Another, perhaps more direct, indication of the relationship between specialization at invention and the practice of selling off patent rights is the higher productivity of patentees who assigned to companies. In table 1.4, we report for our three cross-sectional samples from 1870–71, 1890–91, and 1910–11 the average number of patents received by individual patentees in a single year, grouped by whether the patentee had assigned away his or her rights (and to

whom) before the date of issue of the patent. As is clear, patentees who assigned their patents at issue were more productive (in terms of the number of patents they received in a given year) than those who did not assign. Moreover, inventors who assigned their full patent rights to unrelated individuals or to companies were more productive than those who retained a share of their patents. The patentees who consistently received the most patents per year were those who assigned at issue to companies, and it is interesting to note that the relatively small but growing number of patentees who assigned away all rights to companies that bore their last name were by 1890–91 the most productive of all.

1.3 Inventors and Firms

Both the growing tendency of inventors to assign all rights to their patents at issue to companies and the greater productivity at invention of patentees who disposed of their patents in this way, raise questions about the identity of these inventors and the nature of their relationship with the companies to which they assigned. There are three main possibilities: first, that the inventors were independent agents who sold their patents in arm's-length transactions; second, that they were principals (for example, officers or proprietors) of the firms to which they assigned; and third, that they were employees of their assignees. These three possibilities have different implications for the extent to which invention was integrated with development. The first case, of course, implies a clear division of labor between those who invented and those who developed the inventions commercially. The second case is more ambiguous, because we cannot tell from this kind of information alone whether the patentees formed companies in order to integrate invention with commercial development or whether they were seeking to provide themselves with a better vehicle to support their specialization in inventive activity. The third case is the one most favorable to those who would argue for an increased integration of invention and development within large firms. However, to the extent that inventors who assigned to their employers obtained more patents than those who did not, the difference may not have resulted from efficiency gains deriving from integration, but instead from inventors' greater ability to specialize within large-scale enterprises or from cost savings derived from economies of scale in carrying out invention or in filing patent applications.

Unfortunately, because assignments of patents typically take the same contractual form whether they involve arm's-length sales, grants of patent rights by principals to their associated firms, or the acquisition by firms of employees' inventions, it is difficult to get a sense of the relative importance of these different kinds of transactions over time. We have, however, devised a number of alternative ways to approach the problem. Although these alternatives are individually partial and imperfect, collectively they allow us to conclude with reasonable confidence that the acquisition by firms of employees' inventions

Table 1.5 **Relative Numbers of Patents Assigned after and at Issue to Individuals and Companies**

	After Issue		At Issue		
	No.	%	No.	%	Total
1871					
To individuals	454	73.2	166	26.8	620
To companies	112	68.3	52	31.7	164
Total	566	72.2	218	27.8	784
1891					
To individuals	370	45.6	441	54.4	811
To companies	230	41.8	320	58.2	550
Total	600	44.1	761	55.9	1,361
1911					
To individuals	307	40.4	453	59.6	760
To companies	369	33.6	728	66.4	1,097
Total	676	36.4	1,181	63.6	1,857

Source: For a description of the sample, see table 1.1.

cannot account either for the general trend in assignments in favor of companies or the greater productivity at invention of patentees who assigned away their patent rights.

Our first, and least direct, approach is based on the assumption that assignments that occurred in the context of the employment relationship were more likely to occur at the time the patent was issued for the simple reason that, in such cases, the company commonly assumed responsibility for patenting the invention, paying all the necessary fees and providing legal counsel, in exchange for an immediate assignment. Table 1.5 (which is based on the January 1871, 1891, and 1911 samples of assignment contracts) shows that there was nothing remarkable about the propensity of companies to obtain assignments at issue. Although the proportion of assignments to companies that took place before issue always exceeded that of assignments to individuals, the difference was relatively small and showed only a slight tendency to widen over time. More important, the proportion of assignments that occurred at issue increased dramatically over time for both types of assignees, suggesting that the change resulted more from improvements in the general market for technology than from the movement of inventors within firms.[16]

A second approach uses the longitudinal data on our *B* patentees to explore the extent to which there were stable, ongoing relationships between patentees and assignees. In table 1.6, we present, for different classes of patentees, a measure of the degree of "contractual mobility," where contractual mobility is defined as the number of different assignees over time to which a patentee

16. Once again, however, it is important to note that the time interval between application for a patent and issue by the Patent Office also increased over this period.

Table 1.6 **Contractual Mobility among Patentees, by Their Productivity at Patenting**

Number of Patents Received by Patentee over Career	% Assigned	% Assigned to Companies	Did Not Assign Any Patents		1		2–3		4–5		6+		Total	
			No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
			Distribution of Patentees											
1	19.2	5.3	122	80.8	29	19.2	—	—	—	—	—	—	151	26.9
2–5	18.5	7.2	121	62.1	62	31.8	11	5.6	1	0.5	—	—	195	34.8
6–10	26.3	16.3	31	38.8	17	21.3	25	31.3	7	8.8	—	—	80	14.3
11–19	31.7	21.7	10	16.7	22	36.7	15	25.0	11	18.3	2	3.3	60	10.7
20+	49.3	41.3	4	5.3	9	12.0	29	38.7	15	20.0	18	24.0	75	13.4
Total			288	51.3	139	24.8	80	14.3	34	6.1	20	3.6	561	100.0
			Distribution of Patents											
1	19.2	5.3	122	80.8	29	19.2	—	—	—	—	—	—	151	2.5
2–5	19.5	6.2	352	57.8	209	34.3	43	7.1	5	0.8	—	—	609	10.1
6–10	28.8	15.2	238	38.5	129	20.9	194	31.4	57	9.2	—	—	618	10.2
11–19	35.0	23.3	138	15.8	330	37.8	214	24.5	157	18.0	33	3.8	872	14.4
20+	58.0	47.2	117	3.1	466	12.2	1,361	35.8	864	22.7	999	26.2	3,807	62.9
Total			967	16.0	1,163	19.2	1,812	29.9	1,083	17.9	1,032	17.0	6,057	100.0

Source: The estimates were computed from the *B* data set described in the note to table 1.3.

Notes: The top panel presents the distribution of the 561 inventors in the data set, broken down by the total number of patents the inventor received over his "career" (defined as the twenty-five years before and after he appeared in the sample) and by the number of different assignees to whom he assigned patents at the time of issue. Where the inventor assigned a patent to a group of individuals, that group was treated as one assignee. In the top panel, the estimates of "% Assigned" and "% Assigned to Companies" were calculated from a subset of patents consisting of one randomly drawn patent for each of the 561 patentees. The distribution in the lower panel pertains to all of the 6,057 patents received by the 561 inventors over their careers. The figures for "% Assigned" and "% Assigned to Companies" are accordingly based on all of the patents received by the patentees in the respective categories.

transferred patent rights at issue. The upper panel reports the distribution for the individual *B* patentees, broken down by the total number of patents received over their careers and by the number of different assignees to which they transferred patent rights. The lower panel reports the analogous distribution for all of the patents received by the *B* patentees. This distribution is equivalent to a weighted version of the distribution in the upper panel, where the weights are the numbers of patents received by the patentees over their careers.

As the figures in table 1.6 indicate, the most highly productive patentees (those with twenty or more career patents) were not generally tied to single assignees. Only 12 percent of the patentees in this class relied on one assignee throughout their careers. By contrast, 44 percent contracted with four or more different assignees over time. (The analogous figures for the number of patents associated with this group were 12.2 and 48.9 percent respectively.) These results make it difficult to believe that stable employment relationships were responsible for the high productivity at patenting we observe among inventors who assigned away their patent rights. If these inventors were in fact employees, then they were employees who often either moved restlessly from job to job or who, despite their positions, behaved entrepreneurially and assigned their patents to buyers other than their employers. This conclusion appears even stronger when one recognizes that the percentages in the table pertain only to patents that were actually assigned at issue. The highly productive patentees in this group chose to retain control at issue of the rights to more than 40 percent of the patents they received, reserving for themselves the ability to sell or license their inventions in the future. It is likely that if we had information on subsequent assignments or licensing agreements, our estimates of the extent of contractual mobility would only increase.

In order to get a more direct understanding of the relationship between patentees and their assignees, we traced the inventors in our *B* sample through city directories and, wherever possible, recorded their occupations and/or places of employment for the years in which they were issued patents.[17] The resulting subset is certainly not representative of the general population of patentees. In the first place, it is more urban.[18] In the second, it is biased in favor of those who were more occupationally settled and therefore more likely to be picked up in the directories. As a consequence of this bias in favor of stability, one

17. For this exercise we used an earlier version of the longitudinal *B* sample that included data on most but not all of the fifty years surrounding each patentee's appearance in a cross-sectional sample. The effect of using the incomplete sample was to reduce the average number of assignees per patentee and thus to increase the likelihood of finding apparently stable relationships between patentees and assignees. Although the period of time for which we have data ranged from 1843 to 1935, 96 percent of the observations fell between 1867 and 1930.

