NBER WORKING PAPER SERIES
ON
HISTORICAL FACTORS IN LONG-RUN GROWTH

THE DEMOCRATIZATION OF INVENTION DURING EARLY INDUSTRIALIZATION: EVIDENCE FROM THE UNITED STATES, 1790-1846

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Working Paper No. 10

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
December 1989

The authors thank Francesca Bray, Stanley Engerman, Naomi Lamoreaux, Pamela Neckless, Jean-Laurent Rosenthal, Michael Waldman, and Gordon Wood for helpful discussions and comments. Research support was provided by the California Institute of Technology, the Center for Advanced Study in the Behavioral Sciences, as well as the Institute of Industrial Relations and the Academic Senate at UCLA. This paper is part of NBER's research programs in the Development of the American Economy and Productivity. Any opinions expressed are those of the authors not those of the National Bureau of Economic Research.

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ABSTRACT

We argue that the rapid growth in inventive activity during early American industrialization was characterized by a disproportionate increase in invention by segments of the population with relatively common skills and knowledge. Rather than being accounted for by an elite who possessed rare skills or commanded large amounts of financial resources, the rise in patenting coincided with a broadening of the ranks of patentees to encompass many individuals, occupations, and geographic districts which had been only modest participants beforehand. This conclusion is based on findings of : (1) major shifts in the occupational and geographic distributions of patentees; (2) a growing share of patents being awarded to patentees with few career patents; (3) a generally low level of specialization in invention on the part of patentees, with no trend over the period; and (4) a pattern of individuals with few career patents and low specialization being disproportionately represented among patentees in transitional counties which had only recently realized substantial increases in patenting. We further suggest that these results are consistent with the hypothesis that the nature of technology during this era permitted a range of relatively elastic supply of invention, and accordingly allowed the expansion of markets to spread high levels of inventive activity.

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In recent years, there has been a renewal of interest in the study of inventive activity during early industrialization.[1] The basis for this concern is obvious. If economic growth is derived from gains in productivity, then a knowledge of the conditions underlying the increase in invention, which is the basis for such progress, should help us better understand the process. In this paper, we extend work begun by Sokoloff on the rise of inventive activity in the United States during the early nineteenth century. Employing a sample of patent records filed between 1790 and 1846, he found evidence from temporal and cross-sectional analyses that the expansion of markets was associated with a substantial increase in patenting. Although Sokoloff followed Schmookler in suggesting that the expansion of markets stimulated invention through raising the expected rate of return on such activity, other mechanisms may also have played a part in accounting for the results.

Exogenous advances in knowledge, and in its diffusion, have long figured prominently in discussions of the acceleration of invention during early industrialization. Some scholars believe that such surges of invention were, at least in the American and British cases, propelled by fundamental breakthroughs in technology which yielded a profusion of secondary innovations.[2] They hold that these major improvements in the stock of knowledge available to "would-be" inventors, or a shifting out of the supply curve, were the primary source of the increase in invention. Others, however, view the era as one in which the knowledge required for invention was rather basic and widely diffused across the population, and in which the supply of ideas was relatively elastic. From this perspective, the unparalleled increases in demand and in competition facing

producers, which accompanied the emergence of extensive markets, helped frame new problems to be addressed with the existing stock of knowledge and induced growing numbers of people to invest more in inventive activity and innovation.[3]

One of the chief problems with attempting to investigate the role of advances in knowledge, or its diffusion, in stimulating inventive activity is the difficulty of distinguishing empirically between the different kinds of knowledge at issue. We focus here on technical knowledge or skills which, like specific human capital, were costly to obtain, largely restricted to members of particular occupations or industries, and scarce among the general population. We argue that much insight into the significance of this sort of knowledge can be gained from examining the characteristics of American patentees, including their occupation, degree of specialization in invention, and career commitment to patenting. Although this approach excludes consideration of a broad range of other types of knowledge or information, such as those concerning market conditions and general technology, it is not an arbitrary choice on our part. Rather, we are interested here in whether most advances were made by a small group of individuals who were exceptionally well qualified for invention because of their technical background or expertise.

The principal argument of this paper is that the rapid growth in inventive activity during early American industrialization was characterized by a disproportionate increase in the involvement of segments of the population with relatively common sets of skills and knowledge. Rather than being accounted for by an elite who possessed rare technical knowledge or commanded large amounts of financial resources, the

rise in patenting coincided with a broadening of the ranks of patentees to encompass many individuals, occupations, and geographic districts which had been only modest participants beforehand. This conclusion is based on findings of: (1) major shifts in the occupational and geographic distributions of patentees; (2) a growing share of patents being awarded to patentees with few career patents; (3) a generally low level of specialization in invention on the part of patentees, with no trend over the period; and (4) a pattern of individuals with few career patents and low specialization being disproportionately represented among patentees in transitional counties which had only recently realized substantial increases in per capita patents. We further suggest that these results are consistent with the hypothesis that the nature of technology during this era permitted a range of relatively elastic supply of invention, and accordingly allowed the expansion of markets to spread high levels of inventive activity.

