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# Economies of Scale and Efficiency Gains in the Rise of the Factory in America, 1820–1900

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Sometime between 1820 and 1870 production processes were mechanized in many American industries. This change had a significant impact upon the country's industrial structure. Mechanized production emerged first in the cotton textile industry at the start of the nineteenth century, and it spread only slowly to other industries before mid-century.[1] Thus, in 1820 most manufacturing was carried on either in households or small artisan shops. By 1870, however, home manufactures had all but disappeared and manufacturing was increasingly concentrated in large factories.

This paper investigates the supply forces that brought about these changes. It explains the transition to large-scale mechanized production techniques in terms of productivity gains and scale economies. Despite the cost reductions afforded by these techniques, they were not adopted by all firms in each industry and the size distributions of firms became increasingly bimodal. A few large firms produced a substantial and growing proportion of each industry's total output, while seemingly inefficient and uneconomically small firms proliferated. It is argued that this structure was a result of improving transportation in the developing and expanding economy of nineteenth century America.

The study was sparked by the apparent contradiction between the meager total factor productivity gains for the transition from handicraft to factory production, reported by Kenneth Sokoloff for the first half of the nineteenth century and Carroll D. Wright's late nineteenth century estimates of multifold labor productivity gains from mechanization.[2] Factories, by definition, employed mechanized production techniques, but while Sokoloff's results suggest little competitive advantage from the adoption of factory production, Wright's research implied strong incentives to mechanize.

Despite the fairly small productivity gains from its adoption, the factory spread quite rapidly during the period. It is in search of an economic explanation for this that the paper investigates the possibility of scale economies favoring larger producers. Whereas total factory productivity gains may be thought of as a downward shift in the firm's entire average cost curve as the structure and organization of production is changed, scale economies result in falling unit costs along a given curve as the level of plant output is expanded. The former case assumes scale elasticity to be constant and equal to unity, but production methods change; the latter case rules out shifts in the production function, and hence in the average cost curve, but any change in unit input requirements that are scale related are captured in the elasticity coefficient. Economies of scale proved to be quite substantial. It is argued that they helped to determine the level of production while the productivity differences between factories and other forms of large-scale production explain the choice of techniques.

Most historians have used the term *factory* rather loosely, probably because they have not sought to quantify the extent of the phenomenon. For this essay, however, a precise definition is needed, despite a certain amount of oversimplification that such a definition introduces to the analysis. Factory production depended upon steam or water power to drive machinery. Artisan shops, sweatshops, and manufactories, on the other hand, relied upon hand tools. Human muscle was sufficient for their power needs. Artisan shops, sweatshops, and manufactories are therefore differentiated from factories by the absence of an inanimate source of power, and from one another by the size of their labor forces.[3]

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[1] Victor S. Clark, *History of Manufactures in the United States* (New York: McGraw-Hill for the Carnegie Institution, 1929); vol. 1, pp. 448–455.

[2] See Kenneth L. Sokoloff, "Was the Transition from the Artisanal Shop to the Small Factory Associated with Gains in Efficiency?: Evidence from the U.S. Manufacturing Censuses of 1820 and 1850," *Explorations in Economic History* 21, (Oct. 1984), pp. 351–382; U.S. Department of Labor, *Thirteenth Annual Report of the Commissioner of Labor. 1898. Hand and Machine Labor,* 2 vols. (Washington D.C.: U.S. Government Printing Office, 1899). Wright's study was brought to my attention by Stanley Lebergott's recent text, *The Americans: An Economic Record* (New York: Norton, 1984), p. 135.

[3] The categories are Artisan shops: No steam or water power, 1–6 employees; Sweatshops: No steam or water power, 7–25 employees; Manufactories: No steam or water power, over 25 employees. This classification is similar to that developed by

However, reliance upon inanimate power alone is not sufficient to identify a factory since plants using inanimate power were called mills from the very beginning. Consequently, this paper uses a second distinguishing characteristic of a factory, namely, that labor was specialized. Despite Victor Clark's observation that "it is impossible to define precisely at what point the . . . mill became a factory,"[4] it is assumed for the purposes of this essay that specialization could not be practiced extensively unless a mill had more than twenty-five workers. A factory is therefore defined as an inanimately powered plant employing over twenty-five workers.[5] The division between mills and factories is arbitrary but was selected so that it was more likely that some factories would be misclassified as mills than vice versa.

The transition from shop to factory was of great importance for later development. Alfred D. Chandler, Jr. regards the factory as the genesis of the modern business enterprise. In his analysis, the factory emerges as a response to new power sources and widening market opportunities.[6] To Marxists, the factory represents a further decisive step in the divorce of the worker from control over the means of production. Craftsmen in the artisan's shop often owned their own tools, and they worked at their own pace; in factory production the rhythm was determined by machines that the laborers operated but did not own.