18. Patentees in the subsample came from more than fifty cities, but more than 50 percent of the observations in each of our three subperiods came from the same six cities (Baltimore, Boston, Chicago, Cleveland, New York, and Philadelphia). One potential problem: the post-1910 subsample is very different from the others in the limited representation of New York and the large fraction of observations from Chicago (over 30 percent).

might expect that assignments made to companies by patentees in long-term employment relationships would be more prominent in this subset of the data than in the *B* sample as a whole.[19] As we will show, however, employees who assigned their patents to their companies still played only a minor role.

In table 1.7, we summarize the information collected for this subsample of urban patentees by presenting for each of three time periods descriptive statistics on the distribution of patentees (based on one randomly selected patent per patentee) and on the distribution of all their patents. The distributions are broken down in the upper panel of the table by occupational class and, in the bottom panel, by type of relationship between patentee and assignee. Caution in generalizing from this data is warranted because the subsample is clearly not representative of the entire population of patentees and because we were not able to determine the employment status of all of the inventors. Nevertheless, the results strongly suggest that, until well into the twentieth century, when inventors transferred the rights to their patented technologies to others, their assignees were unlikely to be their employers. The proportion of patentees in the subsample who were employees averaged only 28 percent over the entire period, and the fraction of patents they accounted for was even less (20.7 percent on average). Moreover, the share of assignments at issue made by employees to employers hovered around the modest level of 10 percent.[20]

Although the relatively small role played by employee patentees was an enduring feature of this era, several major changes in the market for technology are evident in the patterns of assignments at issue. First, as we have already documented using other data sets, patentees became increasingly likely over time to assign away all rights to their patents at the time of issue. This trend is reflected in table 1.7 in the sharp decline in the fraction of patents not assigned at issue (from 75.1 percent before 1890 to 29.7 percent after 1910). Second, there was also a significant increase over time in the proportion of patents transferred at issue to assignees who had a formal association with the patentee—that is, to patentees' employers or to firms in which patentees were principals or officers. This total rose from a mere 6.6 percent of patents before 1890, when arm's-length exchanges were more common, to 43.6 percent after 1910. Virtually all of the increase resulted from the dramatic growth both in the proportion of patents accounted for by principals and officers in firms and in the tendency of such individuals to assign their patents to their companies. The share of patents awarded to principals and officers rose steadily from 37.2

19. Comparison of the patenting and assignment data for individuals from the *B* sample whom we could locate in city directories with similar information for individuals whom we could not suggests that such a bias is probably present.

20. Because there is a significant group of patent assignments for which we were unable to determine the association (or lack thereof) between the patentee and the assignee, the actual figures for assignments by employees to employers were likely somewhat higher. However, the qualitative result that patentees assigning to their employers did not account for a large share of the assignments of patented technologies seems firm. The bias owing to measurement error would almost certainly be offset by that attributable to our relying here on assignments at issue.

Table 1.7 **Occupations of Patentees and Relationships to Assignees as Indicated by City Directories**

		Before 1890	1890–1910	After 1910	All Years
Occupations					
Principals and officers of firms	% of patentees	20.6	33.9	40.4	30.8
	% of patents	37.2	46.5	60.5	49.0
Employees	% of patentees	20.6	36.9	19.2	28.0
	% of patents	18.1	25.9	17.3	20.7
Unknown or independent	% of patentees	58.8	29.2	40.4	43.2
	% of patents	44.7	27.6	22.2	30.3
Total	No. of patentees	68	65	52	185
	No. of patents	454	641	603	1,698
Relationship between patentee and assignee					
No assignment	% of patentees	77.9	53.9	51.9	62.2
	% of patents	75.1	49.0	29.7	49.1
Patentee to employer	% of patentees	1.5	6.2	5.8	4.3
	% of patents	2.0	8.9	6.6	6.2
Patentee is principal or officer in assignee firm	% of patentees	2.9	9.2	13.5	8.1
	% of patents	4.6	19.2	37.0	21.6
Patentee and assignee are related by name	% of patentees	0.0	4.6	0.0	1.6
	% of patents	1.3	1.4	0.5	1.1
Unknown relation	% of patentees	5.9	10.8	23.1	12.4
	% of patents	7.5	7.2	21.1	12.2
Patentee has no relation to assignee	% of patentees	11.8	15.4	5.8	11.4
	% of patents	9.5	14.4	5.1	9.8

Notes: The data on which this table is based were constructed by searching the available city directories for information on the occupation and place of work of the patentees in our *B* sample (described in the note to table 1.3). This search was conducted on an earlier, incomplete version of the sample, which did not include all of the career patents issued to each of the 561 patentees. The effort yielded information on 185 patentees, who were responsible for 1,698 patents according to our partial listing. The information retrieved from the city directories was then used to classify each of the patentees we found, at the time of each of his patents in our partial sample, by occupation and by relationship to the assignee of the patent (if the patent was assigned at issue). Three occupational classes were defined. A patentee was classified as a "principal" if listed in the respective directory as an officer of a firm (president, vice president, treasurer, secretary, or general manager), or with an occupation that seemed to indicate proprietorship (for example, manufacturer or inventor). A patentee was classified as an "employee" if listed in the respective directory with an occupation that suggested a subordinate position in a firm (for example, manager, superintendent, salesman, clerk, chief engineer, or foreman). A patentee was classified in the "independent" or "unknown" category if it was unclear from the occupation whether the individual was a principal or employee (for example, agent, engineer, machinist, brewer, chemist, or printer), and if no firm was listed as a place of work. As for the classification of the relationship between the patentee and the assignee, six categories were defined, the first being those cases where the patent was not assigned at issue. An assignment was classified as being from a patentee to an employer if the patentee was an employee and the assignee had the same or a similar name as the firm listed as the place of work. A patent assignment was classified as from a principal to his firm if the patentee was a principal in the firm to which the patent was assigned. An assignment was classified as one that involved no relationship between the patentee and the assignee if a place of work was listed that was different from the name of the assignee, or if the assignee was an individual with a different surname. An assignment was classified as a case of a patentee assigning to a family member if the patentee and the assignee had the same surname. The classification "unknown relation" was used when there was no report of a place of work and the patentee was classified in the unknown or independent category. It was also used in miscellaneous cases where it was unclear whether the patentee and assignee had a formal relationship.

percent in the years before 1890 to 60.5 percent after 1910, and the fraction of patents that were assigned to a firm in which the patentee was a principal or officer increased from 4.6 percent before 1890 to 37 percent (more than half of all assignments at issue) after 1910. The increased prominence in the subsample of patentees who were principals and officers of firms was to some degree paralleled by a decrease in the proportion of patentees who were independent inventors. The difficulty of establishing that a patentee was an independent inventor means that there is greater uncertainty about trends in this category of patentees, but we know that the share of patents granted to patentees of independent or unknown status declined from 44.7 percent before 1890 to 22.2 percent after 1910. One possible explanation for these parallel patterns may have been an increase in the propensity of independent inventors to incorporate their enterprises (perhaps as an aid in raising capital). If this was indeed the case, then part of the growth in the proportion of patents issued to principals and officers of firms (as well as in the proportion of assignments at issue that went from such individuals to their companies) may have owed to a change in industrial organization rather than to a decrease in the extent of arm's-length transactions.[21]

We continue to explore changes over time in the pattern of assignments with the help of table 1.8, which reports the same distributions of patents and patentees as table 1.7, but now broken down first by categories of association and then by occupational class and time period. As is apparent from the lower percentages of patents not assigned in the distribution of patents compared to that of patentees, inventors who assigned their patents at issue received more patents on average than those who did not, across all occupational classes and time periods. Although the difference is not very large in the independent or unknown class during the two earlier subperiods, the result suggests that the higher productivity of patentees who assigned their patents at issue is not an artifact generated by a particular occupational group or type of patentee/assignee relationship. The secular trend toward higher rates of assignment at issue was likewise not specific to a single occupational class; nor did it result from a change in the occupational composition of patentees.

The advantage of the distributions presented in table 1.8 is that they allow us to explore trends in assignment behavior within each occupational class. Once again, the most important changes were the growing share of patents awarded to patentees who were principals or officers in firms and the increasing propensity of patentees in this group to assign to the companies with which they were associated. Although the employee category was the occupational

21. Two developments were probably at work here. The first was a general shift in the preferred form of organization for small firms away from proprietorships and partnerships to corporations. The second was a concomitant shift in the propensity to assign patent rights to the firm. The peculiarities of partnership law and the short time horizon of most firms that were organized as partnerships may have discouraged inventors from assigning their patents to their companies. Corporations, on the other hand, may have found it difficult to raise share capital unless the firm acquired title to its principals' important patents.

