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8 Invention, Innovation, and Manufacturing Productivity Growth in the Antebellum Northeast

Kenneth L. Sokoloff

8.1 Introduction

Economic growth and advances in the standard of living are ultimately rooted in the processes by which improvements in techniques, organization, and products are discovered and implemented to make more productive use of available resources. These processes of invention, innovation, and the diffusion of technical change involve many aspects of social and economic behavior, and are fundamental to long-run progress in a population's material welfare. They appear to have first accelerated and become self-sustaining in the United States early in the nineteenth century, gaining strength in the Northeast and later spreading to other areas of the country. This initial phase of growth has long been associated with marked productivity growth in manufacturing, and the relative expansion of that sector. How, why, and to what extent manufacturing enterprise realized such gains at this time are thus central questions to any understanding of the onset of American industrialization and of the course of living standards.

Work on antebellum economic growth has been much influenced by a general controversy about the sources and potential for productivity advance in

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manufacturing by preindustrial societies (Rostow 1960; Landes 1969; Marglin 1974; Wrigley 1988). One group of scholars has always been skeptical about the achievement of a rapid rate of growth before 1840 (Martin 1939; Taylor 1964; Chandler 1977). Although their views derive partially from the available national data series, they typically hold that only very limited increases in productivity were feasible prior to either major capital deepening or the introduction of a new generation of technologies and capital equipment quite different from those preceding. Since neither the use of machinery driven by inanimate sources of power nor highly capital-intensive techniques became widespread in manufacturing until the 1840s and 1850s, adherents of this position regard the possibility of substantial progress before then as quite unlikely. Others have suggested that changes in production methods or organization that did not involve new types of capital equipment were often implemented to undercut labor costs or autonomy, and questioned their effectiveness at increasing actual efficiency (Ware [1924] 1959; Dawley 1976; Faler 1981; Wilentz 1984).

Another intellectual tradition can be traced back at least as far as Adam Smith and has been represented in the dispute over the record of U.S. economic growth during the antebellum period by Simon Kuznets, among others (Smith [1776] 1976; Kuznets 1952; David 1967; Gallman 1971). This perspective views preindustrial economies as generally characterized by high transportation costs, low incomes, limited commercial development, and accordingly extensive opportunities for productivity and income growth without visibly dramatic alterations in technology. In particular, the extension of markets and shifts in expenditure patterns that accompany the beginning of economic growth stimulate economy-wide improvements in productivity through a variety of means, including more effective or intensified use of resources, scale economies, the introduction of new or higher-quality products, learning-by-doing and other forms of human capital accumulation, as well as increased specialization by factors of production. For example, I have argued in a series of articles that manufacturing industries drew on quite different sources of productivity growth during the first phase of American industrial development—often involving changes in the organization of workers or modest alterations in products or tools rather than major increases in capital intensity or mechanization—than they did later (Sokoloff 1982, 1984a, 1984b, 1986; Goldin and Sokoloff 1982). With these and similar advances in agriculture and other sectors, the U.S. economy was able to realize rapid and sustained growth by the 1820s (Gallman 1975; Rothenberg's chapter in this volume). They were followed by a perhaps more dramatic and enduring era of gains associated with widespread use of machinery driven by inanimate power sources.

These two streams of thought differ about the actual record of growth in the antebellum period, as well as in their basic conception of the process of technological change during early industrialization. The former emphasizes the primacy of radical innovations and downplays the returns to improvements in organization. Its proponents see such major technological breakthroughs as arising independently of Smithian processes, being embodied in capital equipment, clustered in a few key industries, and producing an unbalanced and highly discontinuous pattern of productivity increase (Rostow 1960; Chandler 1977; Crafts 1985; Wrigley 1988; Mokyr 1977, 1990). In highlighting the sweeping effects of a few specific advances such as the diffusion of inanimately powered machinery, the railroad, and the telegraph, this interpretation diminishes the significance of general mechanisms at work and focuses attention on the idiosyncratic aspects behind all singular events.

In contrast, what might be called the Smithian view focuses on the stimuli to increases in productivity provided by the expansion of markets (Landes 1969; Habakkuk 1962; Lindstrom 1978; Sokoloff 1986, 1988). Gains were realized through a variety of means, including changes in the utilization and organization of resources, the production process, and the design of products or capital goods. Although perhaps individually modest, the cumulative impact of an economy-wide series of incremental improvements of this sort was substantial. This perspective presumes that there was a broad potential to increase productivity while operating within the bounds of existing technical knowledge, and argues that the responses of firms to the increasing opportunities and challenges associated with the extension of markets involved an accelerated tapping of this potential. Once the process got under way, the people were not simply passive observers to these developments, but actively sought through both private and government intervention to promote and quicken their pace—say, by building roads and canals. This conception is one of rather balanced productivity growth, in which commercial development spurred advances that were realized and diffused gradually across a broad range of industries. Moreover, it allows for a greater flexibility of traditionally organized establishments and can more easily explain the persistence of regional differentials in performance.

Our understanding of manufacturing productivity growth during early American industrialization has been enhanced over the last decade by a number of studies based on material not previously examined systematically. This paper reviews these contributions, with particular attention to what the patterns of advance in measured productivity suggest about the sources of technical change and the circumstances that encouraged this progress. Overall, the evidence indicates that Americans were quite responsive to economic opportunities, and that the expansion of markets during the antebellum era stimulated a wide spectrum of producers to raise their commitments of resources to inventive activity and to squeeze out whatever increases in productivity could be obtained.

8.2 Data and Measurement

Scholars of antebellum manufacturing have benefited considerably from sharply falling costs in the collection and analysis of machine-readable data. Most prominent among the windfalls have been the samples of manufacturing-firm data drawn from various censuses or from archives of business records. Jeremy Atack, Fred Bateman, and Thomas Weiss have been pioneers in assembling such data sets for the mid- to late 1800s, and I as well as William Lazonick and Thomas Brush have followed in working with materials from the first half of the century (Atack 1976, 1977, 1985, 1987; Bateman and Weiss 1981; Sokoloff 1982, 1984a, 1984b, 1986; Lazonick and Brush 1985). These new bodies of evidence have made it possible to compute indexes of productivity across firm-specific characteristics—both cross-sectionally and over time. Information on individual establishments provides a much richer and more accurate understanding of how and why productivity varied than alternatives like state totals. The study of technical change has also been aided by the construction of samples of patent records linked to patentees and the localities in which they lived (Sokoloff 1988).

Of course the task of establishing the record of antebellum productivity growth in manufacturing has not yet been reduced to a matter of mere arithmetic. On the contrary, the measurement and analysis of productivity are always difficult, and the problems are especially severe in early industrial economies. At a basic level, the first censuses were conducted by and of a society with limited experience in such national efforts to gather comprehensive information. Not surprisingly, the surveys suffer from underenumeration, with the deficiencies in coverage varying systematically across classes of establishments (Fishbein 1973; Atack 1987; Sokoloff 1982, 1986). Questions of how to assemble a representative sample of observations afflict those working with other sources as well.

At a more global level, the major changes in technologies, the extent of markets, relative prices, and tastes that are characteristic of the onset of economic growth raise a special set of problems. Perhaps chief among them is the difficulty of distinguishing between changes in allocative efficiency and changes in the productivity of resources, given their allocation to a particular use. The expansion of markets, encompassing decreases in transaction and transportation costs, led to significant gains through greater specialization of factors, declines in seasonal unemployment, and other such improvements in the utilization of resources (Taylor 1951; Lindstrom 1978; Sokoloff and Dollar 1992). One would, for example, ideally like to decompose the substantial advance in the productivity of rural manufacturing between the portion due to the demise of inefficient producers driven by enhanced market competition and that attributable to the diffusion of or improvement in best-practice technology. Such calculations are challenging in any context, but are made immensely more complicated by the general lack in the antebellum censuses of a detailed accounting of the amount of time per year in which the designated inputs were actively involved in the manufacture of the specified output. Productivity is thus understated for enterprises operating part-time—where labor divided its year between agriculture and manufacturing.[1] Given the decline over the period in the prevalence of such establishments, the raw data yield biased estimates of productivity growth over time. Although the finding of rapid progress may not be sensitive to the choice between reasonable adjustments for this issue, the results concerning the relative significance of different sources of that progress almost certainly are.

Another sort of measurement problem stems from the inadequacies of the price indexes available for the deflation of reported current values of output over time to constant dollars. The principal issue is that the conventional indexes underestimate the rate of productivity growth, because they do not fully capture the improvements in the quality of goods over time (Brady 1964, 1966, 1972; Gordon 1990). The resulting bias could well be of a significant magnitude, because of the great increase in the variety and quality of goods and services made available for consumption during this phase of economic growth (Depew 1895; Larkin 1988). A second problem, however, is that high overland transportation costs often produced significant geographic differences in commodity prices, particularly between rural and urban districts. Without location-specific price indexes, cross-sectional productivity comparisons will be biased in favor of, and estimates of progress over time biased against, firms in areas with relatively high prices (Sokoloff and Villaflor 1992).

A further obstacle is that it is difficult to discern from census data much detail about the techniques and inputs in use at the firm level. Instead, one must rely on indirect inferences from the quantitative information provided on inputs and outputs. Without a knowledge of how firms differed with respect to technique, organization of production, equipment, products, social infrastructure, or the intensity of labor, however, there appears to be little hope of unambiguously establishing the contributions of specific changes in methods of manufacture to variation or increases in measured total factor productivity. Part of the problem is conceptual, because there are unresolved questions about how to treat phenomena like the increased intensity of labor, but most is due to the limitations of the bodies of evidence we have to work with.

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[1] A number of the northeastern establishments enumerated in the 1820 census of manufactures appear to have been operating part-time, either seasonally or irregularly throughout the year. Nearly all of these were located in rural areas. By 1832, however, well over 90 percent of the firms covered by the McLane Report were reported to be in full-time year-round production. The exceptions are overwhelmingly composed of putting-out establishments in the boot and shoes, tobacco, and palmleaf hats industries, or iron and steel establishments located on streams that froze during the winter months. In the census manuscripts for 1850 and 1860, few of the northeastern firms seem to have been operating part-time, but a great many in the South and Midwest evidently were—especially in the liquors and grain-milling industries. See Tchakerian (1990) for an extensive discussion of the latter, as well as Sokoloff (1982, 1986).