A random sample of U.S. patent records from 1790 to 1846 is the chief source of data, although additional information on many of the patentees has been added to the original data set.[4] Among the new variables are the number of career patents, which was compiled from a complete listing of patents through 1846, and a measure of the degree to which the inventions of each patentee were specialized in any of five sectoral classifications. Some use is also made of a preliminary sample of "great inventors", which is currently in the process of being assembled. The key assumption underlying the research is that careful analysis of patent counts can provide a valuable indicator of the variation in the level of inventive activity over the period under study. Many economists have found patent

data useful for this and related purposes.[5]

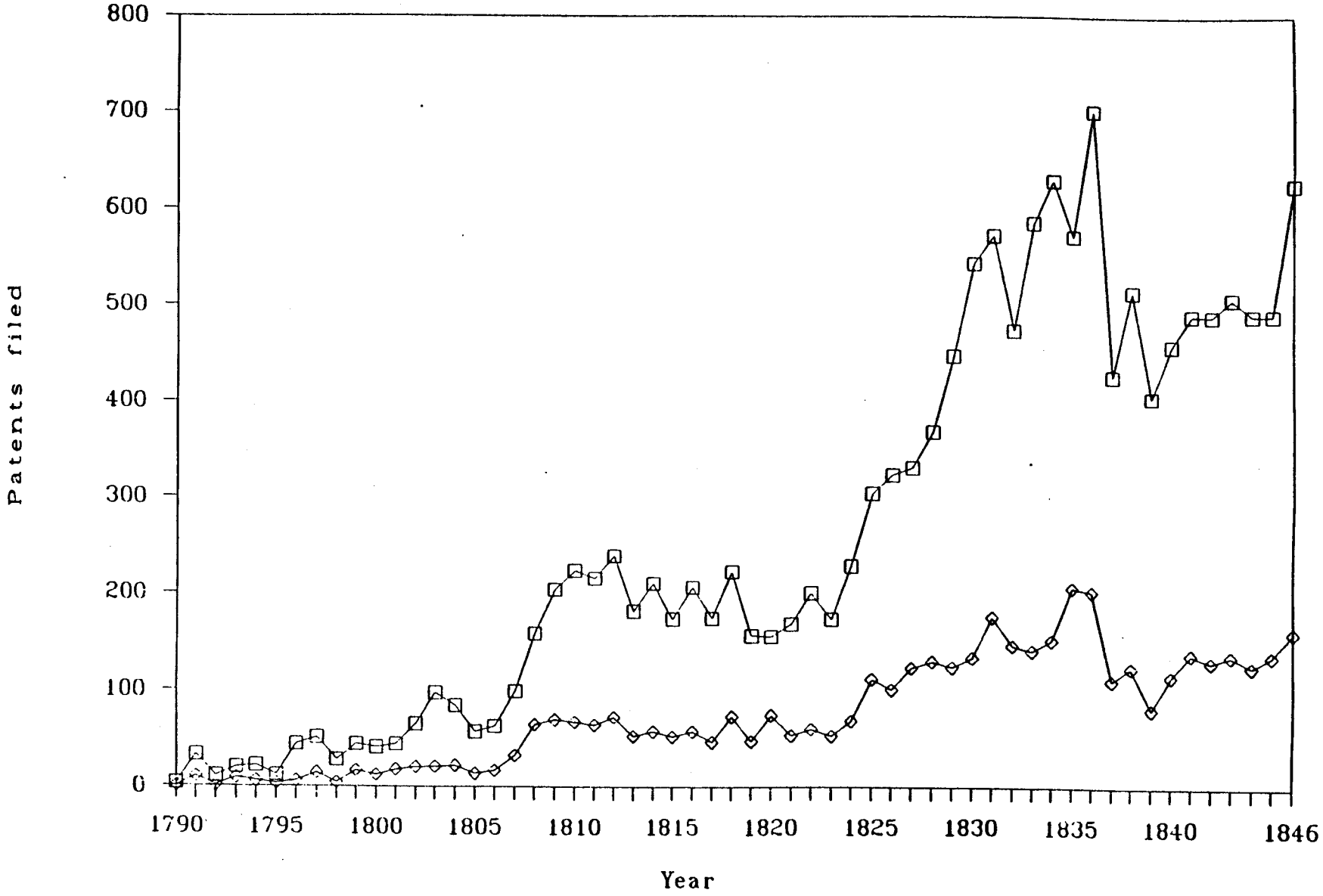
Patent counts are not without limitations however. On the contrary, there are at least three deficiencies relevant to the analysis presented here. The first is that patents do not fully encompass the many inventions which are either difficult to enforce a patent on or not patentable. Since patents are easier to enforce when they pertain to a physical product or capital equipment, they overrepresent such inventions relative to advances which do not require capital goods; for this reason, the use of patents may exaggerate the relative significance of inventors with large investments in invention-generating capital.[6] A second problem is that institutional factors related to the perceived costs of securing a patent or enforcing one can alter the proportion of inventions which are ultimately patented. Finally, patents do not contain direct information on the value of the underlying ideas, and thus patent counts provide a less reliable indicator of the value of inventions being introduced than a series weighted by value (either ex ante or ex post) would. These issues are serious, but we have tried to maintain a sensitivity to them throughout our analysis. Objections to our inferences should be examined in context.

I

A salient feature of the growth of patenting in early industrial America is that it was far from continuous. As is clear from Figure 1, patenting was pro-cyclical, with virtually all of the increase between 1790 and 1846 realized during two concentrated intervals of expansion.[7] These periods of rapid growth in patenting do not appear to have been

Figure 1

Annual Totals of Patents in the Population and the Sample, 1790-1846



stimulated by specific breakthroughs in technology. Instead, they seem rooted in macroeconomic events which spurred the expansion of markets. The first upswing in patenting, for example, began slowly during the prosperous 1790s, but accelerated during the years in which British interference with shipping lanes, and a series of non-importation acts such as the Embargo of 1807, curtailed the supply of foreign manufactures. This interval of sustained increase in patenting was brought to an end by the War of 1812 and the long contraction that followed. The advent of the second span of rapid growth in patenting, however, coincided with the economic recovery of the early 1820s. As the upturn in the economy continued, patenting increased steadily until a change in the patent system in July 1836 introduced more stringent requirements. The number of patents awarded fell immediately, and then stabilized at this lower level for nearly eight years. It seems likely that the contraction which began with the Panic of 1837, and persisted through the early 1840s, played some role in accounting for this second spell of stagnation in patenting.