Table 1.8 **Distribution of Patents and Patentees by Occupational Class and Relationship to Assignee, Based on Information from City Directories**

		Before 1890			1890–1910			After 1910			All Years		
		Principal or Officer	Employee	Unknown or Independent	Principal or Officer	Employee	Unknown or Independent	Principal or Officer	Employee	Unknown or Independent	Principal or Officer	Employee	Unknown or Independent
No assignment	% patentees	85.7	78.6	75.0	50.0	50.0	63.2	61.9	30.0	52.4	63.2	54.2	66.3
	% patents	78.7	64.6	76.4	46.1	40.4	61.6	33.1	14.4	31.3	47.2	38.4	59.5
Patentee to employer	% patentees	—	7.1	—	—	16.7	—	—	30.0	—	—	16.7	—
	% patents	—	11.0	—	—	33.7	—	—	38.5	—	—	29.8	—
Patentee a principal or officer in assignee	% patentees	14.3	—	—	27.3	—	—	33.3	—	—	26.3	—	—
	% patents	12.4	—	—	41.3	—	—	61.1	—	—	44.1	—	—
Patentee and assignee related by name	% patentees	—	—	—	9.1	—	5.3	—	—	—	3.5	—	1.3
	% patents	0.6	3.7	1.0	2.0	—	1.7	0.8	—	—	1.2	0.9	1.0
Unknown relation	% patentees	—	7.1	7.5	—	12.5	21.1	—	30.0	42.9	—	14.6	20.0
	% patents	—	11.0	12.3	2.7	11.5	10.7	0.3	39.4	63.4	1.1	19.6	25.1
Patentee no relation to assignee	% patentees	—	7.1	17.5	13.6	20.8	10.5	4.8	10.0	4.8	7.0	14.6	12.5
	% patents	8.3	9.8	10.3	7.4	14.5	26.0	4.4	7.7	5.2	6.3	11.4	14.4

Note: See table 1.7.

class with the highest rates of assignment at issue, the estimates in table 1.8 provide further support for the idea that the transfer of patent rights by this group of patentees to their employers was not the major force behind the rise in assignment rates. Not only was the proportion of patents registered to employees relatively constant over time at a modest level, but when employees sold their patents, they appear to have been more inclined than principals and officers to assign to parties with whom they had no formal association. This inclination decreased over time. By our estimates, half or more of the patents (depending on the weighting scheme) assigned by employee patentees before 1890 went to parties other than the employer, with this percentage dropping into the 15 to 20 percent range after 1910. Nevertheless, given that the share of patentees we can identify as employees had by then shrunk below 20 percent, and that employee inventors still had relatively low rates of assignment to parties with whom they had formal associations, it is clear that the behavior of this group was not accounting for the aggregate patterns.

The evidence we obtained by tracing patentees through city directories thus leads to several generalizations about the evolution of patent assignments in the late nineteenth and early twentieth centuries. First, assignments were extensive and growing in overall volume and, at least until late in the nineteenth century, seem to have most often involved arm's-length transactions. Second, all groups of patentees increased the proportion of patents they assigned over time and exhibited an empirical association at the individual level between rates of assignment and productivity at patenting. Third, a major change in the patterns of assignment began to be apparent between 1890 and 1910, and was even more pronounced afterward. Patentees who were principals and officers or employees became more inclined to assign their patents to the firms with which they were associated, and the relative share of principals and officers among the population of patentees grew substantially. Moreover, inventors who were principals or officers in the firms to which they assigned were the most prolific patentees of any group.[22] Whether they were like the classic inventors who commercially exploited their inventions themselves (through firms that integrated invention with development and other general business activities) or whether they had organized firms that were specialized at generating new technologies remains unclear. Further research is required to determine whether this structural break reflects a renewed emphasis on integrating invention with other business activities or an extension to the level of firms of the trend toward division of labor between those concerned with invention and those concerned with commercial exploitation.[23]

22. Here again we should remind the reader that the greater difficulty of locating mobile individuals in city directories may have resulted in an overrepresentation of patentees who had stable long-term relationships with firms. However, the problem should have affected our proportions of employees as well as of principals and officers in firms.

23. It should be noted that Thomas P. Hughes (1989) has argued that this period was the golden age of the independent inventor. Our work could be interpreted as providing a quantitative basis for his assertion.

Table 1.9 **Distribution of Assigned Patents by the Number of Assignments Received by the Assignee in the Year**

	1 Assignment	2–3 Assignments	4–5 Assignments	6–10 Assignments	>10 Assignments
1870	63.4%	19.9%	5.4%	2.6%	8.7%
	(795)	(250)	(68)	(32)	(109)
1891	54.8%	23.5%	8.1%	8.3%	5.3%
	(2,097)	(898)	(310)	(316)	(203)
1911	41.5%	19.0%	7.3%	6.5%	25.7%
	(2,536)	(1,160)	(446)	(396)	(1,572)

Sources: These estimates of the distribution of assigned patents were calculated from a data set constructed by collecting the number of assignments received by the assignee in the respective year for all patent assignments appearing on every other page of the *Annual Report of the Commissioner of Patents* for 1870, 1891, and 1911 (assignees, like patentees, were listed in alphabetical order).

Notes: Because we ran over to the off pages in order to get a complete accounting of all the patent assignments received by the assignees sampled, our procedure is likely to overstate the concentration of patent assignments across assignees. Numbers of observations are in parentheses.

Finally, the results of our analysis of this urban subset of patentees is consistent with the notion that trade in the rights to patented technologies involved broad segments of the industrial sector and that the growing proportion of patents that were assigned to companies did not simply result from employees in the R&D departments of large firms transferring their inventions to their companies. Further evidence for this view is provided by table 1.9, which reports evidence on the frequency distribution of assignments among samples of assignees drawn from the *Annual Report of the Commissioner of Patents* for the years 1870, 1891, and 1911. These results, which were calculated in such a way as to provide upwardly biased estimates of the degree of concentration, suggest that the assignment of patents was extremely unconcentrated during the first two of these years, though much less so by the third. Over 60 percent of patent assignments in 1870 went to assignees who received only one assignment in that year, and more than 80 percent went to those with three or less.[24] In 1891 the proportion of those with three or less assignments was still nearly 80 percent. By 1911, however, the figure had dropped close to 60 percent, and there is evidence of a substantial shift toward greater concentration. In particular, the increase in the proportion of assignments to firms with more than ten assignments from under 10 percent in 1870 and 1891 to over 25 percent in 1911 (when General Electric alone received over 300 patent assignments) is an indication that the character and organization of trade in patented technologies had begun to change during the intervening years.

24. In 1870, the fraction that went to assignees that received more than ten assignments was 8.7 percent, a rather modest proportion but one that would have been even lower (below 3 percent) if it had not been for one outlier, the Erwin Russell Manufacturing Company in Middlesex County, Massachusetts. This company, which produced doors, door knobs, and related products, had nearly thirty patents (over half of which were design patents) assigned to it in 1870 by a single patentee.

1.4 Firms and the Market for Technology

We can get a better idea of what was accounting for this shift by looking at the behavior of the firms themselves. The case of the American Bell Telephone Company, one of the "high-tech" enterprises of the period, offers an instructive example. Bell's patent department issued annual reports detailing the number of patents it evaluated from both inside and outside sources. For example, in 1894, it investigated seventy-three patents submitted "by the public" and twelve brought to its attention by employees.[25] The company filed patent applications for virtually all of its employees' inventions—not apparently because the patent department found the ideas particularly valuable, but for morale reasons and because the cost of obtaining patents in this way was low (typically the company paid bonuses of $50 to employees whose inventions it patented).[26] The asking price for outside inventions was often thousands of dollars, and the department recommended against purchasing almost all of them. Consequently, if one were to divide the company's patents into two categories—those purchased from outsiders and those that originated within the firm—the latter would be numerically preponderant. Nonetheless, it is clear that, during this early period, it was on the assessment of outside inventions that the department spent most of its energies and resources. Company records contain numerous reports evaluating the novelty and importance of inventions offered by the public for sale. These reports were by no means pro forma; rather they included a great deal of technical detail that was specific to the invention at hand. Moreover, the company seems to have devoted the same painstaking attention to the messy, handwritten submissions of unknown inventors as it did to the more polished presentations of high-priced patent solicitors.[27] It seems, in other words, that the company was determined not to overlook any possible source of technological advantage that might be obtained by purchasing the patents of independent inventors, even though it found most of the inventions it reviewed not worth pursuing.

Indeed, documents extant in the company's records suggest that American Bell attached much greater importance in its early years to assessing inventions that originated in the external environment than it did to promoting inventive

25. It also investigated twenty-six inventions originating with employees of the local phone companies to which American Bell licensed its technology (Annual Report of the Patent Department, 1894, 7, American Bell Telephone Co., box 1302, AT&T Corporate Archives).

26. As the director of the patent department, T. D. Lockwood, wrote in his 1894 annual report (1–2), "So far as concerns the devices gotten up by our own employees . . . , the practice of the year has been, in a general way, to file an application for patent on nearly every device presented for consideration; . . . and to keep all questions of merit, and the presence, or extent of invention, largely in the background." See also Lockwood's "Statements of Objectives and Practices of AT&T Patent Department, 1877–1937," extracted in "Memorandum for Messrs. Root, Ballantine, Harlan, Bushby & Palmer," 22 November 1949, 15, Divestiture Collection, location 451 01 01, folder 17, AT&T Corporate Archives.