A final issue related to measurement is how to identify and better understand the processes generating the increases in manufacturing productivity during early industrialization. Competition in product markets and improvements in transportation can presumably explain the onetime gains due to greater specialization as well as the diffusion of innovations, but what accounted for the sustained acceleration of technical change? If a valid measure of invention were available, one could distinguish empirically between the view that the evolution of technological knowledge was driven by its own internal dynamic and was relatively independent of economic conditions, and the hypothesis that the expansion of markets was a major promoter of technical progress. Recent attempts, including my own, to use patent counts for this purpose have been very useful, but are obviously imperfect and quite controversial (Schmookler 1966; Sokoloff 1988; MacLeod 1988; Sullivan 1990; Mokyr 1990; Sokoloff and Khan 1990). Patents not only miss a good deal of, and probably most, invention but also include many valueless contributions. The variation in patenting in this particular context, however, may be at least qualitatively representative of the resources consumed in inventive activity. Since patent counts seem to provide the best measure currently available, they should be carefully examined rather than broadly dismissed (Griliches 1990). Alternative interpretations of their patterns of systematic variation can be more easily assessed in specific cases.

8.3 The Growth of Patenting and Inventive Activity

Americans were concerned with improving the material welfare of their families from the first days of settlement. They cherished a culture and set of social institutions that protected individual expression and the returns to enterprise, and defended them during the Revolution (Doerflinger 1986; Greene 1988). The debates over the early patent system reflected these sentiments, as well as an appreciation of the long-term social benefits of stimulating inventive activity through granting inventors limited property rights to the income yielded by their inventions (Machlup 1958). It was taken for granted that would-be inventors were influenced by the prospects of material gain. On that basis the drafters of the Constitution authorized a patent system whose establishment and improvement followed quickly in the laws of 1790 and 1793. From various alternative methods of rewarding inventors, a patent system was specifically selected. Both the designers and the judicial enforcers of the system intended and judged the increase in patents over time to manifest an increase in inventive activity. The recent use of patent records to investigate the growth of invention might thus be said to draw intellectual support from those who lived through the period.

As evident in figure 8.1, a sustained acceleration of patenting began during the first years of the nineteenth century, with the per capita rate rising more

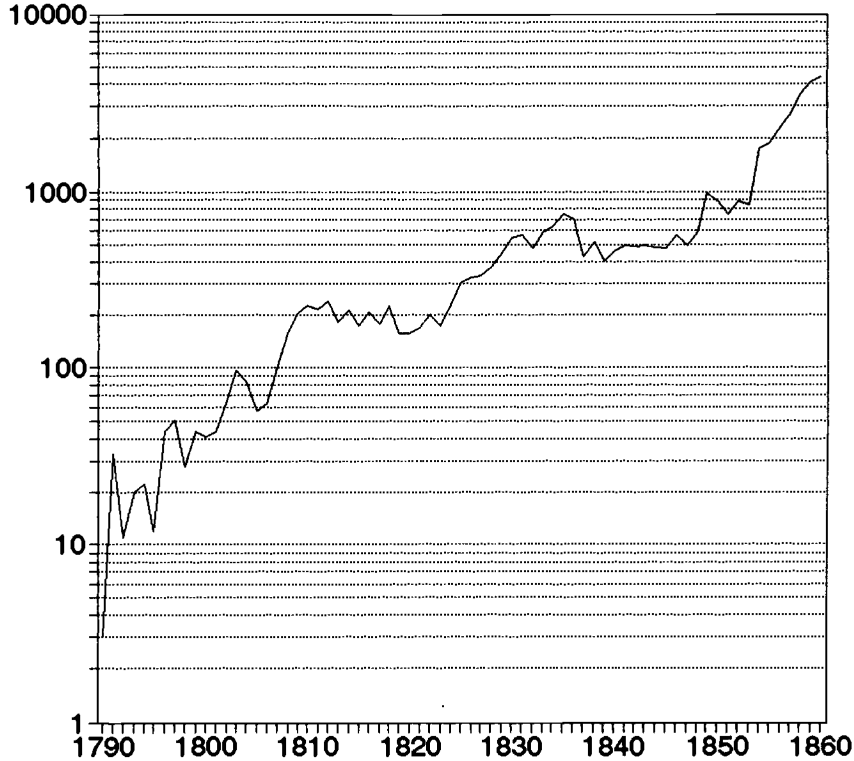

Fig. 8.1 Annual numbers of patents issued, logarithmic scale, 1790–1860
Source: U.S. Bureau of the Census (1975, ser. W99).

than fifteen times from 1790 to 1860. Conspicuous in virtually all industries and geographic districts, especially where markets were expanding, the increase was remarkable in scope as well as magnitude. The key issues about this development are whether the higher rates of patenting are representative of higher levels of inventive activity and, if so, what conditions accounted for the change. Although its sources are many and complex, I have argued that the extraordinary expansion of markets characteristic of the early stages of industrialization must have played a quantitatively important role (Sokoloff 1988). Several features of the evidence suggest this interpretation. First, the numbers of patents filed were quite sensitive to macroeconomic conditions, as seen in the sharp rise in activity before the War of 1812, when interruptions in the supply of foreign manufactures sparked a burgeoning of intraregional trade within the Northeast. This was an unusual source of boom times for domestic producers, but the remainder of the antebellum patent records was more conventionally procyclical, with downturns associated with the protracted contractions following the war and the Panic of 1837, and growth accompanying the long upturn of the 1820s and early 1830s.[2]

Even more compelling support of an association between patenting and the size of markets is the finding of much higher levels of patenting per capita in regions and counties with low-cost access to market centers as well as in urban centers (see table 8.1). In districts along the Erie Canal, where a more precise timing of the gaining of access is possible, there was a rapid and dramatic response in patenting to the opening of such facilities for low-cost transportation. Moreover, since the quantitative significance of extending navigable waterways on patenting was formidable in itself, a more comprehensive gauge of the expansion of markets would presumably yield a major impact. This combination of cross-sectional and longitudinal evidence indicates that the extent of markets influenced the rate of patenting, but the specific mechanisms remain unclear. These patterns could be due to the reactions of potential inventors or innovators to the greater commercial opportunities posed by larger pools of customers, the heightened competition arising from distant producers, improvements in the flow of information about technology, or changes in preferences and cultural attitudes.

Another salient aspect of the record of invention during the early American industrialization is that the same geographic areas maintained leadership in patenting throughout the antebellum period. By 1805–11, southern New England and New York had attained per capita patenting rates that were more than twice as high as those in any other part of the Northeast, and nearly three times the national average. Although the gaps had narrowed slightly by the mid-1840s, these two subregions still enjoyed an advantage of more than 50 percent over the next highest, Pennsylvania. By 1860, southern New England and New York were accounting for more than half of the nation's patents with only a fifth of its population. Southern New Englanders were especially inventive, with a rate that was 150 percent that of New Yorkers, 250 percent that of Pennsylvanians, and more than 300 percent that of northern New Englanders.[3] This persistent superiority of southern New England and New York cannot be attributed solely to more extensive transportation networks, larger

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[2] See Sokoloff (1988) for more discussion of the procyclicality and of how its variation in intensity across sectors and regions is very consistent with the view that the cycles were accounted for by market demand. The sharp rise in patenting during the late 1840s and 1850s may be more attributable to the nature of the technical change being realized at that time, however. In particular, these were years in which many new machines were developed and mechanization spread throughout the manufacturing sector for the first time. Patents for inventions embodied in capital equipment were easier to enforce.

[3] The annual numbers of patents per million residents during the 1850s were 249.6 for southern New England, 166.0 for New York, 100.3 for the southern Middle Atlantic, 95.8 for Pennsylvania, and 75.0 for northern New England. Connecticut and Massachusetts had the highest rates—274.1 and 252.3, respectively. Overall, the leadership of southern New England, and Connecticut and Massachusetts in particular, increased from the 1840s to the 1850s in both absolute and percentage terms. See U.S. Patent Office (1891).

Table 8.1 **Annual Patent Rates per Million Residents, by Subregion, 1790–1846**

	1791–98	1799–1804	1805–11	1812–22	1823–29	1830–36	1836–42	1843–46
Northern New England								
Rural	0.7	4.5	13.0	15.4	33.8	69.1	28.1	16.3
Urban	—	—	9.8	11.4	9.9	50.2	42.1	27.6
Metropolitan	—	—	—	—	—	—	—	—
Total	1.9	7.5	15.2	15.1	33.0	65.5	32.9	20.0
Southern New England								
Rural	2.0	7.5	68.7	51.1	61.9	65.4	49.9	45.9
Urban	0.0	22.4	34.6	37.9	44.0	106.3	68.8	57.0
Metropolitan	11.9	78.5	291.5	244.9	160.0	226.9	213.9	265.5
Total	7.2	26.7	65.2	55.4	60.4	106.4	79.5	74.5
New York								
Rural	0.0	0.8	46.6	32.5	56.5	72.0	20.8	23.6
Urban	12.3	15.3	33.3	39.7	86.5	62.1	34.4	54.1
Metropolitan	24.8	68.0	121.4	116.0	159.7	196.7	131.9	148.4
Total	10.9	16.4	62.0	49.9	81.3	95.6	49.6	65.8
Pennsylvania								
Rural	0.0	0.0	11.9	11.3	20.3	38.1	18.8	22.8
Urban	0.0	8.6	17.3	8.7	8.4	31.4	20.7	22.1
Metropolitan	63.4	6.7	122.2	162.1	118.7	140.7	98.3	130.9
Total	17.2	14.5	29.7	33.6	32.2	53.3	32.9	42.5
Southern Middle Atlantic								
Rural	0.9	6.0	7.8	19.9	17.7	17.3	29.2	8.9
Urban	4.8	11.9	12.3	20.6	8.0	21.1	24.1	47.1
Metropolitan	17.6	35.2	131.7	108.7	105.6	134.4	82.1	111.8
Total	4.1	17.0	23.7	34.9	31.9	41.4	40.8	40.0
Other states	1.2	3.4	3.4	6.1	10.4	13.2	7.7	9.9
National average	5.2	11.3	23.9	22.9	30.0	41.8	24.5	27.3

Notes: Northern New England includes Maine, Vermont, and New Hampshire; southern New England includes Connecticut, Massachusetts, and Rhode Island; southern Middle Atlantic includes New Jersey, Delaware, Maryland, and District of Columbia. The counties were categorized for urbanization in each census year, and the reported figures for urban and rural districts are based on a rolling set of counties. Metropolitan counties, however, are composed in all years of those counties that contained a city of 50,000 or greater in 1840; urban counties are those that contained a city of at least 10,000 residents or were adjacent to a metropolitan county in the respective years. See Sokoloff (1988) for further information.

urban populations, or relative specialization on manufacturing. In regressions that control for these and other relevant variables, the higher patenting rates in southern New England and New York counties were estimated to be highly significant in a statistical sense (Sokoloff 1988).