This aspect of the subject has received widespread attention in British economic history,[7] but the emergence of the factory in America has been little explored, especially by cliometricians.[8] Only three recent quantitative studies have looked at aspects of this issue. Bruce Laurie and Mark Schmitz have studied the transformation of manufacturing from nonmechanized to mechanized production in Philadelphia between 1850 and 1880. Their results show significant diseconomies of scale and contradict those presented here and elsewhere.[9] Kenneth Sokoloff has published estimates of the efficiency gains realized in the transition from artisan shops to small factories between 1820 and 1850.[10] He found the gains to be small. John James examined the shifts in the range of scale economies between 1850 and 1890, and found evidence both that they can help explain the rise of big business and that nonneutral technological change may play a role in this explanation.[11] To the extent that the estimates by Sokoloff and James overlap with those presented here, they are mutually consistent, despite the differences in our approaches and techniques.

This study, like Sokoloff's and James's, focuses upon the supply. This is the conventional wisdom. The role of technological change in both factor saving and shifting industry cost curves is stressed. Declining market prices for commercially manufactured goods coincided with an expanding industrial sector and this is consistent with a fixed downward-sloping demand curve and rightward shifts in the supply curve. We do not, however, need to assume that demand is invariant but only that rightward shifts in the industry supply curve are greater than any increases in market demand.

In the case of cotton textiles, however, Robert Zevin has argued that more than half of the industry's expansion may be attributed to demand changes alone, particularly after 1833.[12] Between 1815 and 1833, out-

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Bruce Laurie and Mark Schmitz, except that they call all mechanized establishments factories. See Bruce Laurie and Mark D. Schmitz, "Manufacture and Productivity: The Making of an Industrial Base, Philadelphia, 1850–1880," in *Philadelphia: Work, Space, Family, and Group Experience in the Nineteenth Century,* Theodore Hershberg, ed. (New York: Oxford University Press, 1981), pp. 43–92. Their category of "factories" has been divided into mills and factories on the basis of employment. See text and note 5 below.

[4] Clark, *History of Manufactures,* p. 447.

[5] Mills: Steam and/or water power, 1–25 employees; Factories: steam and/or water power, over 25 employees.

[6] Alfred D. Chandler, Jr.: *The Visible Hand: The Managerial Revolution in American Business* (Cambridge, Mass.: The Belknap Press of Harvard University Press, 1977).

[7] See, for example, George Unwin, "Transition to the Factory System," *English History Review* 36 (1922), pp. 206–218 and 383–397; Paul Mantoux, *The Industrial Revolution in the Eighteenth Century,* rev. ed. (London: Jonathan Cape, 1961), especially pp. 220–270; Jennifer Tann, *The Development of the Factory* (London: Cornmarket Press, 1970); S. D. Chapman, *The Cotton Industry in the Industrial Revolution* (London: Macmillan for the Economic History Society, 1972).

[8] Even those economic historians who rely more upon qualitative data and historical narrative, such as Stuart Bruchey or Thomas Cochran, have not given the subject much attention. See, for example, Stuart Bruchey, *Growth of the Modern American Economy* (New York: Dodd, Mead, 1975), or Thomas C. Cochran, *The Frontiers of Change: Early Industrialism in America* (New York: Oxford University Press, 1981). An exception is Alfred D. Chandler, Jr., "Anthracite Coal and the Beginnings of the Industrial Revolution in the United States," *The Business History Review* 46 (Summer 1972), pp. 141–181, and Chandler, *The Visible Hand.*

[9] See Laurie and Schmitz, "Manufacture and Productivity," especially pp. 74–75 and 82–83, and compare with Jeremy Atack, "Estimation of Economies of Scale in Nineteenth Century United States Manufacturing and the Form of the Production Function," (Ph.D. diss., Indiana University, 1976), or Jeremy Atack, "Returns to Scale in Antebellum United States Manufacturing," *Explorations in Economic History* 14 (Oct. 1977), pp. 337–359, and Sokoloff, "Transition from the Artisanal Shop." Laurie and Schmitz make explicit mention of the conflict between their results and those in Atack, "Returns to Scale." See Laurie and Schmitz, pp. 86–87.

[10] Sokoloff, "Transition from the Artisanal Shop."

[11] John A. James, "Structural Change in U.S. Manufacturing, 1850–1890," *Journal of Economic History* 43 (June 1983), pp. 443–460.

[12] Robert B. Zevin, *The Growth of Manufacturing in Early Nineteenth Century New England* (New York: Arno Press, 1975), p. 10-6. Note that the pagination in this book is inconsistent. In the sections of the book cited herein, page numbers are hyphenated. The specific reference here is to page 6.

put of cotton goods expanded at an average annual rate of 16.3 percent; growth from 1833 to 1860 was slower, averaging 5.2 percent. Population growth averaged about 3 percent, but urban and western populations rose by about 5.5 percent up to the 1830s and this then accounts for about one-third of the expansion in the industry before 1833. Further, if we assume an income elasticity in the neighborhood of unity, then per capita income growth from the 1820s to 1860, as estimated by Paul David, would increase demand by another 1–2 percent.[13] Zevin also attributes a 1-percent annual increase in demand to the effects of transportation improvement.[14] He argues that most of the change occurred before 1824, but the early growth of the railroad, beginning in the 1830s in the East and continuing later into the Midwest, as well as the increasing use of the steamboat on the Mississippi and Ohio rivers make it certain that the effects were not all concentrated before 1833.[15] Zevin argues that in the post-1833 period, each of these factors grew more slowly and consequently demand expanded by only 3–4 percent a year.[16]