27. See T. D. Lockwood, Reports of Inventions (Not Approved), 1904–8. These evaluations became especially important after 1894, when the patents that had given American Bell an effective monopoly of the telephone business expired (Galambos 1992, 99).

activity within the firm. The architect of this policy was T. D. Lockwood, longtime head of the company's patent department and a vigorous opponent of what we would now call investment in R&D. As Lockwood wrote in an 1885 letter to the company's general manager, "I am fully convinced that it has never, is not now, and never will pay commercially, to keep an establishment of professional inventors, or of men whose chief business it is to invent; or a corps of electricians who are assumed or expected as a part of their duty, to invent new and valuable telephones or telephonic appliances, in their employ."[28] Lockwood's vision, as embodied in his summary later that same year of the duties of the patent department (and in the department's actual practice), placed emphasis first and foremost on examining "patents or inventions submitted by the public for consideration" and second on examining "descriptions of inventions forwarded by the company's employees." Only at the end of the report, seventh in a list of miscellaneous duties appended after a lengthy discussion of the department's library, did he include the responsibility for suggesting "special and suitable lines of experimentation" within the firm. Much more important in his mind was the duty to "receive copies of electrical patents from Patent Office . . . , bringing to the attention of the company, such as may commend themselves for novel or striking features," "to constantly acquire information upon all classes of electrical patents," and to maintain a well-stocked library. In other words, Lockwood was mainly concerned with building American Bell's capacity to learn about and assess the merits of inventions generated elsewhere in the economy. The central mission of the company's patent department, as he saw it, was to collect information from a wide variety of sources so as to maintain familiarity with (and be in a better position to evaluate) technological developments occurring throughout the economy. Not until Theodore N. Vail became president in 1907 would the company shift resources to internal R&D.[29]

Bell's policy, as articulated by Lockwood, was extreme, but George Wise

28. The text of the letter is included in an 11 September 1952 memo by Lloyd Espenschied, "Early Company Inventing—A Revealing Letter," Western Electric Collection, location 91 05 140, folder 6, AT&T Corporate Archives. Lockwood was not completely consistent, however. He brought Stephen D. Field into his department in 1897 after the company bought some of Field's patents: "I engaged his services in 1897 or thereabouts, to make other inventions of the same kind. . . . Prior to that time he had been for a long time a sort of guerilla inventor on his own hook" (Testimony of Lockwood in *Read v. Central Union Telephone Company*, abstracted in "Memorandum for Messrs. Root, Ballantine, Harlan, Bushby & Palmer," 68).

29. T. D. Lockwood, "Duties of Patent Department," 23 November 1885, AT&T Collection, box 1302, AT&T Corporate Archives. Lockwood's sense of his own duties was confirmed by Vail in testimony given in 1908: "Mr. Lockwood's duties were, first to examine every patent that was issued—I mean connected with the telephone or electricity—to see whether it had any bearing on our business, and if so we tried to get some rights under it and possession of it. Next he was to examine all the devices in the carrying on of the business. . . . Of course new devices in the new business were all the time occurring to the people. Those were submitted to us from our licensees, and Mr. Lockwood would examine them as to the patentability and as to the value, and whether they had been gone over before, and all that sort of thing" (extracted in "Memorandum for Messrs. Root, Ballantine, Harlan, Bushby & Palmer," 30). On Vail's own support for internal R&D, see Galambos (1992).

has argued that Westinghouse and Edison Electric/General Electric (two other high-tech firms of the period) followed a similar strategy in the late nineteenth century of "purchas[ing] patents and short-term consulting services from independent inventors" rather than developing their own R&D facilities (Wise 1985, 69–70). We have found much the same story for firms that used older mechanical technologies as well. For example, Channing Whitaker built up the patent department and library at the Lowell Machine Shop, arguing that it was essential to keep track of patents issued to outside inventors so that the company did not waste resources reinventing what had already been developed elsewhere. He also argued that the purchase of outside patents should be considered "not a net expense, but a net saving" because it enabled managers to solve technical problems more cheaply than they could if they relied exclusively on internal resources.[30] Two decades into the twentieth century, the giant Standard Oil of New Jersey was still struggling to build up this kind of general tracking capacity. As George S. Gibb and Evelyn H. Knowlton argued in their study, *The Resurgent Years, 1911–1927*, the company had long shown little interest in promoting R&D internally and had been lax as well in building the capacity to assess and gain control of technological ideas originating in the external environment. In 1918, E. M. Clark, the new general manager of the company's Bayway refinery, began a campaign to improve the company's knowledge of outside technologies. His first step was to arrange for its patent work to be shifted to the Chicago firm of Dyrenforth, Lee, Chritton and Wiles, patent solicitors, a firm that had a great deal of expertise in petroleum-refining technology.[31] He then, in consultation with Frank A. Howard, a member of this firm, planned and promoted the creation within Standard of a development department whose purpose was to collect information about and assess new technologies originating outside the firm. According to Gibb and Knowlton, the new department was founded on the principle that "new ideas and inven-

30. "How the Patent Library Came into Existence," box 1, file 8; "The Value of a Patent Department to a Manufacturing Concern," box 2, file 17; both in Channing Whitaker Papers, Lambert Collection, Center for Lowell History.

31. It was common for firms without their own capabilities for assessing externally generated technology to achieve the same ends in a vertically disintegrated way by establishing a long-term relationship with a firm of patent solicitors. The Waltham Watch Company, for example, had such a relationship with the firm of Wright, Brown, Quinby and May. The solicitors' detailed, highly technical reports assessing the patentability of inventions (generated both inside and outside the company) are evidence that they were providing technological as well as legal services. In addition, the firm performed a variety of other functions for its manufacturer client: it brought new inventions to the attention of the company, compiled lists of all patents in force on particular subjects, searched out inventors in other parts of the country, and negotiated assignments with inventors both inside and outside the company. See, for example, Arthur H. Brown's 27 July 1912 report on the patentability of an instrument invented by George H. Lang and manufactured by the Stover and Lang Speedometer Company. See also the 3 March, 30 March, and 6 May 1905 letters from Wright, Brown, Quinby and May to the American Waltham Watch Company, and the 31 March 1913 letter from Olaf Ohlson, the 16 November 1914 letter from George T. May, Jr., and the 25 January 1915 letter from the Waltham Watch Company to the solicitors (Wright, Brown, Quinby & May Correspondence Files, Waltham Watch Company, 1854–1929, case 2).

tions . . . would arise in the main from external sources, and that [its] primary job . . . would be to uncover these ideas, test them out, and carry them forward to some practical end. . . . [T]he new plan was not aimed at fostering creative research." What Standard did, in essence, when it created this department was to internalize the services of its patent solicitors (Howard himself was brought in as manager) so as to acquire capabilities (similar to those developed much earlier at American Bell) for keeping abreast of outside inventions. Only in the next decade would Standard make a serious effort to promote internal R&D (Gibb and Knowlton 1956, 113–14, 122–23, 522–25).[32] Nor was Standard particularly slow in moving to this next level. Although a small number of large firms—Du Pont is the prime example—built in-house R&D facilities before World War I, Standard's experience was more typical.[33]

1.5 Inventors within Firms

The extensive efforts made by firms, including those in high-tech industries, to gain information about and evaluate inventions originating outside their bounds are strong evidence against the notion that information problems made it difficult to contract for technology at arm's length. As we shall see, the evidence suggests to the contrary that contracting problems were if anything worse within the firm than without during this period of time. Indeed, it took many firms quite a long while to work out employment relationships that enabled them to gain title to inventions developed in their shops and labs. Here, however, American Bell was an exception on the progressive side. As early as the 1880s, Bell required its employees to sign contracts giving it first right of refusal on their inventions. Such contracts were relatively rare until the period following World War I, and we have found only a few examples from the last two decades of the nineteenth century. William R. Baker, a foreman at McCormick Harvester, had this type of employment contract in the 1880s; so, in the 1890s, did William T. Smith, a foreman at William Knabe and Company's piano works.[34] According to testimony by Lockwood in 1916, even within the

32. We are indebted to David Mowery for suggesting this reference. Despite Mowery's emphasis on the difficulties of contracting for technology in the market, he recognized that one of the most important functions of early R&D facilities was to assess externally generated inventions (Mowery 1995).

33. For an overview of the development of industrial research in the United States, see Mowery and Rosenberg (1989, 35–97). On Du Pont, see Hounshell and Smith (1988).