To the extent that patenting is a meaningful gauge of inventive activity, these findings bear directly on the hypothesis that technical change depended on breakthroughs in mineral-based technologies and in the design of machinery. First is the matter of timing. Although major waves of diffusion of mechanization, steam power, and the railroad beginning in the late 1840s were accompanied by an upturn in patenting, the acceleration of the secular trend was by then forty years old. It was not therefore inspired by these heroic "macroinventions" (Mokyr 1990). Second, the responsiveness of patenting to market demand across a wide range of industries directly contradicts the claim that invention was exogenous with respect to economic conditions. Instead, the finding is consistent with the position that in early industrial America, where familiarity with the basic elements of technological knowledge was common among the population, valuable improvements in technique, organization, and design of product were induced by market pressures. Finally, the enduring leadership of southern New England and New York suggests that the more capital-intensive technologies of the late antebellum era evolved out of those in use during the preceding phase of Smithian growth.

The changes over time in the composition of patentees is consistent with this framework of two phases in technical change during the antebellum period. Merchants, professionals, and others from elite occupations had their share of patents fall substantially over the very beginning of the nineteenth century, with a growing contribution by artisans and other manual workers, those in the countryside, and individuals who had limited investments in technical skills or other invention-generating capital (Sokoloff and Khan 1990). This broadening of participation in patenting reveals a process in which an increasingly wide range of individuals was coming to redirect attention and resources toward commercial endeavors including invention and innovation (Gilmore 1989). Greater involvement by men with relatively ordinary endowments is suggestive of markets expanding opportunity for greater numbers rather than of technical breakthroughs facilitating further invention by the select few able to apply or refine them.

Although my work with Zorina Khan (1990) emphasized how the early rise in patenting was associated with a growing proportion of the population being involved in inventive activity, we also noted indications of the increasing importance over time of investment in what we termed "invention-generating capital." For example, trends toward greater specialization and increases in the number of lifetime patents by patentees were evident by the middle of the nineteenth century. We interpreted these findings as reflecting a rise in the return to, and investment in, invention-generating capital—and the beginning of the modern pattern in which the bulk of invention is carried out by factors specialized in that activity. Individuals with such investments would be expected to cluster in cities where there were greater incentives to specialize as well as a relative abundance of resources to support inventive activity or innovation. Indeed, we found that patentees in urban areas were more specialized and filed more patents over their lifetimes. Although the first phase of growth in patenting was marked by the democratization of invention, the later stages of development were characterized by the growing importance of technical expertise for effective invention.[4]

Despite the apparent relevance of patenting rates, some scholars have expressed skepticism about the usefulness of the information contained in the rates for the study of the origins of technical change. These reservations are generally based on either the variability in the value of inventions underlying patents or in the rates at which individuals choose to patent their inventions. Both of these conditions tend to erode the quality of patenting rates as a measure of inventive activity. To the extent that patents are representative of invention or other efforts to improve technique or products, however, there should be a relationship between these rates and productivity.

To explore this point, estimates of manufacturing productivity by geographic area are reported in table 8.2. Overall, they support the interpretation of patenting rates as reflective of inventive activity and of other efforts to improve efficiency, because manufacturing productivity was higher in areas with higher patenting rates. For example, southern New England had the highest number of patents per capita for virtually the entire antebellum period, and it stands out here as the subregion with the highest productivity, even after adjusting for urbanization. This superior performance by firms in southern New England is consistent across all four samples, and is generally statistically significant.[5] Another regularity in the data is that firms in urban counties were more productive than their rural counterparts, just as city residents outpatented their neighbors in the country. At the bottom of the scale, rural Pennsylvania and northern New England counties had both the lowest manufacturing productivity and patenting rates in the Northeast.[6]

Since cross-sectional variation in patenting across subregions was relatively stable over time, there is no effort here to explore whether comparisons be-

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[4] See Sokoloff and Khan (1990) for evidence on the greater specialization of patentees in urban areas and from more technical occupations. In research yet unpublished, we find a marked increase from the first to the second half of the nineteenth century in both specialization and the average number of career patents filed over a patentee's lifetime among a sample of 160 inventors whose inventions have been judged to be especially significant. Also see Thomson (1989) on this point. We also find that these "great inventors" disproportionately originated from areas with high patenting rates like southern New England and urban centers like New York, and that those born elsewhere were disproportionately inclined to migrate to these same districts.

[5] The results from the 1820 sample diverge from the others in that the geographic differentials are uniformly lacking in statistical significance. The higher standard errors on the coefficients may reflect the effects of the severe economic contraction, which ended shortly before the census and had sharply reduced the demand for industrial products (Thorp 1926). Many of the enumerated establishments reported operating at far below capacity, and this could have increased the variance of the distribution of firms by productivity (Sokoloff 1982; Atack 1987). The results might also be partially due to the procedure by which likely "part-time" firms were identified and dropped from the analysis. See Sokoloff (1986) for details.

[6] It is noteworthy that the rural counties in these two subregions had both their relative productivity and patenting rates decline significantly over the 1850s relative to those in southern New England and New York.

Table 8.2 **Indexes of Regional Manufacturing Productivity, 1820–1860**

	1820	1832	1850	1860
Northern New England				
Rural	88	87*	90*	83*
Urban	—	—	109	91*
Southern New England				
Rural	100	100	100	100
Urban	85	111*	114	106
New York				
Rural	91	—	89*	92
Urban	107	—	101	106
Pennsylvania				
Rural	88[a]	—	91*	74*
Urban	92[a]	—	98	98
Southern Middle Atlantic				
Rural	—[a]	—	104	91
Urban	—[a]	—	109	98

Sources: These indexes were computed from regressions estimated over the same subsamples of manufacturing firms examined in table 8.4. See the note to that table. The regressions employed only dummy variables for industries and for interactions between region and urbanization as independent variables. The logarithm of a value-added-based measure of total factor productivity served as the dependent variable. See Sokoloff (1986) for the selection of output elasticities.

Notes: Northern New England includes Maine, New Hampshire, and Vermont; southern New England includes Connecticut, Massachusetts, and Rhode Island; southern Middle Atlantic includes Delaware and New Jersey. Urban counties are those that contained cities with populations of 10,000 or greater and those adjacent to counties with cities of 25,000. Rural counties are the residual counties. Productivity in rural southern New England was set equal to 100 in each year, and productivity in other areas is reported relative to that standard. Asterisks indicate that the difference between the denoted districts and the standard of rural counties in southern New England is statistically significant.

[a] The Pennsylvania and southern Middle Atlantic observations were pooled in 1820, because of their small number.

tween productivity and current or lagged patenting activity would be more appropriate. Despite the lack of explicit attention to the issue of the rate of technological diffusion, the estimates do yield some insight on the subject. When product markets are in a stable competitive equilibrium, there should be no systematic regional differences in productivity. Then why are such differentials observed in the manufacturing data, and why are they correlated with patenting activity?

One possibility is that the differentials existed because transportation costs insulated certain areas from the market and allowed inefficient firms to survive in competition. That those same districts had lower patenting rates was strictly coincidental and did not contribute to the lower productivity. Another explanation is that the deviation from a competitive equilibrium was due to technical change being generated from investment in inventive activity at particular geographic sites and then slowly diffusing. At any point in time, the districts that were the technological leaders (i.e., southern New England) accordingly exhibited higher productivity. Firms in persistently backward areas were able to survive in competition, however, if they avoided or reduced the costs associated with acquiring new technologies by being a follower, or enjoyed lower factor costs. Although transportation costs undoubtedly protected pockets of inefficient establishments, the evidence seems to indicate that differences in inventive activity must have also played some role. It is hard, for example, to explain the roughly constant geographic differentials over time with transportation costs when the latter were declining. Moreover, the association between patenting rates and productivity held among urban counties, which were unlikely to be insulated from competition, as well as rural.[7]

8.4 Manufacturing

Increases in income from the reexport trade and gains in agricultural productivity stimulated expenditures on manufactures through the 1790s and into the first few years of the 1800s, but significant growth of domestic production appears not to have begun until just before the War of 1812. Domestic manufacturers had previously found it difficult to compete with British goods, but the interruptions of foreign trade greatly enhanced their effective opportunities (Cochran and Miller 1961; Spivak 1979). Due to the small scale of manufacturing enterprise, many firms could be quickly established in response, and production became concentrated in the Northeast. The lure of material benefit was reinforced by patriotic appeals and public sentiment in favor of national autonomy in manufactures. Also conducive were the extensive investments in transportation infrastructure undertaken privately but encouraged by government at all levels (Meyer, MacGill, et al. 1917; Goodrich 1960; Goodrich et al. 1961). As an increasing number of workers specialized in nonagricultural products, and as household incomes rose, the markets for farm produce in the Northeast expanded as well. The volume of intraregional trade grew rapidly, and areas that had previously been largely isolated economically were gradually drawn into a broad northeastern, if not national, market (Lindstrom 1978).

This growth in manufacturing production occurred from a very modest base. At the turn of the nineteenth century, even the cities relied on foreign sources for many high-value items. Rural residents produced many of their

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[7] In multivariate regressions, wage rates at the firm level were found to be positively and significantly related to local patenting rates and to firm productivity. Although relevant, this evidence does not help to discriminate between the two competing theories. On one hand, if the wage differentials pertained to identical workers, they could reflect the protection from competition provided by transportation costs to firms in outlying areas. If they were due to workers in counties with high patenting rates and high measured productivity having more human capital, however, then they might reflect a difference in the quality of labor required to operate with a new technology. In either of these cases, higher labor costs per worker might partially or even fully offset the advantage in measured productivity enjoyed by firms in the latter set of counties and slow the process by which the old-technology establishments were forced to upgrade or fail.

manufactured goods at home, or obtained them from travelling artisans who toured the countryside with their tools and materials. Because both the 1810 and 1820 censuses of manufactures are flawed by irregular enumeration, it is difficult to precisely identify how the number and organization of manufacturing establishments evolved over the first two decades of the nineteenth century in the dynamic Northeast (Sokoloff 1982). What is clear, however, is that manufacturing capacity expanded during the embargo and war years and was reflected in decreased household production as well as increased factory production (Tryon [1917] 1966). Though many of the new enterprises did not survive the severe economic contraction that followed the peace, the physical plants often endured and helped support the resumption of the industrial expansion during the 1820s (Ware 1931).