In general, the tendency for patenting to increase during business expansions or events like the Embargo, which raised the effective demand for domestic manufacturers and encouraged the extension of domestic markets, is consistent with an emphasis on the role of demand-induced advances in inventive activity.[8] This does not imply, however, that the stocks of knowledge were irrelevant. On the contrary, if the level of technical knowledge previously available had not been sufficient to yield inventions worthy of being patented (with expected private returns exceeding the cost of securing a patent), the growth of market demand alone could not have led to the substantial increases in the number of

patents filed. Hence, the pro-cyclicality of patenting suggests that at least a significant portion of invention involved the application of existing techniques, or modest extensions thereof. In conventional economic terms, the states of knowledge and technology allowed for a relatively elastic supply of patentable ideas, at least in the short run.

Another perspective is provided by Table 1, which presents the distribution of patents over time by classes of patentees defined by the total number of patents ever received over their career as a measure of longterm commitment to patenting.[9] The most important finding here is the growing prominence over time of patentees with only one or two patents over their career. For example, whereas patentees with only one career patent accounted for 46.1 percent of those awarded between 1790 and 1804, their share rose to 53.3 percent during the Embargo years of sharp increase in patenting, and remained in the high 50s and low 60s through the 1840s. With the rest of the structure generally stable, this change in composition implies that patentees with relatively small longterm investments in inventive activity were the group which responded most strongly to whatever conditions were responsible for the increased economy-wide commitment to invention and innovation. Further evidence that patentees with smaller numbers of career patents were especially sensitive to economic conditions is the contrast between the pro-cyclicality of their activity and the virtual absence of pro-cyclicality on the part of those with large longterm commitments. This feature is reflected here in the sharp rises in the share of patents going to patentees with ten or more patents during the two prolonged economic downturns (averaging 64 percent).

TABLE 1

THE DISTRIBUTION OF PATENTS BY PATENTEE COMMITMENT TO PATENTING: 1790-1846

Total Number of Patents Filed By Patentees With:
and row percentages

	1 Pat	2 Pats	3 Pats	4-5 Pats	6-9 Pats	10+ Pats
1790-1804	77	35	12	20	17	6
	46.1%	21.0%	7.2%	12.0%	10.2%	3.6%
1805-1811	186	63	50	19	19	12
	53.3%	18.1%	14.3%	5.4%	5.4%	3.4%
1812-1822	388	117	50	51	35	42
	56.8%	17.1%	7.3%	7.5%	5.1%	6.2%
1823-1829	435	132	52	58	43	28
	58.2%	17.7%	7.0%	7.8%	5.8%	3.7%
1830-1836	686	190	95	100	80	45
	57.4%	15.9%	7.9%	8.4%	6.7%	3.8%
1836-1842	416	127	61	53	28	40
	57.4%	17.5%	8.4%	7.3%	3.9%	5.5%
1843-1846	329	96	48	39	13	19
	60.5%	17.7%	8.8%	7.2%	2.4%	3.5%
ALL YEARS	2517	760	368	340	235	192
	57.1%	17.2%	8.3%	7.7%	5.3%	4.4%

Notes and Sources: The total number of all patents received were counted for each patentee from 1790 through 1846. Hence, there will be downward-biased estimates of the numbers of lifetime patents (or patentable inventions) filed by patentees active at both the beginning and the end of the period. For a description of the sample, see Sokoloff, "Inventive Activity...".

The increase in the proportion of patents awarded to individuals with few career patents leads one to question how significant technical knowledge and skills were in accounting for the growth of inventive activity experienced during the period. After all, if capital investments, such as in the acquisition of such knowledge and skills were associated with an advantage in generating patentable ideas, or in exploiting them commercially, and if this advantage was becoming larger over time as advances in technology were realized, then one would expect that patentees with many career patents to have garnered an increasing share. Moreover, the same logic should apply to improvements in the diffusion of knowledge; if individuals with investments in technical knowledge were better equipped to understand the significance of new information, and act on it, then their patenting should have been disproportionately affected by a geographically-wider diffusion of information. However, given that the share of these "high-commitment" patentees actually declined, it would appear that the most salient developments behind the rise in the numbers of patents during the era were those which stimulated individuals with relatively limited investments in such invention-generating capital.[10]

It is true that patentable ideas vary enormously in both private and social returns, and that evidence of a growing share of patents does not necessarily indicate an increase in the relative value of inventions contributed by "low-commitment" patentees. Indeed, some would assert that these patentees yielded few important inventions, and dominated only in the registration of low-value patents. This possibility is difficult to evaluate with the data currently on hand, but indirect evidence bears against it. As mentioned above, the 1836 change in the patent law involved

a tightening of the requirements for an award. If the patents previously filed by "low-commitment" individuals were of lower average quality, one would expect the new standards to have screened out a larger fraction of their applications and to have produced a decline in their proportion of total patents. Since there was no such drop, however, this rough test of the value of patents supports the inference drawn above about the growing significance of inventions from individuals whose lifelong commitments to patenting were relatively modest.

Another means of assessing the sources of patentable invention over the period is to examine the occupations of patentees. Such information has been retrieved for a subset of urban patentees appearing in the sample. Distributions of these urban patentees across six occupational groups are presented in Table 2 for four sub-periods between 1790 and 1846. The salient pattern is of a major shift in the occupational structure. Men in commerce and the professions (largely merchants) enjoyed a dominant (50 percent) share of patents through the 1790s and up to the Embargo, but their position then began to erode as various classes of artisans and other occupations raised their totals much more rapidly.[11] By 1836-1846, the commerce share had declined to only 18.6 percent. Given that the concentration of patenting in urban centers also diminished over the period, the movement away from the predominance of the merchant class would likely be even more pronounced if rural patentees were also considered.