The primary sources of data for this study ~~are the~~ manuscripts of the federal censuses of ~~manufactures~~ for 1820, 1850, 1860, and 1870. These sources are supplemented where necessary by data drawn from published census volumes for the period after 1870, but these contain only aggregated data and have many arithmetic mistakes and extensive printer's errors.[17]

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[13] Paul A. David "The Growth of Real Product in the United States before 1840: New Evidence, Controlled Conjectures," *Journal of Economic History* 27 (June 1967), pp. 151–197, especially p. 155.

[14] Transportation costs may be represented by shifts in either the supply or demand curves. Zevin's argument is that transportation improvements reduce the price to consumers and lead to a greater quantity demanded at the mill, that is, a movement along a given demand curve. See Zevin, *Growth of Manufacturing*, 10–14. Transportation improvements, however, shift the c.i.f. supply curve and hence it is usually treated as a supply-side factor.

[15] See, for example, Albert Fishlow, *Railroads and the Transformation of the Antebellum Economy* (Cambridge, Mass.: Harvard University Press, 1965), on railroads; and James Mak and Gary M. Walton, "Steamboats and the Great Productivity Surge in River Transportation," *Journal of Economic History* 32 (Sept. 1972), pp. 619–640, on steamboats.

[16] Zevin, *Growth of Manufacturing*, 10-28 and 10-32. Zevin also argues that demand became less responsive to price as time passed, with the short-run price elasticity of demand falling from 2 or 3 to about 1.5 because one-time luxuries came to be regarded as necessities. This further retarded the rate of industrial expansion by reducing the increase in quantity demanded in response to increased supply, which reduced prices.

[17] For an appraisal of the errors in the 1850–1870 censuses, see Jeremy Atack, *Estimation of Economies of Scale in Nineteenth Century United States Manufacturing* (New York: Garland Publishing, 1985), pp. 49–56; Fred Bateman and Thomas Weiss, *A Deplorable Scarcity: The Failure of Industrialization in the Slave Economy* (Chapel Hill: University of North Carolina Press, 1981), pp. 169–171.

The sample from the 1820 census was drawn by Kenneth Sokoloff. It covers New England and the Middle Atlantic states.[18] Southern industry was also enumerated at the 1820 census, but it was not sampled by Sokoloff. The limited extent of southern manufacturing at the time and allegations of serious errors in the enumeration suggest that this omission is of minor consequence.[19]

Many scholars have regarded the 1820 census data with great skepticism. Much of this doubt derives from the jaundiced views of contemporary observers. For example, the editors of *Niles Register* were arguing that "the returns will be so imperfect that it will have been better if the subject of the inquiry had been altogether omitted," even before the 1820 census was taken.[20] Afterward, many congressmen complained that the published summaries omitted the returns for their districts.[21] A supplement was subsequently published, but even so, many errors remain.[22] Most of the objections, however, concern the published "Digest."[23] Anyone who has worked with the original documents cannot but be impressed by the quality, detail, and consistency of the information reported.

The samples for 1850, 1860, and 1870 were drawn by Fred Bateman and Thomas Weiss. They cover every state in the Union for which the data were available.[24] These censuses, particularly those for 1850 and 1860, are generally thought to be reliable, with consistent data from state to state in a given census year.[25] Among the data collected were information on capital, employment, wages, inputs, and outputs.

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[18] See Kenneth L. Sokoloff, "Industrialization and the Growth of the Manufacturing Sector in the Northeast, 1820–1850," (Ph.D. diss., Harvard University, 1982).

[19] For a general discussion of the nineteenth century manufacturing censuses, including that for 1820, see Meyer H. Fishbein, "The Censuses of Manufactures, 1810–1890," *Reference Information Paper No. 50*, (National Archives and Record Service, 1973.)

[20] *Niles Weekly Register*, 18 (26 Aug. 1820), p. 450.

[21] Congressional complaints over inaccuracies and omissions appear in *Annals of Congress*, 17th Cong., 2d sess., 1823, pp. 887–901. For a summary, see Fishbein, "Censuses of Manufactures."

[22] *American State Papers*, Finance, vol. 4, "Digest of Manufactures (Supplementary Returns)," Doc. 675, 17th Cong., 2d sess., 1823, pp. 291–299. See especially pp. 298–299 for list of counties from which no returns were received.

[23] *American State Papers*, Finance, vol. 4, "Digest of Manufactures," Doc. 662, 17th Cong., 2d sess., 1823, pp. 28–223.

[24] See Bateman and Weiss, *Deplorable Scarcity*, especially pp. 165–184. Since their study was concluded, new data have been added, including Illinois (1850), Kansas (1870), and Michigan (1850, 1860, and 1870). Data for the Pacific states (California and Oregon) has been excluded for this study.