From the information on manufacturing firms contained in the manuscripts of the 1820 census, it is apparent that the great majority of establishments in that year continued to operate at small scales and rely on traditional production processes and capital. Textile mills were of course the prominent exception. Both cotton and wool manufacture were in the process of being transformed by major leaps in the design of machinery and other equipment, and large establishments using the new technologies were springing up throughout the Northeast (Cole 1926; Ware 1931). Virtually all other industries, however, were dependent on hand tools or simple water-powered devices, such as gristmills or trip-hammers, with which manufacturers had long been acquainted; land, structures, and inventories absorbed nearly all of the capital invested in these enterprises (Sokoloff 1984a). In rural areas, firms in such labor-intensive industries were quite small, with fewer than five adult males and perhaps an apprentice. It was typical in such "artisanal shops" for all workers to be skilled and involved in carrying out all steps in the production process (Sokoloff 1984b). Firms in or near urban counties were generally larger and organized differently. Although operating with essentially the same capital to labor ratios as those of the small shops, these manufactories or so-called nonmechanized factories were distinguished by work forces disproportionately composed of women and children, an extensive division of labor, a more intense pace of work, and greater standardization of output (Goldin and Sokoloff 1982).

Recent examinations of manufacturing-firm data have found substantial evidence that these manufactories were significantly more productive than artisanal shops (Sokoloff 1984b; Atack 1987). Cross-sectional analyses indicate significant differences in total factor productivity between the two modes of organization, with economies of scale being exhausted in labor-intensive industries at a size of about twenty employees. Other approaches to testing the hypothesis yield supportive results as well. For example, average firm size in such industries increased steadily over the antebellum period and was strongly related in cross-section to proximity to market. As their shares in output fell over time, the artisanal shops that survived the competition were increasingly located in small towns insulated by high transportation costs or were focused on satisfying narrow market niches like the demand for custom-made goods.

Detailed studies of the evolution of technology in industries such as boots and shoes, clocks, coaches and harnesses, furniture, glass, iron and steel, meat packing, paper, tanning, and cotton and wool textiles suggest a two-stage process in antebellum productivity growth (Hazard 1921; Cole 1926; Ware 1931; Davis 1949; Habakkuk 1962; Smith 1971; Hirsch 1978; Walsh 1982; Paskoff 1983; Hounshell 1984). The first stage was to occupy most of the sector for the first half of the nineteenth century, and was exemplified by the rise of manufactories. Their increases in technical efficiency stemmed from a series of improvements or refinements in the organization of production and from relatively subtle modifications of output and in traditional capital equipment. Just as the data from the manufacturing censuses reveal only a modest increase in the capital intensity of most industries until the 1850s, when mechanization diffused widely, industry studies highlight the gradual development of a more extensive division, with an accompanying intensification, of labor and the substitution of less-skilled workers for more-skilled as the most salient changes in technique prior to midcentury. Also noted are improvements in traditional tools and instruments like drills, lathes, and planes, as well as alterations in the product aimed at differentiation or at facilitating standardized production under the new organization of labor (Hounshell 1984; Smith 1977). As important as some of these changes proved to be, few outside of textiles seem to have either constituted or required a fundamental breakthrough in technical knowledge.

The second phase of technical change in manufacturing was distinguished by an increasing reliance on machinery driven by inanimate sources of power, although it also encompassed some modifications in organization to exploit the full potential of the more sophisticated capital stock (Lazonick and Brush 1985; Rosenberg 1963, 1972). Precisely where one draws the line in classifying a particular invention is not always clear, but those scholars who claim a revolutionary character to mechanization perceive a qualitative difference between the introduction of a new type of equipment and an alteration to a familiar tool. The textile industries are clearly the first to have entered into this stage of technical change, but many other industries had joined them by 1860. Judging both from industry studies and the degree of capital intensity revealed in firm data, the 1850s were the crucial decade of transition in the Northeast.

Estimates of the growth of labor and total factor productivity between 1820 and 1860 have been computed from the samples of manufacturing census manuscripts by class of industry for rural and urban counties in the Northeast. Perhaps the most important aspect of these figures, reported in table 8.3, is how rapid the rates of advance were. Despite the late diffusion of mechanization and inanimate power sources to most industries, total factor productivity in each of the categories grew over the entire period at almost the same rate as

Table 8.3 **Per Annum Growth Rates of Labor and Total Factor Productivity, by Classes of Manufacturing Firms, 1820–1860**

	1820–50	1850–60	1820–60
Mechanized Industries			
Labor productivity			
Rural	1.2%	3.5%	1.8%
Urban	2.8	2.0	2.6
All	2.1	2.4	2.2
Total factor productivity			
Rural	1.2	4.2	1.9
Urban	2.2	2.2	2.2
All	1.8	2.7	2.1
Less- or Non-mechanized Industries			
Labor productivity			
Rural	1.8%	4.3%	2.4%
Urban	0.5	3.7	1.3
All	1.5	3.9	2.1
Total factor productivity			
Rural	1.8	2.0	1.9
Urban	0.8	2.0	1.1
All	1.5	1.9	1.6
Capital-Intensive Industries			
Labor productivity			
Rural	1.4%	2.8%	1.8%
Urban	2.3	1.8	2.2
All	1.9	2.3	2.0
Total factor productivity			
Rural	1.2	3.3	1.8
Urban	1.8	1.9	1.8
All	1.6	2.5	1.8
Labor-Intensive Industries			
Labor productivity			
Rural	1.6%	5.6%	2.6%
Urban	0.7	4.4	1.7
All	1.7	4.5	2.4
Total factor productivity			
Rural	1.9	2.8	2.1
Urban	1.0	2.5	1.4
All	1.8	2.1	1.9

Notes and Sources: These estimates are for value-added-based measures of labor and total factor productivity. Similar qualitative results were obtained when using total value of output as the measure of product. The classification of firms as urban or rural was based on the population figures in the current censuses. A firm was treated as rural unless it was located in a county with a city of 10,000 people or greater, or in a county that was adjacent to a county with a city of more than 25,000. The mechanized industries consist of cotton textiles, wool textiles, paper, glass, flour milling, and iron and steel. The capital-intensive industries consist of cotton textiles, wool textiles, paper, flour milling, iron and steel, liquors, and tanning. The other industries included in the analysis are boots and shoes, coaches and harnesses, furniture and other wood-

Table 8.3 (notes, continued)

work, hats, and tobacco products. These estimates were computed with the same data and virtually identical procedures to those employed in Sokoloff (1986). See the notes in that paper to tables 13.7 and 13.12 in particular. The figures differ slightly; because of the small number of observations the glass industry was dropped from the calculations, and industry weights obtained from the subsample of firm data were used rather than those from the 1850 aggregates by state.

the long-term trend in manufacturing since 1860.[8] Skepticism about the centrality of capital equipment for technical change is further enhanced by the finding that total factor productivity rose in the labor-intensive and less-mechanized industries nearly as fast before the 1850s as in that decade of intense capital deepening and widening mechanization. Comparisons of the rates of labor and total factor productivity growth sow other doubts; in a growth accounting framework capital deepening explains little, and total factor productivity growth virtually all, of the substantial growth of labor productivity over the antebellum period—even in the most capital-intensive and mechanized industries. Only during the 1850s was capital deepening quantitatively important, accounting for more than half of the increase in the labor productivity of labor-intensive and less-mechanized industries.[9] Given that these same industries registered increases in total factor productivity that rivalled those of their counterparts, the clear implication is substantial technical change overall and a relatively limited role for physical capital accumulation within the manufacturing sector.

Disaggregating the record of productivity growth by class of district offers some insight into the spread of technical change. Of greatest interest is that between 1820 and 1860 the labor-intensive and less-mechanized industries realized more rapid total factor productivity growth in rural areas than in urban. The contrast is especially stark over the first thirty years, when progress was composed largely of changes in the organization of production and incremental improvement of tools and products. This pattern is consistent with the view that earlier access to broad markets had by 1820 already induced firms in cities to take advantage of scale economies as well as to explore these other means of increasing productivity. As falling transport costs expanded markets geographically over the next thirty years, rural firms were similarly stimulated to innovate, adopt, and make up ground on their urban competitors. Both sets of firms registered a sharp acceleration in technical change over the 1850s,

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[8] See Kendrick (1961) for his estimate that total factor productivity in manufacturing grew at 1.8 percent per annum between 1869 and 1953. See Sokoloff (1986) for further discussion.

[9] In the framework adopted here in which value added serves as the measure of output and capital and labor are the only inputs, the contribution of capital deepening is equivalent to the rate of labor productivity growth minus the rate of total factor productivity advance. The striking increase in capital intensity and in the relative contribution of capital deepening during the 1850s is characteristic of virtually all of the relatively labor-intensive industries. See Sokoloff (1986), especially tables 18.8 and 13.13, for further discussion and evidence.

and their close-to-equivalent rates of progress may indicate a more rapid rate of diffusion for major advances embodied in capital equipment.[10]

The pattern was different among capital-intensive and mechanized industries. Here, the urban sector drew ahead between 1820 and 1850, but rural firms caught up with extraordinary 4.2 and 3.3 percent per annum rates of advance in total factor productivity over the next decade. Since the performances of the two sets of establishments were virtually identical over the period as a whole, one might be impressed by how quickly or evenly the early technological advances, such as power looms in textiles, had diffused between urban and rural areas. If one focuses on the unbalanced progress before and after 1850, however, the experience appears more consistent with invention or technological innovation originating in cities before spreading slowly to the countryside.