One interpretation of this change in the occupational composition is that it reflected an opening up of opportunities for deriving returns from invention. Prior to the Embargo, when domestic markets were less developed, the bulk of patenting was carried out by merchants and men of

TABLE 2

OCCUPATIONAL DISTRIBUTION OF URBAN PATENTEES

DURING FOUR SUB-PERIODS, 1790-1846

	1790-1804	1805-1822	1823-1836	1836-1846
General Commerce and Professional (i.e. merchants, doctors, gentlemen)	13	60	59	43
	50.0%	38.7%	24.6%	18.6%
Artisans Working with Renewable Materials (i.e. carpenters, shoemakers)	4	32	58	41
	15.4%	20.7%	24.2%	17.8%
Precision Artisans (i.e. makers of watches, jewelry, instruments)	5	16	22	26
	19.2%	10.3%	9.2%	11.3%
Machinists/Toolmakers	1	17	34	40
	3.9%	11.0%	14.2%	17.3%
Other Producers/Dealers of Metal Products (i.e. stove mfg., blacksmith)	2	17	40	49
	7.7%	11.0%	16.7%	21.2%
Other Occupations or None Listed	1	13	27	32
	3.9%	8.4%	11.3%	13.9%

Notes and Sources: See the note to Table 1. Working from the sample of patent records, the occupations for 444 patentees were retrieved from various issues of city directories. Since the surviving city directories are disproportionately from later years, it was easier to establish the occupation for patentees who were active later. Hence, one should not place much significance on the increase in the number of patentees covered over time. The table reports, for each sub-period, the number and share of patents which were filed by patentees of the particular occupational category. Among the cities represented in this table are Albany, Buffalo, New York, Rochester, Troy, and Utica in New York; Newark in New Jersey; Bangor and Portland in Maine; Philadelphia and Pittsburg in Pennsylvania; Baltimore in Maryland; Boston, Newburyport, and Salem in Massachusetts; Providence in Rhode Island; and Hartford and New Haven in Connecticut. The third sub-period, 1823-1836, runs through July 3, 1836, when the patent law was changed. Of the 1057 patents in the sample awarded to residents of these cities over the entire period, occupations were retrieved for 458 (or 43.3 percent) of the respective patentees (with many patentees responsible for more than one patent). We also were able to identify occupations for some individuals who reported residences other than these cities in their patent applications. Nearly all of these were at some point residents of these cities.

similar occupations, who were best placed to commercially exploit useful ideas. Not only did they have the most direct access to wider markets, but they also were more likely to control financial resources to support inventive activity and innovation. Francis Lowell, founder of the Boston Manufacturing Company, epitomises this class of merchant. Having decided to expand from a profitable base in foreign trade into textiles, he and a fellow merchant proceeded, without previous mechanical experience, to study the existing technology and construct their own power loom. For the most part, enterprises such as Lowell's were inspired by superior business acumen - not advanced technical knowledge.

With the growth of domestic markets that accelerated during the interruptions in foreign trade, more and more individuals began to compete to satisfy extensive demand for their products, as well as to exploit expanded opportunities for extracting returns from invention. These developments should have boosted invention and patenting throughout the population, but such gains were likely proportionally higher for occupational groups other than commerce.[12] It is hardly surprising, therefore, that the major rise in patents per capita was accompanied by a shift in the occupational mix of patentees.

Prior to the Embargo, the more technical groups, such as machinists and metalworkers, whose skills and knowledge were scarce and costly to acquire, received only 3.9 and 7.7 percent respectively of patents.[13] Their relative significance among urban patentees did increase substantially over time, perhaps signalling an enhanced importance of a technical background for effective invention, but even by the 1840s when mechanization was spreading quickly, their shares had risen to only 17.3

and 21.2 percent. The totals are large, but their impacts are diminished somewhat when one remembers that machinists and metalworkers/dealers were certainly overrepresented among urban patentees as compared to the general population of patentees, and that the former were a smaller proportion of the latter in the 1840s than they were earlier.[14] Given these caveats, and that relatively few patents were awarded to these trades before the 1830s, it is doubtful whether breakthroughs in machinery and metalworking alone could go far in explaining the rise in patenting during the early nineteenth century. Rather this progress depended more on the pragmatic problem-solving abilities of a kind pervasive among artisans of the era. As George Gibb suggested, "varied and dextrous mechanical abilities were all but universal...the Industrial Revolution in its infancy produced surprisingly few basic technical skills not already familiar to American mechanics."[15] Indeed, the most signficant inventions of the age, such as Whitney's cotton gin or Blanchard's lathe, were typically based on commonly available information applied to a specific problem.

Another way to explore the significance of technical skills and knowledge is to examine the extent of specialization by patentees. One would expect that most technical knowledge at the frontier would be sector-specific, or limited in direct applicability to inventions in the same sector.[16] Hence, if such human capital did raise the productivity of inventive activity in a particular sector, and was costly to acquire, a patentee who had invested in it would tend to concentrate his efforts, as well as his patents, in that sector. For example, individuals who had acquired an expertise in power looms or sewing machines would tend to file manufacturing patents, as opposed to ones in agriculture, construction,

trnasportation, or miscellaneous (the other four sectors in our classification scheme). The more important these sector-specific skills and knowledge were, the more specialized by sector the patents of inventors are likely to be.