[25] Beginning with the 1840 census, for example, Robert Gallman in his Presidential

There are three issues that might be raised regarding these data for the purposes of this study. First, the census officials repeatedly expressed doubts about the comparability of data on capital from census year to census year.[26] Second, the census did not report until 1880 how many months per year each firm worked. These data show considerable variations from firm to firm, industry to industry, and region to region, even at the end of the century, and it is likely that the length of the work-year was even more variable at midcentury.[27] We have not tried to adjust for this. Moreover, the greater the ratio of fixed to variable cost, the greater the incentive for year-round production, so that we would expect factory production to be more stable and regular than artisan production, and this should be reflected in higher productivity.[28]

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address to the Southern Economic Association declared, "I want to notify both [economists and historians], in the strongest possible terms, that the 1840 income estimates [based upon the 1840 census] are composed of data worthy of respect assembled within a relevant theoretical structure." See Robert E. Gallman, "Slavery and Southern Economic Growth," *Southern Economic Journal* 45 (April 1979), pp. 1007–1022. The quote is from n. 8, p. 1009.

[26] See, for example, remarks by Francis A. Walker, a propos the inquiry for 1870, in *Statistics of Wealth and Industry of the United States at the Ninth Census* (Washington, D.C.: U.S. Government Printing Office, 1872); p. 381. See also similar remarks by successive Superintendents of the Census at the Twelfth Census (*U.S. Twelfth Census, 1900*, "Manufactures"), and at the Fourteenth Census ("Manufactures, 1919.") See also S. N. D. North, "Manufactures in the Federal Census," in *The Federal Census: Critical Essays* (New York: Macmillan for the American Economic Association, 1899), pp. 257–302, especially pp. 283–298.

Most researchers, following Creamer, have assumed that the census capital figures represent gross book value at original cost. See David Creamer, *Capital in Manufacturing and Mining* (Princeton: Princeton University Press for the NBER, 1960). However, in his essay in ch. 7 of the present volume, "Investment Flows and Capital Stocks: U.S. Experience in the Nineteenth Century," Robert Gallman argues that the capital stocks were valued at reproduction cost; that is, these data are current net replacement costs.

[27] There were questions at both the Tenth (1880) and Eleventh (1890) Censuses regarding the number of months of operation at different capacity levels. See Carroll D. Wright, *History and Growth of the United States Census* (Washington, D.C.: U.S. Government Printing Office, 1900), especially p. 315 and p. 363.

[28] Data collected by the 1820 census on the related issue of recent and current business conditions are ambiguous with respect to the hypothesis that factory employment was more stable than that in artisan shops.

A little over half of the largest establishments in 1820 described business conditions variously as "in decay," "limited," or "not worth pursuing," while a marginally smaller faction (44 %) of the smallest establishments made similar comments. Larger establishments would thus seem to have been marginally more pessimistic than smaller businesses. On the other hand, almost 30% of the factories described business as being good or better, whereas only a little more than a fifth of the smallest plants thought so. Indeed, most of the factories that described conditions as "good" thought that they were "very good."

Employment statistics from Philadelphia between 1816 and 1819, however, present a very sanguine picture of employment stability in the factory. In the depression of 1818–1819, manufacturing employment fell almost 75%, from 9,672 employees to 2,137. The most precipitous decline was in the cotton textiles industry, which was wholly mill organized and dominated by factories. There, employment fell from 2,325 to only 149. See *Niles Weekly Register* 17 (23 Oct. 1819), p. 117.

Third, the samples were collected by state and are unweighted. The aggregation of these separate samples to regional and national samples, therefore, gives too much weight to plants in newer areas of settlement and in the less industrialized states. The possible effects of these problems will be noted where appropriate.

The number of separately identified industries expanded at each successive census. This study, therefore, focuses upon sixteen industries that were among the more important in the nineteenth century. Some of these industries, such as meat packing, tobacco, and clothing, do not appear in the sample from the 1820 census. For the most part, however, there were an adequate number of observations in each year on which to base empirical estimates.[29] All regressions had at least thirty degrees of freedom, and where other sample statistics are based on fewer observations, this is noted.

At the 1850, 1860, and 1870 censuses, manufacturers were asked about the firm's source of motive power. This information is crucial to our study for differentiating mills and factories from other establishment types, and it seems to have been reported quite reliably. Regrettably, however, data on motive power were rarely recorded in the 1820 census. It is doubtful that the lack of mention reflects no use of inanimate motive power, for while steam engines were almost certainly always recorded, waterwheels were probably often overlooked.

Only about 10 percent of all establishments in the 1820 sample mentioned the use of water or steam or gave information from which such use could be inferred. The sample shows wide variations from industry to industry. These may reflect differences in use and in the accuracy of reporting. For example, virtually all flour mills and cotton mills probably used inanimate power, but only about three-quarters of the flour mills reported a waterwheel, while less than 10 percent of the cotton mills reported a source of power. It is debatable whether or not the percentage of plants using power to grind grain is too low, but there can be no doubt that the estimate of the percentage of steam- or water-powered cotton mills is too low.