34. "Record of William R. Baker," 10, *Baker v. Miller,* case 9,957, box 1,402, Interference Case Files, 1836–1905; "Record in Behalf of William T. Smith," 20, *Smith v. Perry v. Keidel,* case 16,028, box 2,212, Interference Case Files, 1836–1905. The earliest example we have been able to find of such an employment agreement was the hiring of mechanic Allan Pollock by the Boston Manufacturing Company in 1820. However, the preoccupation of Channing Whitaker (head of the patent office at the Lowell Machine Shop during the late nineteenth and early twentieth centuries) with the problem of obtaining title to employees' patents suggests that the Boston Associates did not continue to insist upon this condition of employment. See Gregory (1975, 156–57) and Whitaker's notes on court cases involving employee patent rights in box 7, file 4, Channing Whitaker Papers.

telephone industry the practice was limited to a few firms: the New England, Chicago, and Central Union telephone companies, in addition to American Bell. New York Telephone did not have such an arrangement with its employees, and as a result, American Bell was able to purchase an invention patented by one of its men.[35]

Some employment contracts explicitly mentioned patents, but gave the employing firms the right only to use—not own—inventions devised by their employees. For example, inventors in the employ of the Waltham Watch Company typically agreed only to grant the company an exclusive right to the use of their patents during the term of their employment. When the company was reorganized in 1907, it tried without much success to acquire property rights to the patents it was using, but could do little more than ask its solicitors to write polite notes inquiring whether the inventors would now be willing to make assignments.[36] At least some key employees flatly refused to assign their patents to the watch company. For example, the firm's general superintendent responded that "he has an agreement with the Company, providing for the use of his inventions, but that he does not expect to make formal assignments relating to them."[37]

Inventors at many other firms had no contractual obligations whatsoever to provide their technology to their employers and, indeed, felt little compunction about exploiting their inventions themselves, even if they came up with the ideas while working in their employers' shops. August Markert, who worked as a carpenter for A. P. Lorillard and Company (a tobacco manufacturer),

35. Testimony of T. D. Lockwood in *Read v. Central Union Telephone Company,* abstracted in "Memorandum for Messrs. Root, Ballantine, Harlan, Bushby & Palmer," 69, 71. Even American Bell was willing to acquiesce in the entrepreneurial independence of some of its employees. As late as the 1930s, for example, AT&T (American Bell's successor) negotiated special agreements with employees who preferred "to retain the license [themselves], especially for operating in further than the telephone field" and with employees who claim their "rights are so valuable that they should be paid more than a mere bonus." Similarly, at least in the early years the university scientists it kept on retainer were not required to give the company "first call" on their inventions (testimony of G. E. Folk, General Patent Attorney, before the FCC, abstracted in the "Memorandum," 125–26; testimony of T. D. Lockwood in *Read v. Central Union Telephone Company,* abstracted in the "Memorandum," 68).

36. Wright, Brown, Quinby & May to Ezra C. Fitch, 29 January 1907, Wright, Brown, Quinby & May Correspondence Files, Waltham Watch Company, 1854–1929, case 2. See also the letter from the same parties to Edward A. March, 23 January 1907.

37. Wright, Brown, Quinby & May to Matthews, Thompson & Spring, 28 February 1907, Wright, Brown, Quinby & May Correspondence Files, Waltham Watch Company, 1854–1929, case 2. Apparently, some of the Waltham Watch Company's contracts required employees to assign their patents to the firm, but these agreements do not seem to have been well enforced. So much is clear from a 1906 letter written by patent solicitors for the Waltham Watch Company to the widow of one of the firm's employees: "You are doubtless aware that under an agreement entered into between your late husband and the American Waltham Watch Company, several patents now standing in his name are to be assigned to the Company, the agreement providing that all his inventions made during a period which has not yet expired, relating in any way to Watches or to the Manufacture of Watches, shall be assigned to the Company. A large number of the patents have already been assigned; but those that have been granted since 1896 have not yet been assigned" (Wright, Brown, Quinby & May to Mrs. Duane H. Church, 24 January 1906).

reasoned that the company had a right to his inventions when its managers instructed him to work on a particular problem and told him how to go about it, but that things were different "when I got it out of my own head." Markert claimed that he had invented a device for tagging plug tobacco. When the foreman to whom he showed the machine attempted to take credit for the invention and applied for a patent for the benefit of the company, Markert filed his own application, triggering interference proceedings by the Patent Office.[38] Another inventor, M. V. Smith, testified in an interference suit that he came up with an idea for a new furnace while working as superintendent for the National Rolling Mill Company in McKeesport, Pennsylvania: "I regarded it to my best interest to keep the employees of the National Tube Works as much as possible from knowing anything about my improvement on that furnace, and resigned my position with said company, as superintendent, before I ordered the Patent Office drawings made."[39] Two employees of the American Sheet and Tin Plate Company invented a catcher for tinning machines, building the device on company time with company resources and testing it in the company's Gas City, Indiana, plant. When the machine proved promising, they quit their jobs, reasoning that "if we ever got together again in an independent plant we would have a better opportunity of obtaining suitable remuneration for the patent." The two men subsequently accepted employment with the Carnahan Tin Plate and Sheet Company, one of American's competitors. The Carnahan company promised to bear the expense of patenting the machine in exchange for a license to use it, with the inventors retaining ownership of the patent.[40] Even high-tech firms of the period experienced similar problems. Westinghouse, for example, hired William Stanley to develop a transformer, only to have him claim that a new type of lighting he invented while working on the project was his sole property. Similarly, the manager of the Edison Machine Works in

38. "Testimony on Behalf of Markert," 10, 12, *Hieatt and Hearn v. Markert,* case 8,290, box 2,854, Interference Case Files, 1836–1905. In an interference procceding, thc Patent Office held a hearing to determine which of the conflicting patentees was the first and true inventor and should be awarded the patent. The Patent Office's interference files contain numcrous cases where applications for letters patent were filed both by an employee and his employer, with the former challenging the latter's claim to an invention developcd while hc worked for the firm. For example, S. T. Schofield contested with H. C. Cragg over which of the two men actually invented a screw feed mechanism developed while he was in the employ of the H. C. Cragg Manufacturing Company. Elmer A. Sperry found himself tied up in an interference proceeding with a draftsman he had formerly employed in his factory, and Charles A. Lindstrom had a similar experience with a draftsman he hired. See "Testimony on Behalf of S. T. Schofield," *Cragg v. Schofield,* case 25,592, PF box 3,319, ROPO Interference Case Files, 1900–1925 (the ROPO Interference Case Files are still under the control of the Patent Office but are stored at the National Archives and Record Center); "Sperry's Record," 41–42, *Sperry v. Eickemeyer v. Morgan,* case 16,498, box 2,269–72, and "Testimony on Behalf of Lindstrom," *Lindstrom v. Larson,* case 20,284/20,293, box 2,744, both in Interference Case Files, 1836–1905.

39. "Testimony in Chief of M. V. Smith in the Matter of the Interference of John Pedder vs. Martin V. Smith," 25–26, *Pedder v. Smith,* case 9,448, box 3,077, Interference Case Files, 1836–1905.

40. "Lewis & Williams Record," 4–8, *Lewis and Williams v. Cronemeyer,* case 24,270, PF box 3,133, ROPO Interference Case Files, 1900–1925.

Schenectady, New York, complained to the company's lawyers in 1890 that employees were obtaining patents but refusing to assign them to the firm.[41]

It is important to note that firms' lax policies with respect to their employees' inventions cannot simply be explained as a function of their belief that they owned title to the patents as a matter of common sense or common law. Inventors hotly contested firms' assertions that they deserved such ownership rights, and the courts typically backed inventors over their employers. Indeed, by the turn of the century, it was well established that the mere fact of an employment relationship did not entitle a firm to an employee's inventions, even if the invention was developed at company expense. If the inventor was hired for the specific purpose of building a particular machine or improving a particular product, then the employer had a right to the invention (the reason being that the employee had "only produced that which he was employed to invent. His invention [was] the precise subject of the contract of employment"). More generally, however, the courts refused to hold that a contract of employment, "albeit [one that] covers a field of labor and effort in the performance of which the employee conceived the invention," entitled the firm to an assignment of the patent.[42] This latter rule applied even to cases where a firm had employed someone with technical skills "to take charge of its works, and to devote his time and services to devising and making improvements in articles there manufactured." As the majority of the Supreme Court decided in the 1893 case *Allen C. Dalzell et al. v. Dueber Watch Case Manufacturing Company*, "in the absence of an express agreement" by which the employee promised to assign all his patents to the firm, the company could not claim ownership of the patents.[43] In other words, by their very laxness in not requiring or enforcing such "express agreements," firms jeopardized their rights to inventions developed in their shops.

Firms, however, might still obtain a use right, or shop right, to these inventions. As a principle of equity, the courts often granted firms a nonexclusive,

41. These last two examples are from Wise (1985, 70–72). By 1900, General Electric required its employees to sign contracts promising to assign their inventions to the company. In the only attempt at explaining this phenomenon that we have found in the literature, Wise argues that such contracts were a "social invention" made possible by the growth of large, centrally controlled firms. According to Wise, smaller firms "lacked the legal skills to write such a contract. And even if they hired lawyers to do the writing, enforcing the contract might require too much of the time of the owner and his few assistants." Although it is undoubtedly the case that the cost of such contractual arrangements fell over time as both firms and employees gained experience with them, it is unlikely that, even early on, these kinds of expenses were as prohibitive as Wise suggests. As we saw above, moreover, small firms were among those pioneering in the use of such contracts.