In Table 3, we present estimates, for both the general sample and a sample of "great inventors", of the simple proportions of patentees who were specialized with over 75 percent of their patents in any one of the five sectors. Opinions may vary when there is no clear standard for comparison, but the percentages seem rather low, especially during the early years when barely over half of the patentees with two patents were specialized. Even the "great inventors," who might have been expected to possess highly specialized knowledge, appear only slightly more specialized than the average.[17] Overall, the small proportions of patentees who specialized imply that much of the human capital tapped by inventors could be applied to problems in a wide variety of economic activities. Whatever knowledge or skills were needed for patentable invention appear to have been either general in nature or easily acquired.

Although these figures hint at an increase in specialization over time, the multivariate regressions presented in Table 4 reveal that there was no trend (judging from the insignificant time period dummies). The finding may seem surprising, because it conflicts with the normal conceptions of what the advance of knowledge and the development of markets lead to, but it is robust to whatever other variables are controlled for. Skeptics might question whether our measure is actually picking up specialization, but confidence in the analysis is bolstered by the results that the degree of specialization was greater among occupations associated

TABLE 3

THE SPECIALIZATION OF PATENTEES IN ONE OF FIVE SECTORS: FOR ALL PATENTEES AND THOSE DESIGNATED GREAT INVENTORS, BY TIME PERIOD AND NUMBER OF PATENTS, 1790-1846

		1790-1822		1823-1846	
		All	Great	All	Great
Patentees With:					
Two Patents	%	52.2%	62.5%	57.7%	66.7%
	N	113	8	248	21
Three Patents	%	25.6%	70.0%	43.1%	58.8%
	N	39	10	65	17
Four or More Patents	%	32.3%	30.8%	46.5%	50.0%
	N	31	26	43	44

Notes and Sources: The figures report, for the general sample of all patentees and for a list of "great" inventors who were responsible for especially prominent patents, the number of patentees in each cell, and the proportion who have over 75 percent of their patents in a single one of five patent classification sectors: agriculture, construction, manufacturing, transportation, and other. The number of patents attributed to a patentee refers to the totals appearing in the sample. Hence, the numbers of patentees with three patents refer to those individuals who had three patents appearing in the sample. The analagous percentages for patents for all patentees with two or more patents in the sample are 40.0 percent during 1790-1822 and 52.1 percent during 1823-1846. Over the entire period, the proportions of patents accounted for by individuals who were more than 75 percent specialized in the sector are 48.0 percent for agriculture, 47.6 percent for construction, 57.5 percent for manufacturing, 27.5 percent for transportation, and 39.8 percent for other. For information on the general sample, see the note to Table 1. Overall, a list of 129 "great inventors" was drawn from inventors appearing in the Dictionary of American Biography (New York, 1937); and Who Was Who in America - Historical Volume, 1607-1896 (Chicago, 1963). A complete record of their history of patents between 1790 and 1846 was then compiled from Edmund Burke, List of Patents For Inventions and Designs Issued By the United States From 1790 to 1847 (Washington, D.C., 1847).

TABLE 4

REGRESSIONS WITH THE PERCENT SPECIALIZATION IN PATENT SECTOR

FOR PATENTEE AS THE DEPENDENT VARIABLE: 1790-1846

	(1)	(2)	(3)	(4)
Constant	106.864	79.829	79.056	81.615
	(16.53)	(9.66)	(9.09)	(9.83)
Proportion of Labor Force in Manufacturing	-1.134	-0.176	-0.140	-0.171
	(-1.61)	(-2.12)	(-1.69)	(-2.07)
Log (Annual Patents per Million in County)		7.828	7.729	7.839
		(5.15)	(5.16)	(5.16)
(Number of Patents Over Which Index Computed)^2	0.984	0.940	1.032	1.024
	(3.84)	(3.72)	(4.12)	(4.00)
Number of Patents Over Which Index Computed	-12.00	-11.869	-12.945	-12.774
	(-4.98)	(-4.97)	(-5.46)	(-5.26)
Time Dummies:				
1790-1804	-2.143	4.819	5.048	4.326
	(-0.44)	(0.97)	(1.02)	(0.87)
1805-1822	-3.542	-3.487	-2.155	-3.337
	(-1.46)	(-1.45)	(-0.90)	(-1.40)
1823-1836	3.411	1.095	2.066	1.318
	(1.63)	(0.52)	(0.99)	(0.62)
Regional Dummies:				
N. New England	1.433	-2.769	-1.761	-3.119
	(0.32)	(-0.61)	(-0.40)	(-0.69)
S. New England	-2.063	-8.002	-8.969	-9.112
	(-0.72)	(-2.61)	(-2.96)	(-2.93)
New York	1.492	-2.093	-2.333	-2.453
	(0.55)	(-0.75)	(-0.85)	(-0.88)
S. Middle Atlantic	4.401	4.145	5.162	3.485
	(1.31)	(1.25)	(1.56)	(1.05)

Table 4 (cont.)

	(1)	(2)	(3)	(4)
Urbanization Dummies:				
Urban	5.366	4.687	3.636	4.035
	(2.59)	(2.29)	(1.79)	(1.95)
Metropolitan	1.389	-4.662	-7.531	-4.379
	(0.66)	(-1.94)	(-3.07)	(-1.82)
Transportation Dummies:				
Located on Navigable River or Canal	-7.669	-8.284	-7.006	-8.447
	(-2.36)	(-2.57)	(-2.20)	(-2.63)
Located on Ocean	-14.531	-14.087	-13.418	-13.032
	(-3.40)	(-3.33)	(-3.21)	(-3.06)
Occupational Dummies:				
Commerce/Wh. Collar			2.475	
			(0.81)	
Traditional Artisan			7.901	
			(2.83)	
Machinist			13.030	
			(3.63)	
Metal Worker/Dealer			20.234	
			(4.64)	
Great Inventor Dummy				6.090
				(2.00)
R^2	0.093	0.114	0.144	0.117
N	1016	1016	1016	1016

Table 4 (cont).