Some of the estimated rapid growth in manufacturing total factor productivity may be due to the realization of scale economies or to problems in measurement, but it is clear that taking account of such factors does not alter the qualitative results. Scale economies, for example, will not help explain the advances registered by firms in urban counties. Moreover, both Atack (1987) and I (1984b, 1986) have found that the extent of cross-sectional variation in total factor productivity with firm size pales relative to the estimated increase between 1820 and 1860.[11] As for part-time establishments, their declining prevalence is also unlikely to explain much of the pattern of widespread substantial advances. Not only were the growth rates computed from 1820 data that were carefully screened to exclude such firms, but information contained in the 1832 McLane Report indicates that they were no longer common in the Northeast.[12] Finally, because the price indexes underestimate the improvement over time in quality, as well as the fall in output prices for rural firms, the figures in table 8.3 likely understate, rather than overstate, productivity growth—especially for the rural establishments (Sokoloff and Villaflor 1992).

Given the robustness of the finding of rapid technical change to a consider-

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[10] See Hirsch (1978) for a detailed and well-documented discussion of the diffusion of technical change in many of these labor-intensive industries over the 1850s. Her evidence from the census manuscripts for Newark is quite consistent with the interpretation offered here.

[11] Neither Atack nor I have presented a precise decomposition of the proportion of measured total factor productivity increase due to the realization of scale economies. Although one could be prepared, it would be unlikely to significantly advance the state of knowledge. The qualitative answer is already clear, and the deficiencies of the 1820 census complicate the task of obtaining a robust point estimate. Of particular concern are the unrepresentativeness of the firms enumerated in that census and the inclusion of establishments operating part-time.

[12] See Sokoloff (1986) for a discussion of the procedures employed to identify and omit from the analysis those firms more likely to have been operating part-time. As mentioned in note 1, many of the firms enumerated in the McLane Report provided information about the number of weeks they operated each year. Long average workdays were also indicated (Atack and Bateman 1992). Based on both pieces of information, year-round full-time production appears to have been the norm by 1832, except for a few narrow categories of enterprises. Given the conventional understanding of what part-time operations pertain to, it appears unlikely that the decline in their prevalence could account for much of the increase in measured productivity.

ation of scale economies and measurement problems, the fundamental question to ask is from whence it came. The popular view that the onset of growth arose from a few key and exogenous inventions has been influential, but is it consistent with the available evidence? The record of manufacturing productivity suggests not. Instead of a strong association between mechanization or capital deepening and technical advance, the data indicate that more modest changes in organization and tools boosted productivity across a broad range of industries. Such gains seem unlikely to have been contingent upon a few exogenous breakthroughs. Rather, they were the sorts of improvements that would be expected if market conditions induced firms to experiment and develop better ways of carrying out production. Additional evidence of demand-induced or endogenous technological change comes from the demonstration that the growth in patenting rates was closely related to the expansion of markets and from the geographic correspondence across subregions between higher manufacturing productivity and higher patenting. If higher patenting rates do indeed reflect greater inventive activity or more of a commitment to searching for ways of improving productivity, what remains to be established is a linkage between firm productivity and local patenting rates that is robust to controlling for other variables.

Table 8.4 establishes such a linkage in presenting cross-sectional regressions estimated over samples of firm data for 1820, 1832, 1850, and 1860. The logarithm of total factor productivity is the dependent variable, and the independent variables include the logarithm of the current or most recent rate of patents per capita in the local county, as well as various dummies for industry, subregion, level of urbanization, and firm size. Although the size and significance of the coefficient varies somewhat across years, the central result of a positive relationship between firm productivity and local patenting rates is robust. With the 1820 and 1832 samples, for example, the qualitative finding is insensitive to reasonable changes in the time intervals used to identify current patenting rates, different definitions of urbanization, the inclusion of dummies for access to navigable waterways, and dropping establishments from mechanized industries out of the analysis.[13]

Since only a small fraction of inventions were ultimately patented, and

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[13] Many alternative specifications were estimated. The qualitative results are insensitive to the use of a measure of total factor productivity based on gross output as the measure of output, as well as to different methods of dealing with issues of firm size, urbanization, access to transportation, regional effects, and the time frame for current patenting rates. The only specifications that yield insignificant coefficients on the patenting rate are those that include a number of other collinear variables such as dummies for firm size, urbanization, subregion, and interactions. The results are slightly sensitive to introducing geographic restrictions on the subset of firms over which the regressions are estimated. Given the relatively small number of counties represented in the samples, however, this pattern is not disturbing. In general, the statistical relationship between productivity and local patenting rates is much stronger for labor-intensive industries than for highly mechanized industries like textiles. Hence, the qualitative results hold when the regression analysis is confined to the former, but not when it is confined to the latter.

Table 8.4 Cross-sectional Regressions with Total Factor Productivity as Dependent Variable, 1820–1860

	1820			1832			1850				1860			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Constant	3.828	3.850	3.820	3.772	3.566	3.563	4.363	4.385	4.353	4.247	4.279	4.227	4.199	4.098
	(39.85)	(37.44)	(33.66)	(19.44)	(17.46)	(17.19)	(44.09)	(42.85)	(42.20)	(41.05)	(39.18)	(37.44)	(37.44)	(35.48)
Log (patents per capita in local county)	0.024	0.027	0.028	0.105	0.106	0.078	0.013	0.011			0.022	0.012		
	(3.18)	(3.13)	(3.02)	(2.63)	(2.69)	(1.93)	(2.30)	(1.74)			(3.01)	(1.61)		
High patenting by 1820									0.175	0.098			0.252	0.174
									(3.42)	(1.78)			(4.02)	(2.37)
High patenting by 1850									0.071	0.056			0.082	0.033
									(1.90)	(1.49)			(1.75)	(0.68)
Northern New England		0.012	−0.002					−0.081	−0.069	−0.047		−0.078	−0.57	−0.025
		(0.17)	(−0.04)					(−1.92)	(−1.63)	(−1.09)		(−1.45)	(−1.05)	(−0.46)
Southern New England		−0.062	−0.043		0.209	0.161		0.044	0.003	0.002		0.131	0.067	0.025
		(−0.98)	(−0.66)		(2.99)	(2.28)		(0.94)	(−0.07)	(0.05)		(2.37)	(1.18)	(0.41)
New York		0.034	0.035					−0.078	−0.096	−0.093		0.092	0.049	0.055
		(0.66)	(0.67)					(−1.46)	(−1.80)	(−1.76)		(1.40)	(0.74)	(0.82)
Urban			−0.060			0.078				0.018				0.074
			(−1.06)			(2.12)				(0.47)				(1.43)

Major urban center										0.102				0.014
										(1.54)				(0.18)
Medium size			0.074			0.178				0.217				0.159
			(1.22)			(3.86)				(4.88)				(2.89)
Large size			0.020			0.149				0.199				0.200
			(0.26)			(3.12)				(3.53)				(3.28)
R^2	0.12	0.12	0.13	0.07	0.09	0.14	0.06	0.07	0.09	0.13	0.03	0.05	0.07	0.10
N	433	433	433	465	465	465	667	667	667	667	566	566	566	566

Sources: These regressions were estimated over all of the observations in the respective data sets that satisfied the criteria underlying the "B" set of productivity estimates reported in Sokoloff (1986). The dependent variable is the logarithm of total factor productivity, where output is measured as value added, and the procedures and parameter estimates used in its calculation are described in that same paper. A set of dummy variables for industry was also included as independent variables in these regressions, but their coefficients are not reported here. The estimates of patents per capita by county are drawn from Sokoloff (1988).

Notes: For 1820, 1832, 1850, and 1860, the patent rates pertain to the years 1812–22, 1822–30, 1843–46, and 1843–46, respectively. Hence, the 1860 regressions rely on a quite dated estimate of patenting activity. The actual estimate of the patent rate was augmented by 0.1, so that a logarithm could be taken for counties with patenting rates of zero. The dummy variables for high patenting signify when counties achieved sustained high rates of patenting, with an annual rate of forty per million residents serving as the threshold. Those that did so by 1820 were flagged by the first dummy. Those that did so by 1843–46, but not by 1820, were flagged by the second. Urban firms were located in counties with cities of 10,000 or more or in counties adjacent to others with cities of 25,000 or more. Firms in a major urban center were located in counties with a city that had attained a population of 50,000 by 1850. The dummies for urban and major urban center are not exclusive. Firms of medium size had six to fifteen employees; large firms had more than fifteen employees. In the 1820, 1850, and 1860 regressions, the constant pertains to a small paper mill in a rural county of Pennsylvania, Delaware, or New Jersey. Because the 1832 regressions could only be run over New England firms, the constant pertains to a northern New England paper mill. *t*-statistics are reported within parentheses below the respective coefficients.

many patented inventions proved to be of little use, the finding is unlikely to be picking up a causal relationship between productivity and patented inventions per se. Instead, the association is probably due to the joint conditions that patenting rates were representative of all of a population's efforts to increase the value of output obtained per unit of input, and that productivity was causally related to the rates of inventive activity in this broad sense—inclusive of innovation, adoption of superior techniques developed elsewhere, and invention. In principle, one might argue that both productivity and patenting rates were higher in some districts for reasons other than invention and innovation leading to increases in efficiency. For example, skeptics could offer the caveat that in counties with a higher level of education or degree of commercialization, productivity and patenting might both be enhanced, but unrelated to each other. When one critically examines the alternative interpretations, however, few prove satisfactory. Some fail to persuade because they fit less well with evidence that increases in productivity were sensitive to market conditions and were achieved through incremental or organizational change. Others do so because they fundamentally reduce to the same basic idea—that is, greater competition led to higher productivity by ensuring that only those firms able to stay on the cutting edge of technology survived.