## I

Data on power use by proportion of plants in each industry (not to be confused with the share of value-added associated with differing power

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[29] Sample sizes, by industry and year, are given in Appendix 8-A at the end of the chapter.

TABLE 9.1

The Changing Use of Steam and Water Power by American Industry, 1850–1870

(Ranked in order of decreasing power use in 1850)

| | 1850 | | 1860 | | 1870 | |
|---|---|---|---|---|---|---|
| Industry | % using inanimate power | % using water power | % using inanimate power | % using water power | % using inanimate power | % using water power |
| Cotton goods | 95% | 78% | 79% | 71% | 93% | 79% |
| Woolen goods | 95 | 86 | 94 | 80 | 90 | 80 |
| Flour milling | 94 | 86 | 95 | 71 | 95 | 70 |
| Lumber milling | 93 | 74 | 96 | 47 | 99 | 47 |
| Iron | 90 | 59 | 96 | 50 | 95 | 24 |
| Liquor | 58 | 17 | 56 | 21 | 64 | 5 |
| Leather | 15 | 11 | 31 | 21 | 26 | 13 |
| Furniture | 13 | 8 | 34 | 20 | 25 | 7 |
| Brewing | 10 | 0 | 31 | 0 | 38 | 5 |
| Meat packing | 9 | 3 | 10 | 0 | 22 | 0 |
| Wagon making | 5 | 4 | 10 | 4 | 7 | 2 |
| Sheet metals | 4 | 4 | 5 | 2 | 5 | 1 |
| Clothing | 1 | 1 | 4 | 4 | 2 | 2 |
| Boots & shoes | 0.2 | 0.2 | 3 | 2 | 3 | 1 |
| Saddlery | 0 | 0 | 2 | 2 | 2 | 2 |
| Tobacco | 0 | 0 | 2 | 2 | 3 | 1 |

SOURCE: Calculated from the Bateman-Weiss samples.

sources) between 1850 and 1870 give some idea of the spread of mill and factory production (Table 9.1).[30] These represent lower-bound estimates of the extent of inanimate power's adoption, because the industrially less progressive parts of the country are overrepresented in these data and because where the source of power was not clearly specified, we assumed that the plants used an animate power source. In 1850, inanimate-power use by industry fell into three quite distinct divisions. There were those industries, such as textiles, iron, flour, and lumber, in which the use of steam or water power was almost universal.[31] In another group of industries, such as cigar making, saddlery, and boots and shoes, power was hardly, if ever, used. Lastly, there were a number of industries, such as tanning, wagon making, furniture, brewing, and meat packing, where inanimate power had made limited inroads. The liquor industry is an outlier in this scheme. Its use of power was far from universal, but also hardly limited. A small majority of liquor firms were using power in 1850. The industry is unusual in another way: it alone was dominated by steam rather than water power.[32] Indeed, except for the liquor industry and, to a much lesser extent, iron, steam had made little progress; the rapid expansion of steam-power use was not to occur until later in the century.[33]

Inanimate power use increased quite slowly between 1850 and 1870, and the essentials of the tripartite division of industries by power use remained.[34] Except for the more extensive adoption of steam and water power by firms in tanning, furniture, brewing, and meat packing, the percentage of power-using firms shows no dramatic changes. Steam power, however, displaced water in most industries, although textiles and flour milling clung to their water rights.[35]

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[30] The census collected the manufacturing data we use by establishment, not by firm. Where a sampled establishment was owned by a firm that owned more than one plant in the same location, data on each establishment were collected. All analytical results reported herein are for plant data.

[31] A small percentage of lumber and flour mills reported wind or animal power (2–4%), and one or two establishments in each of the industries still claimed to depend on hand power. The balance of power use was "mixed," which could mean steam and water, or steam and hand, hand and animal, etc. Short of going back to the original manuscripts, there is now no means of distinguishing these combinations from one another in the machine-readable sample. As a result, we treated establishments that reported "mixed" sources of power as using "animate" power. This biases our estimates of the use of inanimate power downward.

[32] The use of heat in the distillation process made the use of steam power by the liquor industry the natural choice whenever mechanical power was needed. Indeed, this is one industry singled out by Chandler as exemplifying the newer energy-intensive, larger-scale continuous production processes: ". . . the distilling and refining industries lent themselves more readily to mass production . . . enlarged stills, superheated steam, and cracking techniques all brought high volume, large-batch, or continuous-process production of products . . . in the distilling of alcohol and spirits." See Chandler, *Visible Hand*, p. 243.

[33] See Jeremy Atack, Fred Bateman, and Thomas Weiss, "The Regional Diffusion and Adoption of the Steam Engine in American Manufacturing," *Journal of Economic History* 40 (June 1980), pp. 281–308.