Notes and Sources: The regressions were estimated over all of the individual patent records for patentees in northeastern states who had more than one patent appearing in the sample. The constant refers to a patent filed during 1836-1846 in rural Pennsylvania county without access to a navigable waterway, by an individual for whom either no occupation was retrieved or his occupation was different from those represented by the occupational dummy variables. The traditional artisan category refers to artisans who worked with non-metallic raw materials or did fine crafts (i.e., jewelry, watches). For a discussion of the sample, see Sokoloff, "Inventive Activity ..." and the notes to Tables 1 and 2. Regression coefficients are reported, with t-statistics in parentheses below.

with technical knowledge (i.e. machinists), individuals with a high career commitment to patenting (beginning to rise with six patents), and "great inventors". All conform well with our expectations about the relationship between investments in invention-generating capital and specialization.

As patenting increased over time, there may have been two streams of development at work which obscure each other in the general time trend. On one hand, the expansion of markets, which both enhanced the commercial value of inventions and enlarged the population who could benefit from patents, attracted new entrants to patenting whose longterm investments in invention-generating capital were relatively modest and whose efforts were accordingly not as specialized as those of their more-committed peers. On the other, a growing competitive advantage to technical knowledge and skills may have served over time to promote greater investments in such sector-specific human capital, and greater specialization, particularly by patentees in very competitive districts. As long as the former mechanism continued to operate with sufficient strength, it might on average net out the effect of the latter in the aggregate pattern.

This perspective appears consistent with the regression results. They suggest that patentees from rural counties on navigable waterways were less specialized than their counterparts in counties without such low-cost transportation. This finding is of special interest, because the transitional nature of such counties captures an important stage in the process by which levels of inventive activity grew during early industrialization. As documented in previous work, rural counties realized substantial and rapid increases in patents per capita as they gained access to waterways.[18] Moreover, cities invariably emerged in these counties

along the water routes, boosting patenting rates further. Whereas inventive activity appears to have risen continually once the extension of the waterways had opened up an area to the wider market, the pattern of coefficients in these new regressions implies that the degree of specialization by patentees did not move solely in one direction. Indeed, because the coefficient on the waterway dummy is large and negative, and those on the urban and patents per capita variables positive, the evidence indicates that the average patentee became less specialized when water transportation first became available, but that this change was reversed over time as urbanization and further investment in inventive activity progressed. Although other explanations are possible, the above hypothesis seems straightforward. With the initial phase of the increase in patenting driven by an increase in the proportion of the population awarded patents, the influx of new inventors produced a temporary shift in the composition of patentees towards individuals who had no major investments in sector-specific capital and were accordingly less specialized. During the later phases, as local populations adjusted to the greater opportunity and competition of an urban and extensive market, residents made larger investments in invention-generating capital, and focused more on their particular niches.

In Table 5, we present regressions with the log of the number of patents ever received by the patentee as the dependent variable. The assumption underlying them is that career patents provide a reasonable gauge of the longterm commitment of an individual to patenting. Admittedly, there is noise in this measure, and it can be influenced by the investments in invention-generating capital made by the individual as well

TABLE 5

REGRESSIONS WITH THE LOG OF THE NUMBER OF LIFETIME PATENTS

AS THE DEPENDENT VARIABLE: 1790-1842

	(1)	(2)	(3)	(4)
Constant	0.275	-0.048	-0.023	-0.026
	(3.27)	(-0.41)	(-0.20)	(-0.24)
Proportion of Labor Force in Manufacturing	0.001	0.001	0.002	0.000
	(0.83)	(0.52)	(1.35)	(0.41)
Log (Annual Patents per Million in County)		0.100	0.080	0.098
		(3.98)	(3.25)	(4.20)
Time Dummies:				
1790-1804	0.192	0.287	0.273	0.328
	(2.16)	(3.12)	(3.04)	(4.03)
1805-1822	0.030	0.028	0.039	0.049
	(0.66)	(0.61)	(0.88)	(1.15)
1823-1836	0.027	-0.011	0.025	0.002
	(0.65)	(-0.27)	(0.60)	(0.05)
Regional Dummies:				
N. New England	0.074	0.042	0.059	0.075
	(1.08)	(0.61)	(0.89)	(1.20)
S. New England	0.213	0.138	0.119	0.072
	(4.31)	(2.62)	(2.31)	(1.47)
New York	0.139	0.095	0.102	0.067
	(3.03)	(2.02)	(2.21)	(1.57)
S. Middle Atlantic	0.107	0.111	0.158	0.166
	(1.71)	(1.77)	(2.58)	(2.79)
Urbanization Dummies:				
Urban	0.186	0.185	0.142	0.142
	(5.32)	(5.31)	(4.13)	(4.34)
Metropolitan	0.116	0.025	-0.088	-0.055
	(2.85)	(0.54)	(-1.88)	(-1.28)

Table 5 (cont.)

	(1)	(2)	(3)	(4)
Transportation Dummies:				
Located on Navigable River or Canal	-0.001 (-0.01)	-0.021 (-0.41)	-0.026 (-0.52)	-0.020 (-0.44)
Located on Ocean	-0.010 (-0.13)	-0.022 (-0.32)	-0.052 (-0.78)	-0.060 (-0.97)
Occupational Dummies:				
Commerce/Wh. Collar			0.605 (8.60)	0.492 (7.37)
Traditional Artisan			0.259 (4.23)	0.224 (3.83)
Machinist/Toolmaker			0.830 (9.16)	0.607 (7.72)
Metal Worker/Dealer			0.420 (3.98)	0.330 (3.19)
Great Inventor Dummy				1.009 (18.13)
R^2	0.035	0.040	0.090	0.211
N	2957	2957	2957	3140

Table 5 (cont.)