Of course the ultimate persuasion is the richness of the evidence. Beyond robustness, there are several other reasons for believing that the statistical association between productivity and patenting is actually picking up the effect of higher rates of invention or innovation on productivity. First, the regression coefficients imply that the geographic differentials in productivity accounted for by patenting were of quite plausible magnitudes. For example, given the observed variation in patenting rates, the coefficients from the 1820 equations suggest that differences in patenting would lead firms from rural counties in southern New England to be about 9 percent more productive than their rural counterparts in either northern New England or Pennsylvania after controlling for other variables. The size of this effect is thus economically significant, conceivable given the less than perfectly integrated product markets of that era, and roughly equivalent to the geographic differentials reported in table 8.2

Another reason to believe that the regression results reflect a genuine relationship between productivity and inventive activity is that the coefficients on the patenting rate are simply more stable and consistently significant than those on other proxies for background characteristics that might be correlated with measured productivity. Moreover, as seen in equations (4) through (6), the same qualitative results hold when the observations are restricted to estab-

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14. The questionnaires used by McLane Report enumerators to survey firms in New England and the Middle Atlantic were not consistent in their treatments of several variables. Since the two groups of observations cannot be pooled for analysis of productivity, the 1832 regressions were estimated over the New England firms alone. Since nearly all of the Middle Atlantic firms come from western Pennsylvania, and there is little variation in patenting rates across the covered coun-

lishments in a particular region like New England.[14] Although variables for subregion, firm size, urbanization, and access to transportation are correlated with patenting, and typically depress the latter's statistical significance when appearing in the same regressions, this perhaps crude measure of inventive activity outperforms them in accounting for cross-sectional variation in productivity.

If there is any ambiguity in the evidence, it is with the regressions estimated over the 1850 and 1860 data. When the only independent variables are industry dummies and the logarithm of the local patenting rate in 1843–46 (the latest years for which it can be calculated), the results are qualitatively the same as in the earlier years. But the size of the coefficient on and the statistical significance of the patenting rate decrease with the addition of dummies for subregion, urbanization, and firm size. The diminished explanatory power and statistical significance may be due to the greater error in measurement from the use of dated patenting rates.[15] Especially with multicollinearity between subregion and patenting, the additional noise in the measure might lead the subregional dummies to serve as better proxies for inventive activity and pick up more of the explanatory power and statistical significance.

Two other approaches for getting at the relationship between productivity and patenting in these later years were tried. In the first, as continuous variables state-level patenting rates computed from aggregate data for 1840–49 and 1850–59 were included in lieu of the dummies for subregion and found to be positive and statistically significant in both 1850 and 1860. In the other, reported in table 8.4, dummy variables for the local county having achieved sustained high rates of patenting by 1820 or 1850 were included as the proxies for inventive activity.[16] These capture an interesting pattern in the data. Firms in counties that had achieved high patenting by 1820 stand out as being much more productive than their counterparts after controlling for other characteristics. This effect is large overall (about 17 percent in 1860 by equation [14]), pronounced in the rural counties of southern New England, and consistent with the hypothesized relationship between productivity and patenting. The same areas that led in patenting at 1820 (such as around Boston or along the Connecticut River valley; see Sokoloff 1988) also were at the forefront of the rapid surge of the late 1840s and the 1850s (see figure 8.1). Although a fine

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ties, it is not surprising that regressions over only these observations yield an insignificant coefficient on the patenting rate variable.

[15] The sample of patents employed to compute the county patenting rates does not extend beyond 1846. Accordingly, the latest interval for which the country rates can be computed is 1843–46. These figures are of course dated estimates of patenting rates in 1850 and 1860 and, as the figures in note 3 suggest, likely to be systematically biased as well as to contain random measurement error. Both should lead the coefficient on the current patenting rate to be biased toward zero.

[16] These dummies pertain to a county achieving an annual patenting rate of more than forty per million residents and maintaining or increasing it for an indefinite period—by either 1820 or between 1820 and 1850, respectively.

breakdown by county is not yet available for these later years, the point can be illustrated with state data. In each of the two decades, Connecticut and Massachusetts had the highest patenting per capita in the country, nearly twice that of New York and three times that of Pennsylvania.[17]

Taken together, the cross-sectional regressions provide substantial evidence that increases in the commitment of resources to inventive activity or innovation, as reflected in higher patenting rates, raised productivity. In doing so, they support the view that technological change was stimulated by the expansion of markets and that this aspect of early growth helps to explain how the process became self-sustaining. They also reinforce the case established above, that much of the initial advance in manufacturing productivity was realized through improvements in organization and other changes in practice that did not require breakthroughs in technical knowledge and were perhaps easier to generate as a result. They do not, however, reject the influence of supply-side factors on the course of technical change. It remains clear that the effects of a specific change in market conditions on the inputs devoted to inventive activity or on successful invention depend on a range of circumstances including the state of technology, as well as the industrial composition, the endowments of the population, and the supply of capital to entrepreneurs in the respective locality. Since demand-side conditions grew more uniformly distributed by the end of the antebellum period, the persistence of large location-specific effects in patenting and productivity suggest that supply-side factors were important and slow to change.

The significance of both demand- and supply-side conditions on the processes generating technical change is supported by the pooled cross-section regressions presented in table 8.5. Total factor productivity again serves as the dependent variable, with the independent variables including the previous set of dummies for industry, subregion, urbanization, and firm size, as well as the patenting rate in the local county, dummies for the year of the observation and for the achievement in the local county of a high patenting rate by 1820, and interaction terms. Equations (1) and (2) control for changes in industrial and regional composition in finding that productivity grew rapidly between 1820 and 1860, especially during the 1820s and 1850s. The results are consistent with the hypothesis that demand-side conditions contributed to this progress, because the estimated coefficients on patents per capita in the local county are

[17] From the 1840s to the 1850s, the patenting rates rose in southern New England from 82.1 to 249.6; in New York from 63.7 to 166.0; in Pennsylvania from 38.5 to 95.8; in northern New England from 24.5 to 75.0; and in southern Middle Atlantic from 45.5 to 100.3. Connecticut and Massachusetts raised their rates from 83.1 to 253.1 and from 92.0 to 274.1, respectively. It is clear that southern New England experienced a marked increase in its relative patenting rates between the 1840s and the 1850s. Since the change was both substantial and to some degree a reversion to an earlier pattern of great dominance in patenting by southern New England outside of metropolitan centers, it is plausible that the dummies relating to past records of patenting are better representations of the patterns of patenting in 1850 and 1860 than the 1843–46 rates are. See U.S. Patent Office (1891).

Table 8.5 **Pooled Cross-sectional Regressions with Total Factor Productivity as Dependent Variable, 1820–1860**

	(1)	(2)	(3)	(4)
Constant	3.879	3.868	3.879	3.789
	(75.60)	(72.75)	(70.47)	(67.88)
Log (patents per capita)	0.018	0.016		
	(5.02)	(3.78)		
Log (patents per capita) × mechanized industry		−0.014		
		(−1.30)		
Northern New England		−0.073	−0.058	−0.039
		(−2.70)	(−2.14)	(−1.42)
Southern New England		0.049	0.022	0.018
		(1.74)	(0.73)	(0.59)
New York		0.010	−0.003	0.002
		(0.31)	(−0.10)	(0.07)
Urban				0.026
				(1.10)
Major urban center				0.100
				(2.53)
Medium size				0.175
				(6.98)
Large size				0.162
				(5.66)
1832	0.254	0.225	−0.227	−0.104
	(8.55)	(6.72)	(−1.04)	(−0.48)
1850	0.341	0.348	0.319	0.309
	(12.45)	(12.63)	(8.47)	(8.25)
1860	0.529	0.534	0.472	0.460
	(18.86)	(18.95)	(11.91)	(11.70)
Log (patents per capita) × 1820			0.019	0.016
			(2.00)	(1.69)
Log (patents per capita) × 1832			0.125	0.075
			(2.48)	(1.47)
Log (patents per capita) × 1850			−0.002	−0.007
			(−0.27)	(−0.87)
High patenting by 1820			−0.024	−0.130
			(−0.43)	(−2.23)
High patenting by 1820 × 1832			−0.005	0.144
			(−0.06)	(1.91)
High patenting by 1820 × 1850			0.202	0.255
			(2.54)	(3.23)
High patenting by 1820 × 1860			0.288	0.281
			(3.94)	(3.88)
High patenting by 1850 × 1850			0.067	0.069
			(1.47)	(1.53)
High patenting by 1850 × 1860			0.100	0.060
			(2.49)	(1.50)
R^2	0.18	0.19	0.20	0.23
N	2,133	2,133	2,133	2,133

Notes: See the note to table 8.4. The dummy for mechanized industries pertains to cotton textiles, wool textiles, and iron and steel.

positive, highly significant, and similar in magnitude to the point estimates obtained in the cross-sections for 1820, 1850, and 1860.[18] Given the substantial changes in patenting rates over the period, the stability of the coefficient to introducing variation over time in patenting increases confidence that the statistical association is not an artifact. Although only marginally significant, the negative coefficient in equation (2) on the interaction between the current patenting rate and a dummy for mechanized industries highlights the possibility that the patterns of invention and diffusion were quite different for technical change embodied in capital equipment. For example, the weaker association between firm productivity and local patenting activity could be due to such technical change diffusing more rapidly through the sale of the capital equipment, or to its being less responsive to demand-based stimuli.

Dummy variables for firm size, degrees of urbanization, and location in a county that had achieved a high patenting rate by 1820, as well as a number of interactions between year and measures of patenting activity, are added to the specification in equations (3) and (4). Again the qualitative results are essentially the same. Controlling for firm size and urbanization indicates that they account for only a small share of the estimated advance in manufacturing productivity between 1820 and 1860. Most of the increase in total factor productivity was clearly realized through technical change. Even more strongly than in the cross-sectional regressions, there is a shift over time in the relationship between productivity and patenting. The coefficients on the interactions between the year dummies and the patenting rate suggest that productivity was positively and continuously related to patenting in 1820 and 1832. Such interactions yield insignificant coefficients for 1850 and 1860, however. Instead, the terms that interact these years with dummies for counties that achieved high patenting rates by 1820 have large, positive, and significant coefficients. Overall, the general pattern is that the increase of productivity with the record of patenting had become a stepwise function by 1850, whereas it had been continuous earlier on. The step increase is much larger for firms in counties that had achieved sustained high levels of patenting early in the process of growth—by 1820—than for counties that had achieved those levels later.