[34] Probably no importance should be attached to the small declines in power use, as in the textile industry, from 1850 to 1860 and 1860 to 1870. First, the percentage of "mixed"-power users tended to increase. Most of them were combined steam- and water-power users, but they are treated as non-power-using plants so as to maintain a consistent downward bias in the estimates. Second, the percentage of nonreporting plants tended to increase in 1870. Third, given the small sample sizes (under 100 observations) in some of these industries, minor sample variations and errors induce large swings in this statistic.

Aggregate statistics on power use were not reported until the Ninth Census (1870). See U.S. Census Office, *Statistics of Wealth*. The marked increase in nonreporting of motive power biases early estimates of the use of power downward. This has led some authors to drastically overstate the increase in power use between 1870 and 1880. See, for example, Allen H. Fenichel, "Growth and Diffusion of Power in Manufacturing, 1838–1919," in *Output, Employment, and Productivity in the United States After 1800*, Conference on Research in Income and Wealth, Studies in Income and Wealth, vol. 30, (New York: National Bureau of Economic Research, 1966), pp. 443–478.

[35] See Atack, Bateman, and Weiss, "Regional Diffusion." The persistence of water power in the textile industry may be attributed to the monopoly rents accruing to long-term water-right contract holders especially in the face of rising efficiency in water use with turbines. For this reason, many textile mills installed steam engines when they needed more power while maintaining their use of existing water power until dis-

TABLE 9.2

The Percentage of Industry Value-Added Originating from Different Methods of Production in Selected Industries, 1850 and 1870

| | Artisanal Shops[a] | | Sweatshops[b] | | Manufactories[c] | | Mills[d] | | Factories[e] | |
|---|---|---|---|---|---|---|---|---|---|---|
| Industry | 1850 | 1870 | 1850 | 1870 | 1850 | 1870 | 1850 | 1870 | 1850 | 1870 |
| Boots & shoes | 39% | 33% | 23% | 20% | 38% | 25% | 0% | 4% | 0% | 19% |
| Brewing | 41 | 21 | 24 | 0 | 0 | 0 | 35 | 49 | 0 | 30 |
| Clothing | 13 | 16 | 39 | 24 | 48 | 42 | 0 | 0 | 0 | 18 |
| Cotton goods | 0 | 0 | 0 | 0 | 4 | 3 | 16 | 1 | 79 | 96 |
| Flour milling | 7 | 5 | 0 | 0 | 0 | 0 | 91 | 95 | 2 | 0 |
| Furniture | 50 | 18 | 13 | 6 | 7 | 8 | 10 | 26 | 19 | 41 |
| Iron | 0 | 0 | 1 | 1 | 32 | 0 | 22 | 10 | 44 | 89 |
| Leather | 54 | 20 | 16 | 7 | 0 | 0 | 26 | 29 | 4 | 43 |
| Liquor | 9 | 4 | 18 | 4 | 0 | 0 | 73 | 82 | 0 | 10 |
| Lumber milling | 3 | 1 | 1 | 2 | 0 | 0 | 88 | 63 | 8 | 34 |
| Meat packing | 34 | 31 | 10 | 0 | 19 | 0 | 11 | 69 | 25 | 0 |
| Saddlery | 62 | 71 | 19 | 20 | 19 | 8 | 0 | 1 | 0 | 0 |
| Sheet metals | 89 | 41 | 6 | 6 | 0 | 27 | 5 | 2 | 0 | 24 |
| Tobacco | 24 | 30 | 33 | 33 | 43 | 35 | 0 | 2 | 0 | 0 |
| Wagon making | 32 | 33 | 47 | 30 | 15 | 17 | 3 | 3 | 3 | 18 |
| Woolen goods | 0 | 4 | 1 | 0 | 0 | 12 | 39 | 7 | 60 | 77 |

SOURCE: Computed from the Bateman-Weiss samples.

[a] Artisan shops: no power, 1–6 employees.

[b] Sweatshops: no power, 7–25 employees.

[c] Manufactories: no power, more than 25 employees.

[d] Mills: water or steam power, 1–25 employees.

[e] Factories: water or steam power, more than 25 employees.

Despite the minor changes in the proportions of establishments using steam and water power between 1850 and 1870, the percentages of industry production accounted for by factories and mills expanded rapidly over the period.[36] In 1850, the factory system was dominant in only three industries, cotton, iron, and woolens, while mills dominated flour and lumber milling and liquor distilling. Nonmechanized plants dominated in the other ten industries. However, as a result of dramatic gains between 1850 and 1870, mills and factories had become the dominant production technique in most industries by 1870, displacing nonmechanized establishments (Table 9.2).[37]

In five industries (cotton, furniture, iron, leather, and woolens), factories were the leading source of output in 1870. The inclusion in this list of industries not usually associated with large-scale mechanized production in the nineteenth century, such as furniture and leather, is particularly noteworthy. In five other industries in 1870 (brewing, flour milling, liquor distilling, lumber milling and meat packing), mills were the most important source of industry supply.