42. *United States of America v. Dubilier Condenser Corporation, United States Supreme Court Reports*, 77 *Lawyers' Edition* 1114. This 1933 case contains an excellent summary of the case law. See also 16 *American Law Reports, Annotated* (hereafter *ALR*) 1177; 32 *ALR* 1037; 44 *ALR* 593; 85 *ALR* 1512; 153 *ALR* 983; 61 *ALR* 2d 356; Prindle (1908, 84–102); Fisk (1997). Employees could not, however, claim ownership of inventions for which they had merely made suggestions that did not amount "to a new method or arrangement which in itself is a complete invention" (Johnson 1913, 189).

43. *United States Supreme Court Reports*, 37 *Lawyers' Edition* 749.

nontransferable license to use, without payment of royalty, inventions developed by their employees on company time with company resources.[44] Even here, however, the courts found it easier to enforce the principle in the presence of an express agreement with the employee, a circumstance that inspired at least one firm (the Pullman Company) to rethink its employment contracts. After learning about one such case in the fall of 1912, executives of the company began to worry that inventions developed by employees were being patented on the outside and that rights to these devices were being assigned or licensed to the firm's competitors. The executives commenced an investigation into the extent of the problem and, at the same time, began to formulate a policy about inventions patented by employees. Interestingly, in the earliest drafts of the policy, the company claimed no ownership rights to its employees' inventions, seeking only to insure its legal "license to use devices on our own cars without royalty." In these early drafts, the company even planned to pay employee inventors half of any royalties it collected on cars constructed for outside companies and acknowledged that "other outside arrangements" could "be made direct by the inventor."[45] Only after several months and several drafts had gone by did the company decide on a policy to require employees to "give the Company preference in disposing of the title to such invention and the patent therefor, in addition to the shop-right which the law implies." In exchange, the company offered to pay a bonus of $250 for any invention which it decided should be patented.[46] There is no evidence that the articulation of this policy was accompanied by any new R&D initiatives; it was simply an attempt to insure the company control of inventions produced by its employees. The final draft differed from the initial versions mainly in the company's decision to claim full property rights to employees' inventions and thus deny competitors' access to this technology.[47]

The Pullman Company's attempt to gain control of the inventions of its employees was part of a more general move to improve its ability to assess the value of new technologies. The centerpiece of this policy was the creation of a new Committee on Standards in 1912. The committee consisted of senior managers with considerable technical expertise, and was charged with evaluating

44. Key cases included the 1886 *Charles H. Hapgood et al. v. Horace L. Hewitt, United States Supreme Court Reports,* 30 *Lawyers' Edition* 369, and the 1896 *Jabez H. Gill v. United States,* 40 *Lawyers' Edition* 480. For a summary of the case law, see *United States of America v. Dubilier Condenser Corporation;* 61 *ALR* 2d 356.

45. See the minutes of the 22 October 1912 and 7 January 1913 meetings of the Committee on Standards, Operating Department, Chief Engineer, Equipment Standards and Testing Records, 1889–1956, box 2, folder 4, Pullman Company Archives, Newberry Library.

46. "Policy and Procedure in Patent Matters," 21 November 1913, Secretary & Treasurer, Office of the Secretary & Treasurer, box 1, folder 2, Pullman Company Archives.

47. The new policy was articulated in part as an effort to encourage improvements by employees, but this language was mainly an attempt to make more palatable what was really a radical and unilateral change in the nature of the employment contract. The circumstances under which the policy was formulated—and the bulk of the document's provisions—make it clear that the purpose of the policy was to impose restrictions on employees' behavior.

the inventions of employees and deciding which ones were worth attempting to patent. The committee was further charged with responsibility for deciding which outside patents the company should purchase: "no letter recommending a particular invention should be written by an official in this Company without the approval of the Committee on Standards."[48] The committee had additional duties (for example, testing the properties of inputs into the firm's production process and setting and enforcing quality standards for its products) but in other respects functioned much like the patent department that AT&T had set up earlier. It was part of the process by which the firm learned to improve its ability to tap new technologies, whether they were generated inside the enterprise or out.

Although the evidence suggests that employment contracts giving a company ownership of its employees' inventions were not yet routine during the first two decades of the twentieth century, by the 1930s such agreements appear to have been commonplace. The Committee on Patents of the U.S. House of Representatives held hearings in 1936 about proposed revisions to the patent law. As part of its investigation, the committee sent inquiries to a number of companies that included a question about employees' contractual obligation to assign inventions to the firm. Fourteen of the responses (ranging from giant enterprises such as Standard Oil and International Harvester to a number of small aviation companies) were reprinted as appendixes to the hearings. In almost all cases the firms reported that the great majority of the patents they owned originated with their own employees who had contractual obligations to assign their inventions to the company. There thus seems to have been a pronounced shift toward reliance on internally generated technologies in the period after the First World War.[49]

1.6 Learning by Firms

The sources of this shift are complex and involve developments, such as the growth of oligopolistic competition, that are beyond the bounds of our research. But the change can also to some extent be understood as the outcome of the processes we have been describing. In the first place, as firms tightened up their internal affairs, they were in a better position to exploit the inventive talent already present in their organizations. In the second, the capabilities they had built up to assess externally generated inventions could also be put to other uses within the firm—could be employed, for example, to pinpoint fruitful

48. Policy and Procedure in Patent Matters, 8.

49. U.S. Congress, House, *Hearings before the Committee on Patents . . . on H.R. 4523, a Bill Providing for the Recording of Patent Pooling Agreements and Contracts with the Commissioner of Patents* (Washington, DC: Government Printing Office, 1936), parts 2–4. The firms reporting were Beech-Nut Packing, Curtis Aeroplane and Motor, Douglas Aircraft, Great Lakes Aircraft, Hercules Powder, Ingersoll Rand, International Business Machines, International Harvester, North American Aviation, Socony-Vacuum Oil, Standard Oil, Sun Oil Company, Western Union, and Wright Aeronautical Corporation.

areas of research in which the company might itself engage. Moreover, firms that invested in such expertise had to invest as well in facilities to develop and commercialize the inventions they purchased, facilities that could be turned to the development of internally generated inventions and then expanded into departments devoted more broadly to R&D. Indeed, this was the sequence of events that occurred at Standard Oil.

Perhaps more important, as the complexity of technology increased by the end of the nineteenth and especially by the early twentieth century, it became more and more difficult for inventors to maintain their independence. Even though the growth of the market for technology had made it easier for patentees to sell off their property rights at an early date and to form corporations to exploit their inventions, they still faced a great deal of financial uncertainty—especially in those sectors of the economy where the costs of invention, in terms of both human and physical capital, were likely to be greatest. In the electrical field, for example, Elias E. Reis was unable to patent (let alone develop) all his inventions for exploiting the heat generated by electrical currents, because even the preliminary expenses of building models and applying for patents for all of them were too much for his backer to bear. Although Reis "repeatedly" explained "that not only was their filing of great importance, but that unless we did so . . . the applications that have already been filed . . . would suffer very materially, and, perhaps, to an irretrievable extent," his patron would not put up additional money until revenues from the earlier patents he had financed began to materialize. "Had I the means available to enable me to file some of these applications," Reis claimed, "I should certainly have done so long since, but as matters stand, and have stood, I . . . do not find myself at liberty to seek the assistance of others." Desperate for funds, Reis had assigned his backer rights to all his inventions in exchange for financial help. Support of this kind was hard to get, Reis felt, and he was not willing to jeopardize the relationship by seeking other sources of aid.[50]

It is, of course, possible that Reis had difficulty obtaining financing for his inventions because they were not thought to be very valuable, but other inventors whose ideas had proven worth experienced similar difficulties.[51] A good illustration is Charles J. Van Depoele, developer of electrical motive systems for trolleys. Van Depoele was perennially short of the capital he needed to commercialize his inventions, and he repeatedly signed away his rights for what appear in retrospect to be paltry sums. In 1880, for example, he assigned the Canadian patents for all his inventions and any additional ones he would devise over the next thirty years to one Reuben G. Lunt, in exchange for a cash

50. "Record of Elias E. Reis," 26–30, 52, *Thomson v. Reis*, case 13,971, box 1,845, Interference Case Files, 1836–1905.