This shift in the quantitative relationship between productivity and the record of patenting likely reflects some aspect of the course of technical progress in antebellum manufacturing. One hypothesis is that the decline over the period in the explanatory power of patenting activity was due to the slow

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[18] The regressions provide indirect support to the hypothesis that demand-side factors, working through markets, stimulated technical change. Their direct implication is that manufacturing productivity was higher in counties with higher patenting rates, bolstering the interpretation that the latter reflect rates of inventive activity. Not all influences on patenting rates operate through markets, but given that patenting was responsive to market demand and that the extension of navigable waterways accounts for a significant amount of the growth in patenting in the Northeast over the early nineteenth century (Sokoloff 1988), the finding of the relationship between productivity and patenting seems to sustain the more complex causal path from market stimulus to increase in productivity.

geographic diffusion of invention and other advances in technique. In this view, the dummies pertaining to the timing of the achievement of sustained high levels of patenting have more explanatory power in 1850 and 1860 because they are a better proxy for the local cumulation of several decades of technical change than current patenting activity is. Although not completely implausible, technology would have had to diffuse at a glacial speed to account for, say, why in 1860 productivity was so much higher in firms located in counties that had achieved high patenting rates before 1820. Given the relatively small differentials in productivity between subregions, this interpretation does not seem consistent with the evidence.

Another possibility is that the lack of statistical significance for the patents-per-capita variable in 1850 and 1860 results from having to rely on a dated figure. As discussed above, since 1843–46 is the latest period for which the patent rate is available, the measurement error involved in using it to reflect activity in 1850 or 1860 biases the coefficients toward zero and the standard errors up. Since the group averages they focus on would be less disturbed by this imprecision, the dummy variables could continue to have large and significant estimated effects. Unfortunately for this view, the likelihood that whether a county had achieved a high patenting rate by 1820 is a good indicator of its patenting activity in 1850 or 1860 seems remote, unless there were other factors at work.

Perhaps the most compelling explanation is that the relationship between productivity and patenting evolved with changes in the nature of technical advance and in the processes generating it. From this perspective, there was a tighter relationship between productivity and current patenting rates during the first phase of industrialization, when much of the progress was being realized through incremental alterations in the organization of production. A demand-stimulated increase in the commitment of resources to inventive activity, reflected in higher patenting, could reliably yield an increase in productivity in such a context where the supplies of potential inventors and inventions were relatively elastic.

During the late 1840s and 1850s, however, when technological change in manufacturing consisted largely of the spread of mechanization and was more dependent on technical knowledge and breakthroughs, demand-side stimuli alone may not have been as effective in spurring increases in productivity. As technology grew more complex, success at discovering further improvements required more in terms of technical expertise and other resources, and was increasingly out of the reach of the ordinary man or firm. The distribution across counties of individuals with technical backgrounds, of firms specializing in the production of capital goods embodying technology, and of other supply-side conditions conducive to invention had more and more to do with the geographic pattern of manufacturing productivity, while simple access to broad markets had less. An outstanding example is of course the machine tool industry, which was concentrated in several counties in southern New England

and made technological contributions to a broad range of enterprises through the application of general principles to a variety of specific problems (Rosenberg 1963). Coincidentally or not, the counties in which the industry clustered had been among the early leaders in patenting. Such bunching of industries or resources directed at inventive activity may partially account for why firms in counties that had achieved high patenting rates by 1820 had higher levels of manufacturing productivity in 1850 and 1860.

The notion that, as the principal sources of productivity growth changed, the relative importance of demand- and supply-side factors in accounting for technical change did so as well fits with the observation that southern New England and a few other geographic pockets (mostly urban centers like New York City) continued to lead in both patenting and manufacturing productivity from at least 1820 to 1860. Given that the expansion of the transportation grid had extended low-cost access to broad markets throughout most of the Northeast by 1860, it would be difficult to attribute such durable geographic patterns in patenting to demand alone.[19] Moreover, since all areas were realizing substantial productivity growth over time, southern New England's maintenance of leadership in productivity must have been due to an edge in invention and innovation that allowed its firms to stay ahead of those in other subregions while all were making progress. The straightforward inference is that southern New England and these other centers had or developed endowments or supply-side conditions that helped their firms be more inventive, innovative, and productive.

Whether there was something very special about southern New England prior to the onset of industrialization that prepared it for leadership is unclear. What is clear, however, is that with the same areas providing technological leadership throughout the antebellum period, the two phases of technical change are highly unlikely to have proceeded independently of each other. One phase gave way to the next, with southern New England's initial successes serving to build a comparative advantage for what was to come. This advantage undoubtedly flowed from a variety of factors, including a more developed capital market and a local economy and culture geared toward commerce and rapid change, but much of it probably stemmed from the human capital its ranks of entrepreneurs and workers had acquired in pushing out the technological frontiers during the first few decades of industrialization—in response to expanding markets and opportunities. Local blacksmiths and men trained in textile machine shops evolved into specialized toolmakers and machinists. Many more learned of the potential returns to tinkering and to altering the organization of labor. By the late antebellum period, southern New

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[19] Although it might be possible to explain the very high patenting rates in urban centers like New York, Philadelphia, and Boston as attributable to intense competition characteristic of deep markets, the argument would not seem likely to apply to the high-patenting counties in Connecticut and nonmetropolitan Massachusetts. For a discussion of the extension of low-cost transportation throughout the Northeast by 1860, see Meyer et al. (1917) and Taylor (1951).

Englanders were better endowed and positioned to carry manufacturing technology forward into a more technically demanding era.

8.5 Summary and Conclusions

The record of manufacturing productivity during the antebellum period conforms well with the gradualist path of development envisioned by scholars who share the Smithian perspective on early economic growth. Despite a reliance on traditional labor-intensive production methods before midcentury, a broad range of industries in the Northeast was able to realize substantial progress. Indeed, over the entire period from 1820 to 1860, total factor productivity in manufacturing grew nearly as rapidly as after the Civil War and accounted for virtually all of the increase in labor productivity. Only in the 1850s did a second phase of technological development, characterized by mechanization and major increases in the capital intensity of production, spread beyond textiles to the rest of the sector.

The extraordinary expansion of markets that is characteristic of early industrialization appears to have played a fundamental role in the achievement of these gains and in the elevation of such achievements into a self-sustaining process. Their extension not only yielded improvements in productivity through stimulating the realization of economies of specialization and scale, but also induced individuals and firms to raise their commitments of resources to the search for better techniques and products—making possible a long-term acceleration of growth in productivity and in living standards. This latter impact has long been an issue of debate, but the recent analyses of patterns in patenting provide key evidence for its existence and importance. In particular, the procyclicality of patenting as well as the strong cross-sectional relationship between access to broad markets and patenting rates suggests that the expansion of commerce associated with extensions of the transportation network and increases in income may have been a major factor behind the surges in patenting and in manufacturing productivity of the 1820s and 1830s. Although the underlying value of the resources devoted to the search for technical improvements (or of the discoveries made) may not have varied proportionally with patent counts, the quantitative magnitudes of the changes involved are sufficient to allay reasonable doubts about the qualitative relationships. Moreover, the finding that productivity was significantly higher in areas with higher patenting rates suggests that reservations about inferring variation in inventive activity or innovation from such evidence are less than fully warranted in this context (MacLeod 1988; Mokyr 1990).

Even after the relationship between the extent of markets and investment in inventive activity has been established, there is the question of whether such behavior led to more rapid technical change or productivity growth. Surely this would not always be the case as a general proposition. In circumstances where significant progress is circumscribed by technical obstacles, for example, further investment would not yield advances until a breakthrough in knowledge was achieved. In early industrial America, however, it appears from both industry studies and examination of firm-level data that substantial increases in productivity could be and were realized through incremental changes in the organization of production and in the design of tools or output. These are the sorts of technical changes that could well have been realized continuously in response to investments in inventive activity, and with the participation of a broad cross-section of the population in their discovery and implementation. Indeed, the growth of manufacturing productivity (especially in less capital-intensive industries) and of patenting appear to have spread out together from urban districts after 1820, along with the extension of transportation networks and extensive involvement in inventive activity by individuals with rather ordinary skills and backgrounds. The record of productivity growth is, therefore, quite consistent with the hypothesis that during the initial phase of industrialization "demand-induced" investments in inventive activity yielded technological advances across a wide range of industries.

The newest and perhaps most intriguing evidence presented in this paper is the regressions demonstrating the relationship between firm productivity and local patenting rates. Because the expansion of markets during the first stage of industrialization was a powerful stimulus to patenting, the regressions support the view that this era was one of "demand-induced" technical change in manufacturing. They also indicate the importance of "supply-side" factors, however, and suggest that the latter had become more influential by the 1850s when a "second stage" of progress associated with capital-intensive technologies spread across the sector. The significance of these unidentified "supply-side" factors is revealed in the sustained leadership by the same various southern New England counties and urban centers in patenting and productivity throughout the period from 1820 to 1860. This continuity in leadership is a sign that the series of incremental improvements in production methods associated with Smithian growth did not simply exhaust themselves in a one-time increase in productivity, but rather prepared the ground for the next phase of technically more complex advances. Whether they did so by cumulatively altering the factor endowment in ways conducive to technological change or whether some other forms of local externalities in inventive activity were operating is yet unclear and remains for future research to determine.

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Comment

Jeremy Atack

Kenneth Sokoloff has been extraordinarily creative in his use of quantitative data pertaining to America's early industrialization. In this paper he attempts to tie together two separate threads of that work. One half, represented by his work on pre-Civil War productivity growth in manufacturing, is developed to its fullest in volume 51 of the NBER Studies in Income and Wealth (Sokoloff 1986). Those estimates are based upon firm-level sample data collected by Sokoloff from the federal census of manufacturing for 1820 (National Archives 1964) and from the 1832 McLane Report, and by Fred Bateman and Thomas Weiss from the 1850 and 1860 censuses of manufacturing.[1] They show that manufacturing in the northeastern United States experienced rapid growth in total factor productivity of 1.3–1.5 percent per year in many industries, with somewhat slower rates at the start of the period and faster rates during the last decade (Sokoloff 1986, 718). This pace of productivity growth compares favorably with estimates for later periods by Kendrick (1961) and Gallman (1986, esp. 189–91 and table 4.6). The second half of the theme—the contribution and impact of mechanical inventions—is represented by his more recent work on patenting activity between 1790 and 1846 (Sokoloff 1988; Sokoloff and Khan 1990). The source for these is a sample being developed by Sokoloff from Ellsworth's (1840) and Burke's (1847) patent indexes giving information about the type of patented invention, the name and loca-

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[1] For a discussion of the Bateman-Weiss samples for 1850 and 1860, see Bateman and Weiss (1981) or Atack (1985).

tion of the patentee, and the date. These data show a marked relationship between patenting activity and market access as proxied by improvements in transportation and urban concentration.