Some industries experienced sharp increases in the fraction of factory value-added between 1850 and 1870. For example, no boots and shoes or men's clothing came from factories in the samples in 1850, but by 1870, 19 and 18 percent respectively of their industry value-added was accounted for by factory production[38] and a further 4 percent of boot and shoe value-added came from mills.

The structure of the boot and shoe industry in 1850 was much the same as it had been in 1820. There were many small shops, fewer mid-size firms, and a few large ones employing more than twenty-five.[39] Output was more or less evenly divided between the three groups, and

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possessed of water by cities claiming eminent domain over this resource for domestic water supply and sanitation.

[36] I attach no great importance to the decline in mill and factory production of woolens in 1870 and the disappearance of meat-packing factories. The case of woolens simply reflects an increase in the fraction of plants for which no power source was given in 1870. For meat packers, it was the result of chance that none of the large meat packers were included in the random sample.

[37] Jeremy Atack, "Industrial Structure and the Emergence of the Modern Industrial Corporation," *Explorations in Economic History*, 22 (Jan. 1985), pp. 29–52, especially Tables 1 and 2 (pp. 34–35 and 40–41).

[38] These results are not directly comparable with those of Laurie and Schmitz, who describe the spread of the factory system by citing the increasing percentage of the industry's labor force employed in factories. The fraction of total industry value-added originating in factories has been used here. Furthermore, while they give results for 1850 and 1880, the data here are for 1850, 1860, and 1870.

[39] See Blanche E. Hazard, *Organization of the Boot and Shoe Industry in Massachusetts Before 1875* (Cambridge, Mass.: Harvard University Press, 1921), for a discussion of the early industry. Data on the size distribution of plants are from Sokoloff's sample.

none of the boot and shoe shops in the samples reported a source of power before 1860.[40] The industry began to mechanize in the 1850s, with the adaptation of the sewing machine to leather work. This is reflected in the statistics on motive power. Whereas in 1850, 39 percent of industry output had come from large nonmechanized shops, in 1860 their share of industry output fell to 24 percent and the output of factories (power-using establishments with over twenty-five employees) increased from zero to 17 percent, rising to 19 percent in 1870. The share of sweatshops changed relatively little, but manufactories declined even more than artisan shops. The boot and shoe factory thus replaced some larger nonmechanized shops and some very small artisan shops, but it did not drive all of them out of business. Indeed, as we will show below, very small plants continued to increase in number, if not in importance as a source of output, throughout the period.

In a few industries, there was little change in the proportion of mill- or factory-produced goods. These fell into two groups: those that were already extensively mechanized and those untouched by mechanization. In 1850, for example, flour and lumber were almost exclusively produced in steam- or water-powered mills and cotton and woolen textiles were factory products. These industries were the pioneers of mechanized production. No tobacco or saddlery and harness plants, however, were using inanimate power in 1850, but even in these industries things began to change.

Tobacco, the handicraft industry par excellence before the introduction of Bonsack's cigarette machine in the 1880s, had begun to mechanize by 1870. Of industry value-added in the sample that year, 2 percent came from mills, and these made up only 2.5 percent of the tobacco plants in the sample.[41] Moreover, in the Bateman-Weiss special samples of large establishments, four large tobacco plants employing 1,410 and producing over $4.5 million of output,[42] were using steam power in 1870 in New York.[43] Furthermore, the U.S. Census for 1870

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[40] Bateman-Weiss sample data. A few of the larger boot and shoe shops reported the use of "mixed" power sources.

[41] This percentage certainly would have been higher if some of the larger plants in the industry had appeared in the 1870 sample.

[42] In 1870 dollars. Adjusting to 1860 prices, using the Warren-Pearson price index for farm products, to eliminate the residual effects of Civil War inflation would reduce output value by about 25%, to $3.375 million. See U.S. Department of Commerce, Census Bureau, *Historical Statistics of the United States from Colonial Times to 1970* (Washington D.C.: U.S. Government Printing Office, 1975), Series E53.

[43] The special "large firm" samples which Bateman and Weiss collected consist of at least the twenty largest establishments in each state, and sample sizes were often larger than this.

reported 178 steam engines and 26 waterwheels in use by the 5,204 establishments in the industry.[44] However, mill and factory production of tobacco products and saddlery and harness remained the exception in 1870. These industries were the only ones in which mill and factory organization had failed to make much headway.

The rise of the factory usually paralleled a decline in artisan shops. The percentage of industry value-added produced in artisan shops fell in nine of the sixteen industries in Table 9.2. It rose only in tobacco manufacture, woolen goods, clothing, saddlery, and wagons. Each of these latter industries also experienced an increase in mill and factory production, so that sweatshops and manufactories made little or no gains in their share of total industry value-added. Given sample sizes, the changes in their shares appear to be well within the margin of error.[45]

The mechanized mill and factory were thus growing in importance while handicraft industry stagnated or declined. This is hardly unexpected, but the question is, why? One important factor favoring the adoption of mechanization was the rise in labor productivity that it was expected to generate. Comparisons of labor productivity between hand and machine production by Carroll Wright at the end of the nineteenth century show tremendous gains in labor productivity from mechanization.[46] Thus, for example, in 1813 three workers took 236 man-hours with hand tools to produce 29,000 $4^d$ cut nails. Labor costs were $20.24. In 1897, machines produced the same quantity of $4^d$ nails in less than 2 hours. Eighty-three workers were then involved in the production process; labor costs were only 29 cents.[47] For the particular industries in this study, Wright's estimates of the labor-productivity gains for specific tasks ranged from about a twofold increase in leather tanning to an almost sixtyfold increase in the case of lumber (Table 9.3).