51. Moreover, the infringement suit between Reis and Elihu Thomson shows that Reis's ideas were similar to those developed and exploited commercially by Thomson. See "Testimony on Behalf of Elihu Thomson," case 13,418, box 1,845, Interference Case Files, 1836–1905.

payment of $5,000 (much of it conditional on the success of Lunt's enterprise). When the cash was not forthcoming, he was forced to take 10 percent of the company's stock as payment. Earlier that same year he tried to form a joint-stock company capitalized at $100,000 to exploit his American patents. The agreement allocated $70,000 of the stock to George N. Chase "for Services rendered in organizing Said Company & to be sold for Working Capital." The aim of this manipulation was to acquire a working capital of a mere $10,000. Whether this company ever got off the ground is not clear, but in 1885 Van Depoele formed a partnership with William A. Stiles and Albert L. Sweet, to each of whom he assigned a one-third interest in his inventions. The partnership's capital consisted of little more than his patents, though Sweet was to advance the firm $1,000 to get the business started. Finally, in 1888 Van Depoele gave up trying to exploit his inventions himself and took a job with the Thomson-Houston Electric Company, the predecessor of General Electric, accepting in exchange for assignments of his past and future inventions a salary of $5,000 a year, plus a royalty of $5 for every railroad car the company equipped with electrical motive power during the life of his patents. Thomson-Houston had the capital and access to financing that Van Depoele was unable to obtain on his own, despite the undoubted value of his patents.[52]

Few inventors, of course, were able to obtain such lucrative contracts, and as a result few were willing to agree, as Van Depoele did, to assign all past and future inventions to the company. When the Edison Machine Works' manager complained in 1890 that employees were refusing to turn over their patents to the firm, the company's lawyers had responded that the solution was to institute contracts requiring employees to make such assignments as a matter of course. The lawyers hastened to add, however, "We fear our suggestion is somewhat impracticable" (Wise 1985, 71). It is likely that the problem they had in mind was resistance by employees. That at least is the implication as well of a 1908 book on patents written by Edwin J. Prindle and published by *Engineering Magazine*, one of the earliest trade journals to address managers' concerns. Concluding a chapter, "The Patent Relations of Employer and Employee," Prindle urged manufacturers to follow the example of some leading firms and require that "every employee who is at all likely to make inventions" sign contracts providing for the assignment of patents to the company. Prindle admitted

52. Articles of agreement between Charles Joseph Van Depoele, Electrician, and Albert Wahl, both of Detroit, and Reuben Greenliff Lunt of Toronto, 27 November 1880; agreement dated 4 March 1880; agreement between Charles J. Van Depoele, William A. Stiles, and Albert L. Sweet, 6 June 1885; agreement between Charles J. Van Depoele and the Thomson-Houston Electric Co., 1888; all in folder labeled "Business Papers—Agreements, etc. 1877–89," Charles J. Van Depoele, 1877–92, MSS 867, Unbound Papers, Baker Library, Harvard University Graduate School of Business Administration. The folder also includes several other propositions aimed at raising capital, none of which seem to have been successful. According to W. Bernard Carlson (1991, 216) the Thomson-Houston Electric Company, as part of the deal, acquired the Van Depoele Electric Manufacturing Company, which was purchased for its "railway and motor patents."

that it was often difficult to induce employees to sign such agreements, but he argued that the resistance might be overcome if officers set good examples by binding themselves in the same way (Prindle 1908, 101).

A 1912 letter from a consulting engineer named William Wright to Pullman's president, J. S. Runnells, makes a related point in arguing that personnel issues were at the heart of employee resistance to this type of contract. According to Wright, in "recent years many of the large manufacturing industries in this country have established systems for . . . receiving new ideas from employees." Without such systems in place, employee inventors typically acted on their own: "If one of them thinks of an invention, he is afraid to let it be known to anyone else because of the danger of his ideas being appropriated, and so he works them out in secret and sends them to the Patent Office and if successful in obtaining a patent he generally finds himself in possession of something that is impossible for him to handle to advantage, or he disposes of it to some outside concern for a consideration."[53] Thus, in order to induce employees to assign their patents to their employers as a matter of course, firms had to assuage workers' fears that superiors would steal their ideas. They also had to develop ways of rewarding employees for their inventions and of convincing them that these rewards were superior to those that could be earned on the outside.

Even if resistance to this type of employment contract was overcome, however, such agreements were really only meaningful if inventors stayed with the same firm for an extended period of time. Otherwise, it would be difficult for the company to demonstrate that a particular invention was devised during the patentee's term of employment. High rates of turnover by technologically knowledgeable people were a significant problem for firms during the late nineteenth and early twentieth centuries, even though it was increasingly difficult for inventors to establish themselves in independent businesses. As the case of Rollin Abell illustrates, inventors were entrepreneurially oriented and constantly moved in and out of employment positions in response to perceived opportunities and financial exigencies. Abell clearly thought of himself as an independent inventor, but from time to time he found it desirable to seek employment within firms. In 1899 he worked for the General Electric Company in Lynn, Massachusetts, but he left the firm in order to go into a partnership with a Dr. Beard to develop a "coaster break" he had invented. A year later he opened his own office in Boston "to make drawings and design machinery." Apparently, this business was not successful enough to pay the office rent, and after attempting to continue it out of his home, he gave up and took a job with the Sub-Marine Signal Company of Boston. After a short stint at that firm, he testified, "[I] resumed working for myself on patent drawings and designing

53. William Wright to J. S. Runnells, 21 October 1912, Operating Department, Chief Engineer, Equipment Standards and Testing Records, 1889–1956, box 3, folder 21, Pullman Company Archives.

machinery," spending several months in 1903 developing a carpet loom in Worcester, Massachusetts. A couple of years earlier, he had met some businessmen at an automobile show in New York who were interested in steam vehicles. Subsequent conversations led in 1903 to his employment by a Mr. Newcomb to design a steam touring car in New Jersey. Later that same year he was in Boston, again designing a car for someone named Barlow. The task completed, he returned to the "business of making drawings and designing machinery as before," and there our knowledge of him ends.[54] The Patent Office's interference records contain a wealth of examples of inventors with similarly high turnover rates. To give a few examples, William E. Forster, an inventor of sole-leveling machines for the shoe industry, worked for at least five different firms between 1887 and 1894; Arthur F. Randall, an inventor of steam motor vehicles, worked independently and for at least three firms (including a patent solicitor) between 1897 and 1899; and William W. Wilson, an inventor of adding machines, worked for five different companies in that industry between 1901 and 1906.[55]

We can get a more comprehensive idea of what firms were up against by returning to the subsample of *B* patentees whom we were able to track through city directories. The reader will recall that, compared to the full *B* sample, the smaller data set is biased toward patentees with stable careers. Even so, if we focus on the most productive of these patentees (the fifty-one inventors who had at least ten patents for which we were able to find corresponding city directory entries), we find that only seven (14 percent) finished their careers in stable employment positions. By contrast, twenty-eight (55 percent) ended up as long-time principals in businesses. The rest either bounced around from one category to another, or could not readily be classified as either employees or principals. The implication is that productive inventors preferred to end their careers as independent proprietors. If they could not achieve this goal, then they often continued to move restlessly from position to position.

As both the anecdotal and the quantitative evidence suggests, before firms could reap the fruits that might be obtained from internalizing the process of invention, they had to learn to solve a number of important personnel problems. In particular, they had to reduce both employee turnover and inventors' resistance to signing over the fruits of their creativity to their employers. That is, they had to learn how to convince inventors, who had long regarded independent entrepreneurship as the key to upward mobility, that steady employment offered both rewards and opportunities for advancement. In addition, firms had to learn how to tighten up their managerial hierarchies so that they

54. Deposition of Rollin Abell, "Testimony on Behalf of Randall & Bates," 78–82, *Lemp v. Randall & Bates*, case 24,587, PF box 3,309, ROPO Interference Case Files, 1900–1925.

55. "Preliminary Statement and Record in Behalf of William E. Forster," 1–2, 65, *Forster v. Judd*, case 16,542, box 2,279, Interference Case Files, 1836–1905; "Testimony on Behalf of Randall & Bates," 4, 31, 33; "Wilson's Record," 5–7, *Putnam v. Wilson*, case 27,129, PF box 3,255, ROPO Interference Case Files, 1900–1925.

could credibly guarantee inventors that no one else in the firm would steal their ideas.[56]

Although it is beyond the scope of this essay to describe the manner in which these tasks were accomplished, we conclude this discussion by emphasizing how much learning had to be done. In order, for example, to overcome employees' resistance and reduce the negative effect that the requirement to assign patents might have on their incentive to invent, firms typically offered employees monetary rewards for inventions that led to patents. Such bonuses, however, could themselves be a source of difficulty. As one of Western Electric's executives later testified, such a system "put a tremendous incentive" on employees to work "at counterpoints to their own associates," creating a situation where "men would not work with each other, they would not confide with each other, yet the problem which was before us was a problem which required team action." Even worse, bonuses encouraged employees to "work for themselves at the expense of their employer."

> The incentive was to get out as many patents that would pass the Patent Office as possible. An invention was made. It could be covered by one strong patent or it could be covered by a dozen minor patents. It was to the company's advantage to have it one strong patent, but it was to the employee's advantage to have a dozen minor patents, because he profited in a monetary sense. . . . Then, in addition to that, it is only a small fraction of the things which are done in a research and development laboratory that come within the purview of the patent law. It is only those things which are new and novel, and which have not been practiced before, which come within the things which the law says can be patented.[57]

In order to encourage its employees to work together, to build cases for single strong patents rather than multiple weak ones, and to work assiduously on problems that were not likely to lead to patentable solutions (problems that, as Steven Usselman tells us in chapter 2 in this volume, were an increasingly important part of the work of large firms), Western Electric, its parent company AT&T, General Electric, and similar firms stopped awarding their research employees bonuses for patents. Instead, employees in the relevant departments received straight salaries by way of compensation. Patents became only one of the factors that was taken into account in promotion decisions, and firms now faced new difficulties both in measuring the output of their research employees and creating credible incentives to encourage their productivity.[58]

56. This process paralleled in important ways the more general learning about how to manage large numbers of employees that became embodied in personnel departments during the early twentieth century. See, for example, Jacoby (1985).