The marriage between these two important topics, however, is troubled in a number of respects arising both from the very nature of the data and the kind of inferences being drawn as well as from the methodology by which those inferences are made. The eminently reasonable premise underlying the study is that the level of total factor productivity at specific benchmark dates—1820, 1832, 1850, and 1860—is a function of organizational and mechanical improvements made by firms. The role of organizational improvements, represented primarily by the switch from artisanal shop to mill and factory, has been well documented by both of us and is captured in Sokoloff's estimates by the labor force size dummies and use of steam and water power in the regressions (Sokoloff 1984; also Atack 1986). However, beyond a few well-documented cases such as those textile firms whose records are in the Baker Library, we know very little about the technology employed by individual firms other than their use of inanimate power.[2] Nor do we know much about the average level of technology in most industries at any moment of time. Consequently, Sokoloff attempts to proxy the use of new mechanical improvements by the stock of recent patenting activity around each benchmark date.

Unfortunately, as Sokoloff readily acknowledges, the granting of a patent is neither identical to, nor coincident with, the innovation of an economically significant improvement by potential users. Quite when a patent is granted during the interval between invention and innovation is unclear. However, since the purpose of a patent is to assign and secure the property rights in an invention to the inventor, a request for patent protection should follow hard on the heels of the invention itself in order to maximize that protection. Innovation of a proven and truly useful invention is then diffused over an indeterminate number of years as conditions change, complementarities appear, and the invention is improved and perfected. Even so we know virtually nothing about the various time lags in the process, such as between invention and patent application, between patent application and its granting, or between successful patent application and widespread adoption. The Patent Office (and its predecessor's) records *may* contain information on the lag between patent application and its disposition, but we expect that this interval was relatively short, if only because of the terms of the patent legislation. The original patent act of 1790 provided that patents on "any useful art, manufacture, engine, machine or device or any improvement thereon not before known or used" were to be granted after review by a committee of three cabinet members who were empowered to grant a patent "if they shall deem the invention or discov-

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[2] Both the 1820 census and the 1832 McLane Report (and Sokoloff's samples therefrom) contain some references to the use of specific machines, but, presumably, these were insufficient in number or so inadequate in description as to defy classification and categorization.

ery sufficiently useful or important." The flood of claims, however, became so great that the act was soon amended to provide that after 1793 patents could be granted upon the swearing of an oath by the applicant that the invention was original and did not infringe existing patents, the payment of an application fee, and the presentation of drawings and a working model. One might thus argue that the date at which patent protection was granted was within a year or so of invention.

Unfortunately, this is not too useful a case to make. The impact of an invention depends upon its productivity advantage over existing technologies and the endogenous rate of adoption and the proportion of potential users who have adopted at a moment of time. The lag between invention and innovation can be short. Or it can be long. In the well-known table put together by Enos (1962, 307–8), the interval between invention and innovation for thirty-five inventions ranges from a year in the case of Freon refrigerants to seventy-nine years for the fluorescent lamp and averaged about fourteen years. Perhaps a fairer comparison, though, for this purpose is the interval between invention and innovation of industrial machines, such as the steam engine or spinning machine, or industrial processes, such as shell molding or the hydrogenation of fats. Here, the interval is much shorter, ranging from three to eleven years and averaging less than six years (Enos 1962, 307–8).

Whether fourteen years or six, though, these lags are troublesome for Sokoloff's formulation of the model if it is accepted that the date of the patent is within a year or so of the date of invention. The reason is simple: Sokoloff models 1820 total factor productivity, for example, as a function of the patent rate between 1812 and 1822 in the county in which the firm was located after adjusting for population density, proximity to transportation and communications routes, firm size and organization, and industry. Yet, by my argument, patents granted after about 1816 would not have been adopted in time for the 1820 census, and it seems most unlikely that patents after 1819 should have had *any* effect. Despite this, however, the regression coefficients on the logarithm of the county patenting rate between 1812 and 1822 are generally statistically significant and of the "right" sign (that is, positive) in his estimates of the relationship using the 1820 census data. For much the same kind of equation but using data from the McLane Report for 1832, however, the results are not nearly so good. Here, Sokoloff models total factor productivity in 1832 as a function of the patent rate between 1830 and 1836, although by my argument we would expect these to have virtually no impact. The results appear to bear this out. Only one of the four coefficients is statistically significant at the 90 percent level. The others are not statistically significantly different from zero, and one has the "wrong" sign, which implies that total factor productivity declined with increased local patenting activity.

The underlying model for the 1850 and 1860 estimates is somewhat different, and the question of lags becomes mute. In these, Sokoloff models total factor productivity as responsive to past historic high rates of local patenting activity in the 1820s or during the 1830s and early to mid-1840s. The argument is that productivity was higher where inventive activity was endemic and pervasive at an early date. The results generally support this hypothesis, particularly with respect to high and sustained patenting activity by the 1820s. Continued use of the navigable-waterway variable as a proxy for contact with the larger economy, however, is questionable in the age of the steam locomotive. By 1850, the northeastern states had over 5,600 miles of railroad track, compared with less than 2,250 miles of canals (Taylor 1951, 79). Even adding navigable rivers and lakes to the total fails to alter the inescapable conclusion that the railroad had become the principal avenue of commercial intercourse within the region.

There are, however, even more fundamental and philosophical questions raised by Sokoloff's use of patent data as a proxy for technological innovation. First, implicit in the use of these data is the assumption that all useful inventions received patent protection and that all patented devices were useful. Yet there is ample evidence that neither was, nor is, the case. Only those inventions patented before 1793 and after 1836 were required to prove novelty and usefulness. The vagueness of the patenting process following the 1793 revision and the growing problem of overlapping patent claims led to protracted court cases and the denial of patent protection to many deserving inventions. A case in point is Oliver Evans's patent on the high-pressure steam engine—an invention of the first order of importance—which was eventually disallowed after innumerable and lengthy battles with the government and those who Evans felt infringed upon his patent.[3] Similarly, the principles of Evans's automated grist-milling process were to find widespread application in other industries but were not protected by the terms of the patent.[4] Second, even where usefulness and novelty were amply demonstrated and a secure patent obtained, innovation was less than certain. For example, it took years for millers to adopt Evans's automated grist-milling process, especially farther west, where he eventually offered his machinery free to any miller willing to serve as his agent in an effort to stimulate sales (Evans 1816). Third, not all patents were of equal economic significance, but they are counted as such in Sokoloff's models. Fourth, much productivity growth doubtless originated through mechanisms such as learning-by-doing that were not patentable and are only very imperfectly captured by the dummy variables for firms with "medium" and "large" labor forces that serve as proxies for the opportunities for mechanization and the division of labor.

Given these kinds of considerations, I do not find it too surprising that pat-

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[3] See, for example, Evans's spirited defense in Evans (1805).

[4] Evans (1795), which was continually republished and updated in new editions as late as 1860.

enting appears to have only a very small and marginal impact upon total factor productivity. Indeed, the only surprise is that this slender relationship appears to hold under a variety of different specifications.

There is, however, one specification that I wish had been shown—and one that is certainly more in keeping with the theme of this conference on living standards. I would have preferred that Sokoloff look at the impact of patenting (much of which was in labor-saving technologies) upon labor productivity rather than upon total factor productivity. Given the wage-productivity nexus, this would have provided a much more direct route to at least one important determinant of living standards. The counterargument is that the benefits of total factor productivity ultimately accrue to society as a whole and to individual members depending upon their ownership of specific assets and factors. More pragmatically, however, the decision probably reflects Sokoloff's ill-ease with anomalies in these estimates reported in Sokoloff (1986, esp. 683–97).

I also perceive some other problems with Sokoloff's regression estimates. One is the question of reverse causation; that is to say, poor total factor productivity leads to a search for mechanical improvements, some of which are patentable. More important, though, the dependent variable in each of Sokoloff's regressions, total factor productivity, is unobserved. Instead, Sokoloff estimates it from a hypothetical composite Cobb-Douglas production function. There is, of course, a considerable literature debating the existence, meaning, and interpretation of aggregate production functions (e.g., Fisher 1969), but rather than enter into that debate, let me focus upon more immediate concerns here.

As Abramowitz (1956) has made clear, total factor productivity is the residual output unexplained by the factor inputs. Based upon regression estimates, however, it represents much more; namely it becomes the repository for whatever least-squares errors there are from sources such as misspecification or errors in variables. Misspecification, for example, may arise from the estimation of a single production function across all industries, the imposition of Euler's theorem, or the assumption of unit elasticity of substitution between labor and capital and homotheticity implicit in the Cobb-Douglas form. Of these, I think the first is the most troubling. The substitution of labor productivity estimates that are directly observable would have resolved these questions, and the resultant estimates must contain less "noise" than the estimates of total factor productivity that are used. It would not, however, resolve the question of errors in variables that creep into the data in many ways. For example, at the 1850 and 1860 censuses, firms were to report the average number of male and female employees per month. Even assuming that these were accurately known, since not all firms employed both, Sokoloff must aggregate these into a bundle of equivalent labor. In addition, it is strongly suspected that many if not most smaller firms, particularly sole proprietorships and partnerships, made no allowance for managerial or entrepreneurial labor.

Thus, Sokoloff estimates the labor input as the male employees, plus one-half of the child and female employees, plus one to account for the possible omission of entrepreneurial labor.

My point is not to criticize these decisions—they are ones that I have also faced and made—but rather to point out that the dependent variable, total factor productivity, that Sokoloff seeks to explain in these regressions contains a great deal of noise. Sokoloff tries to finesse some of this noise by truncating the data sets to exclude unusually productive or unproductive firms. In 1820, the bottom 21 percent and the top 3 percent were excluded.[5] The proportions for other years are not reported. One inevitably wonders, though, how sensitive the regression results are to these cutoffs.

The bottom line for me is that, while I am convinced that inventive activity is at least partially market-driven, that innovation is a major source of productivity growth, and that total factor productivity growth was the dominant factor behind labor productivity growth, it is not because of the *empirical* results presented here. Rather I am persuaded by the preponderance of qualitative evidence and the tightly woven theoretical arguments that Sokoloff so cogently presents here and elsewhere.

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[5] These figures do not include those observations that were dropped because of missing data.

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