Notes and Sources: The first three regressions were estimated over all of the patents in the general sample filed in northeastern states between 1790 and 1842; the data for the fourth regression also included the additional observations from the "great inventors" sample. The constant refers to a patent filed during 1836-42 in a rural Pennsylvania county without access to a navigable waterway by an individual for whom either no occupation is available or his occupation is different from those represented by the occupational dummies. See the note to Table 4.

as the size of the market, but we contend that it nevertheless contains valuable information about the people who were carrying out patentable invention. The results support the argument that this era of major growth in inventive activity was associated with a disproportionate rise in patenting by segments of the population which had previously not been very oriented toward invention. This increase in patenting participation was especially marked in districts beginning their transition to high levels of patents per capita.

Perhaps the most telling sign of a broadening of the population of patentees is the robust finding that the number of career patents per patentee peaked during 1790-1804. In all of the specifications estimated, the coefficient on the dummy for these years was positive and statistically significant, while those for later sub-periods were close to zero and insignificant. There was evidently a decrease in the number of career patents for the average patentee during the Embargo years which was sustained afterwards. If one accepts the interpretation of the measure, the obvious inference is that the first major surge in patenting was disproportionately accounted for by patentees who had relatively modest investments in invention-generating capital and accordingly pushed the average number of career patents down.

Although the time trend is a decline to a lower plateau, most of the other coefficients suggest that career patents increased with conditions normally associated with development. For example, career patents were higher in urban and metropolitan areas, in counties in which patents per capita were higher, and in Southern New England and New York which were the most economically developed regions. A variety of explanations could be

offered for the greater commitments to patenting in such districts, including differences in occupational composition, or the responses of individuals to the greater opportunties derived from larger markets and richer supplies of capital and information. Whatever the particular source, however, the small coefficient on local patents per capita implies that most of the variation in patents per capita across place and time was due to differences in the proportion of the population who patented - not to differences in the number of patents per patentee.[19]

This aspect of the spread of high levels of inventive activity during early industrialization is reflected in the performance of the dummy variable for proximity to a navigable waterway. Although such access to transportation raised county-level patents per capita between 55 and 90 percent, the regression in column (1) indicates that it did not lead to any immediate increase in career patents per patentee. Again, it appears that the growth of patenting initiated in rural counties when they were opened up to low-cost transportation was realized virtually exclusively through individuals who had limited experience with patenting if not invention as well. These additional patentees were like their peers without proximity to waterways in terms of their longterm commitment to invention, but there were many more of them in proportional terms.[20] Notions that the early rise in inventive activity was confined to a technical elite who were best positioned to recognize and exploit new information seem, therefore, inappropriate for the first stage of the transition in rural counties.

Although most of the growth in patents per capita was accounted for by individuals with a small number of career patents, the regressions demonstrate that individual investments in invention-generating capital did

yield more patentable ideas. This is a crucial point, because the inferences we draw about longterm commitments to invention from information on career patents rest on an assumption that such returns were present. The evidence consists of the large positive coefficients on the dummy variables for machinists, metal workers/dealers, and "great inventors", classifications which are associated with investments in technical or specialized knowledge. Moreover, a similar finding for patentees who were in commerce or the professions may indicate that those who had invested in capital allowing for better commercial exploitation of patentable ideas were also likely to register more patents.

II

This paper has suggested that the beginning of rapid growth in inventive activity in the United States coincided with a substantial broadening of the segments of the population who participated in patenting. Indeed, nearly all of the initial rise in patenting per capita was produced by the increased proportion of the population who patented, as awards became less concentrated among commercial/professional occupations, urban residents, and individuals with multiple career patents. This shift in the composition of patentees was especially pronounced in transitional counties which had gained access to water transportation, but lacked significant urban centers. At a later stage, there may have been a shift back toward patentees with more career patents, especially in the more developed areas, because of change in the occupational composition of the population or the evolution of higher returns to investment in invention-generating capital in such districts.

One of the implications of these results is that the knowledge and skills necessary for patentable invention at the beginning of industrialization were widely dispersed among the general population. Although training in technical occupations did yield many more patents for the particular individual, such backgrounds were not at all required. The state of technology combined with the endowment of the population evidently permitted a rather elastic supply of patentable ideas. These special circumstances undoubtedly made it easier for the economy to realize major and broadly-based increases in invention and productivity growth, once conditions raised the private return to inventive activity and encouraged a reallocation of resources in that direction.[21]

All of this enhances our understanding of the record of inventive activity, but the fundamental issue still remains. What do these patterns in the characteristics of patentees indicate about the source of the sharp rise in patenting during the early nineteenth century? The answer will certainly not be as simple as the question, but it is clear that the explanation will have to focus on what pulled men with relatively common sets of skills and knowledge into invention. For this reason, the new evidence makes it more difficult to maintain that exogenous advances in technical knowledge, or in its diffusion, drove the beginning of the process. Instead, we would highlight the disproportionate responses of "low-commitment" individuals to market demand in these transitional counties and during business cycles. The case is not yet closed, but the greater sensitivity of this key group of patentees provides further evidence that the expansion of markets was a powerful inducement to the increase of inventive activity during early American industrialization.

FOOTNOTES

1. For example, see Kenneth L. Sokoloff, "Inventive Activity in Early Industrial America: Evidence From Patent Records, 1790-1846," Journal of Economic History, 48 (December 1988), pp. 813-850; H.I. Dutton, The Patent System and Inventive Activity During the Industrial Revolution, 1750-1852 (Manchester, 1984); Christine McLeod, Inventing the Industrial Revolution: The English Patent System, 1660-1800 (Cambridge, ENG, 1988); and Richard J. Sullivan, "England's 'Age of Invention': The Acceleration of Patents and Patentable Invention During the Industrial Revolution," Explorations in Economic History, 24 (October 1989), pp. 424-452.