57. Testimony of Dr. Frank Baldwin Jewett, U.S. Congress, House, *Hearings before the Committee on Patents*, part 1, 276–77.

58. Ibid. and testimony of Gerard Swope, 324.

1.7 Conclusions

Recent scholarly literature explains the spread of in-house research laboratories during the early twentieth century by pointing to the information problems involved in contracting for technology. We have argued, by contrast, that these difficulties have been overemphasized—that in fact a substantial trade in patented inventions did develop over the course of the nineteenth century, much of it taking the form of transactions conducted at arm's length through the market. In the middle of the century, assignments of patent rights tended to occur after the patent was issued and were often partial in character, restricted to some (perhaps distant) geographic subdivision of the United States. As the century progressed, however, it became increasingly common for patentees to sell full national rights to their inventions and to dispose of these rights more and more quickly—often by the time the patent was officially issued. These trends cannot be accounted for by the movement of inventors within firms or by the growing tendency of employee inventors to assign their patents to the firms for which they worked. Rather the changes seem to have resulted from improvements in the efficiency of the market for technology—from increases in the flow and quality of information about new technological developments, from a growth in the number of patent agents and solicitors willing to serve as intermediaries in this market, and from firms' own investments in the capacity to track technological developments around the country. As we have seen, enterprises as diverse as the American Bell Telephone Company and the Lowell Machine Shop put great stock during this period in their ability to evaluate externally generated inventions.

Toward the end of the century, however, the nature of the market for technology began to change as the proportion of apparently arm's-length transactions declined in favor of assignments made at issue by patentees who were formally associated with their assignees in some way.[59] Although this change may have betokened a reintegration of inventive and developmental activities within the firm, possibly driven by the kind of information problems discussed in the recent literature, this interpretation is by no means certain. In the first place, the change was largely accounted for by the increasing tendency of inventors who were principals in companies to assign their inventions to their firms. In the second, it is possible that the growing number of patentees who behaved in this manner were forming companies mainly to facilitate their specialization in invention. Once again, the one thing we can say with some certainty is that the pattern was not accounted for by the rising tendency of employees to assign their inventions to their employers. Although the proportion of employee inven-

59. Although the relationship is unclear, it is interesting to note that the beginning of this change in the market for technology coincided with the beginning of a long-term decline in rates of patenting per capita. This latter development occurred first in geographic areas, like New England, that were long-time leaders in invention, and then spread to the national level (Lamoreaux and Sokoloff 1996, 12688; Griliches 1994).

tors who transferred patent rights to their companies increased after 1890, the numbers of these patentees were still too small to account for the aggregate patterns.

Moreover, when large firms began during the early twentieth century to invest in developing their internal inventive capabilities, they faced a number of significant difficulties. Most important, they had to insure that they obtained property rights to inventions conceived on company time with company resources. The solution to this problem was to require employees to sign contracts that obligated them to assign their patents to the firm. Before such contracts could become routine, however, a number of nontrivial difficulties had to be resolved. Firms had to overcome employee resistance, and they had to reduce the high turnover rates that made such requirements effectively unenforceable. In other words, entrepreneurially oriented inventors had to be convinced that loyal service to a firm offered a combination of security and opportunities for advancement superior to that likely to come from self-employment. The increased costs of inventive activity and the resulting greater risks borne by independent inventors by the early twentieth century helped firms to make their case. But there was still a lot of learning involved. Hence, in important ways, the story we tell for the early twentieth century turns the recent literature on its head. Economic actors at that time had a great deal of experience contracting for new technological ideas in the market; what they did not know, and had to spend a great deal of time and energy learning, was how to manage creative individuals within the firm.

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Comment Adam B. Jaffe

This paper provides a fascinating statistical snapshot of invention during the early phases of the transition to organized industrial research from the era of individual invention and entrepreneurship. It demonstrates that, at the turn of

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the century, there was an active market in apparently arm's-length sales of inventions from individual inventors to firms who were not the inventor's employer, apparently commonly including inventors employed by one firm selling patents to another firm. Further, this technology market was economically significant, representing both a significant source of new technology for major firms and a significant destination for the patents of important inventors. This picture raises a number of interesting issues for our understanding of the nature of the invention process and its relationship to organizations.

The long period of time after the emergence of large industrial enterprises during which employees were not typically contractually bound to assign their inventions to their employers demonstrates the danger of the practice, common among organizational theorists, of assuming that observed organizational forms must be optimal. Despite the incentive problems that exist when an employee's ideas become the property of her employer, it cannot be optimal to pay someone full-time, and provide them with equipment on which to experiment, while permitting them to retain residual rights in inventions developed on company time and equipment. Further, it does not appear that lack of knowledge or specific legal impediment prevented the adoption of the more efficient employment contracts, as some firms did adopt this policy, and no apparent change in the law occurred before the practice eventually became widespread. Lamoreaux and Sokoloff's evidence suggests that strong organizational inertia was at work. Companies found it difficult to institute the policy unilaterally; what is less clear from the paper is why they were unwilling to compensate employees sufficiently to induce them to accept what was surely a potentially Pareto-improving regime change. In any event, this story confirms the applicability to the organizational realm of Keynes's observation about the elapsed time before we see "long-run" equilibrium.

The implications for current thinking about technology and organizations of the finding of a robust technology market are more subtle and, ultimately, less clear. The authors accurately represent the current conventional wisdom, that is, that widespread vertical integration between invention and production is inevitable, because of complementarity among the processes of production, marketing, and research, and because of difficulties in contracting over "knowledge" as a commodity. That a robust arm's-length technology market existed for so long, that it grew rather than shrinking during the initial rise of large corporations, and that it was heavily relied upon by the most technologically sophisticated firms of the period does seem to call this conventional wisdom into question. I will devote the remainder of this comment to the discussion of possibilities for reconciliation of the paper's evidence with the conventional view.

One conceptual possibility is that, of the two reasons typically given for vertical integration (complementarity and contracting difficulties in knowledge), it is really the first that is most important, and such complementarity is

much more important today than it was at the turn of the century. Besides being excessively convenient, this explanation is not compelling. The invention of the early period was largely mechanical, and focused on the manufacturing process. It is hard to see how it was a process *less* complementary with manufacturing than today's science-based research.

A second possibility is that interpreting this evidence as contradicting the optimality of vertical integration is falling prey to the fallacy of assuming that observed organizational forms are optimal. Current theory doesn't say that selling technology is impossible, just that it is costly. Perhaps the arm's-length technology market of the early 1900s was a distinctly second-best situation that persisted only because it took a long time to get the superior form of vertical integration going. Indeed, since to really make vertical integration pay firms would have to own their employees' inventions, the inertia that prevented the more rapid adoption of this innovation also thereby limited the effectiveness of integration and perhaps preserved the vitality of the arm's-length market. One can visualize a negative feedback loop, in which the vitality of the arm's-length market makes employees resistant to relinquishing their rights to their inventions, while employers' inability to control their employees' inventions limits the effectiveness of integration and thereby forces them to rely on the arm's-length market. Seen through this lens, this aspect of the paper provides further evidence for the slowness with which superior forms take over, rather than undermining the conventional wisdom about the sources of superiority of the integrated form.

Finally, the evidence of the paper regarding the viability of a market for technology relates only to patented, and hence patentable, inventions. It is well understood that much of industrial technology is not patented and is probably not patentable. Clearly, the lack of an explicit property right such as a patent greatly aggravates the difficulty of selling technology at arm's length. Thus even if it were true that all currently patentable inventions are easily amenable to arm's-length trade, it could still be the case that much if not most of modern technology is not amenable. Further, one of the reasons for inventions not being patentable is the difficulty of reducing them to the kind of explicit description necessary for the patent application. Thus technologies that are not patentable are likely to be inherently harder to contract on.

It is well known that the "propensity to patent," which can be thought of as the ratio of the number of patent applications to the number of inventions, has been falling throughout this century. Thus it is possible that arm's-length trade was feasible for much or most of industrial technology at the turn of the century, but is infeasible or at least inefficient for most of industrial technology today.

While the thrust of these comments is that I remain reasonably convinced that arm's-length purchase of inventions is today expensive and inefficient for much of modern technology, it is interesting to note that "outsourcing" of R&D

is generally believed to be increasing. This takes several forms. Some firms are relying increasingly on grants and contracts to universities rather than performing relatively "basic" research in-house. Firms also seem increasingly to acquire access to technology through a variety of alliances with other firms; these alliances constitute a sort of halfway house between arm's-length purchase and vertical integration. Thus the questions of how efficiently markets and organizations handle inventions, and of what properties of different kinds of technologies affect the relative efficiency of different organizational and contractual forms, remain open and important. The authors have made a very interesting and useful contribution to this discussion.