2. Joel Mokyr, The Lever of Riches: Technological Creativity and Economic Growth (Oxford, 1990).

3. Historians of American technology generally emphasize that many people were familiar with the basic technology of the period and capable of producing useful inventions. See David Hounshell, From the American System to Mass Production, 1800-1932 (Baltimore, 1984).

4. For discussions of the data set, and of the workings of the patent system during the period, see Sokoloff, "Inventive Activity...".

5. For a review of the literature using patent count and patent renewal data, see Ariel Pakes and Margaret Simpson, "Patent Renewal Data," Brookings Papers On Economic Activity: Microeconomics (1989), pp. 331-401.

6. The logic is that individuals with large investments in invention-generating capital will tend to focus their attention on ideas which involve capital equipment - both because they probably have a

comparative advantage in such inventions, and because such inventions are more likely to yield returns to the inventor. For an interesting treatment of the bias toward inventions involving large scale or capital equipment, see Stephen A. Marglin, "What Do Bosses Do?: The Origins and Functions of Hierarchy in Capitalist Production," Review of Radical Political Economics, 6 (Summer 1974), pp. 60-112. For a discussion of the importance of investment in capital equipment, see Kenneth L. Sokoloff, "Investment in Fixed and Working Capital During Early Industrialization: Evidence from U.S. Manufacturing Firms," Journal of Economic History 44 (June 1984), pp. 545-556.

7. Other scholars have noted the pro-cyclicality of patenting. For example, see Dutton, The Patent System...; Jacob Schmookler, Invention and Economic Growth (Cambridge, MA, 1966); W.W. Rostow, The British Economy of the Nineteenth Century (Oxford, 1948); and T.S. Ashton, Economic Fluctuations in England, 1700-1800 (Oxford, 1959).

8. For further discussion of the Embargo period and the cyclicality of patenting, see Sokoloff, pp. 819-830. For a theoretical treatment of related issues, see Paul M. Romer, "Endogenous Technological Change," unpublished working paper (Chicago, 1989). For different perspectives on the pro-cyclicality of invention, see Robert C. Allen, "Collective Invention," Journal of Economic Behavior and Organization 4 (1983), pp. 1-24; and Andrei Shleifer, "Implementation Cycles," Journal of Political Economy 96 (December 1986), pp. 1163-1190.

9. Patentees active at the beginning or the end of the period will have some of their patentable ideas unrecorded in our data, and accordingly have their career patent (or would-be patent) totals undercounted.

Although careful examination indicated that patentees active after 1842 suffered from this problem (leading to a downward bias in the estimate of their career patents), we have not been able to detect much of an effect for those who filed before. Hence, it is only the observations from 1843 on which are suspect and deleted from the regressions below. Since any bias during the 1790s would work against our argument, no adjustments to the sample were made there. The 1836 change in the patent system could also have accounted for some decline in the average number of career patents. However, since most of the shift toward patentees with relatively few patents was realized during the Embargo years, it is unlikely that either the institutional change or the cutoff at 1846 could provide an adequate explanation.

10. The term "invention-generating capital" encompasses any human or physical capital which raises individual productivity in inventive activity. Such effects can be either sector-specific or general.

11. If information on the occupational distribution of the underlying population was available, estimates of occupational patenting rates could be computed. The lack of detail about those individuals who did not receive patents, as well as the absence of information on occupation for most of the sample, raise questions for the interpretation of the regressions presented below.

12. Part of the trend in the occupational distribution may be due to the development of a market for inventions, which reduced the requirement for capital to commerically exploit a patent. Licensing and sales of patent rights became more common over the period. See Dirk J. Struik, Yankee Science in the Making (Boston, 1948) for further discussion.

13. Members of the commercial class may have received patents for ideas conceived by others. The distinction between intellectual and economic responsibility illustrates how complex the sources of invention are.

14. Metropolitan patentees received 31.3 percent of all patents during 1805-1811, but only 22.1 and 28.0 percent in 1830-1836 and 1836-1842.

15. George S. Gibb, The Saco-Lowell Shops (Cambridge, MA, 1950), p. 10.

16. Although there were patentable inventions which could be used in more than one sector, our sectoral classification mitigates the potential mismeasurement of specialization. We were consistent about classifying closely-related inventions in the same sector. Hence, even though a patentee might have registered several patents for steam engines to be used in different sectors, all of his patents would be in the same category, and he would be considered specialized. Inclusion of dummy variables for sectors in the specialization regressions did not alter the qualitative results.

17. Dutton argued that patentees during early British industrialization were not very specialized. Although his classification scheme and estimates of the degree of specialization are not directly comparable, it appears that American patentees were even less specialized. His data also imply that British patents were much more concentrated among patentees with many career patents than U.S. patents were. Although many factors may contribute to these differences, the much higher cost of securing a patent in Britain presumably played some role. See Dutton, chpt. 6.

18. See the discussion in Sokoloff, "Inventive Activity...," pp. 830-847.

19. Accounting decompositions of the differences between metropolitan, urban, and rural counties, or between regions, yield the same conclusion.

20. Those with low-cost transportation were, however, less specialized. They may, at first, have been more inclined to change their livelihoods after the opening to the wider market.

21. See Kenneth L. Sokoloff, "Productivity Growth in Manufacturing During Early Industrialization: Evidence from the American Northeast, 1820-1860,: in Stanley L. Engerman and Robert E. Gallman, eds., Long-Term Factors in American Economic Growth (Chicago, 1986).