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[44] *U.S. Ninth Census*, 1870, "The Statistics of Wealth and Industry of the United States," p. 479. The percentage of power-using plants in the population was therefore greater than that in the sample, provided each plant had only one engine or wheel.

[45] The apparent gains by manufactories in the production of woolen goods and sheet metals are almost certainly a reflection of reporting errors in the power use. A few other industries, not included here (agricultural implements, iron foundries, and steam engine manufacture), also recorded increases in manufactory value-added. It is likely that these were assembly rather than manufacturing operations. See Atack, "Industrial Structure."

[46] Wright's estimates, unfortunately, are usually not for different techniques at the same point in time, although Wright tried to collect as much contemporary data as possible. Rather, they are for hand production of about the time of the Civil War versus machine production toward the end of the century. Nevertheless, Wright felt that they were indicative of the potential scale of labor productivity gains. See U.S. Department of Labor, *Thirteenth Annual Report*.

[47] Ibid., vol. 1, pp. 24–79.

TABLE 9.3
Labor Productivity and the Switch from Hand to Machine Production, 1835–1897

| Product | Technique and date | Number of operations | Number of workers | Man-hours worked | Labor Productivity[a] |
|---|---|---|---|---|---|
| Chewing tobacco (per 1,000 lbs. to 16-oz. plugs) | Hand, 1855 | 7 | 32 | 304.5 | |
| | Machine, 1895 | 55 | 668 | 141.0 | 216 |
| Cotton gingham (500 yds. by 27 in.) | Hand, 1835 | 16 | 3 | 5,130.2 | |
| | Machine, 1895 | 40 | 166 | 119.2 | 4,304 |
| Pine lumber boards (per 100,000 ft.) | Hand, 1854 | 9 | 2 | 16,000.0 | |
| | Machine, 1896 | 38 | 78 | 272.7 | 5,867 |
| Chairs (12 maple chairs) | Hand, 1845 | 15 | 6 | 51.0 | |
| | Machine, 1897 | 33 | 26 | 7.9 | 646 |
| Kid leather (1,200 skins) | Hand, 1860 | 20 | 226 | 1,506.9 | |
| | Machine, 1896 | 30 | 116 | 773.3 | 195 |
| Boots (cheap) (100 pairs) | Hand, 1859 | 83 | 2 | 1,436.7 | |
| | Machine, 1895 | 122 | 113 | 154.1 | 932 |
| Forged anvils (per unit) | Hand, 1855 | 9 | 7 | 62.0 | |
| | Machine, 1896 | 6 | 10 | 15.0 | 413 |
| Men's shirts (per gross) | Hand, 1853 | 25 | 1 | 1,439.0 | |
| | Machine, 1895 | 39 | 230 | 188.2 | 765 |
| Wash basins (per gross) | Hand, 1840 | 31 | 1 | 96.0 | |
| | Machine, 1895 | 22 | 23 | 7.2 | 1,333 |
| Farm wagon (per unit) | Hand, 1848 | 37 | 5 | 242.0 | |
| | Machine, 1895 | 63 | 75 | 48.3 | 501 |

SOURCE: U.S. Department of Labor, *Thirteenth Annual Report*, vol. 1, pp. 24–79.
[a] (Hand man-hours ÷ machine man-hours) × 100.

Labor-productivity gains, however, are not automatically and immediately converted into total factor productivity gains. Mechanization required a new plant and more equipment. The capital component therefore tended to rise.[48] Moreover, mechanization tended to lower the skill level of the work force by substituting machine precision for human skills and experience.[49] As a result, the capital-labor ratio tended to rise, and it is possible for virtually the entire labor-productivity gain to be absorbed by higher capital-labor ratios.

Suppose that the production process can be modeled by a Cobb-Douglas production function of the form

$$Q = AL^aK^b$$

where $Q$, $L$, and $K$ are output (measured as value-added in constant dollars), labor, and capital respectively, and $a$ and $b$ are the output elasticities with respect to labor and capital. If $(a + b) = 1$, then total factor productivity, $A$, is output per unit of input, where in this multi-input case, a unit of input is measured by the geometric weighted mean of the inputs

$$A = Q/(L^aK^b)$$

Total factor productivity may also be expressed as the weighted average of the partial productivity indexes for labor and capital:

$$A = \{Q/L\}^a \cdot \{Q/K\}^b$$

This may be written as[50]

$$\{Q/L\} = A[\{K/L\}^b]$$

Thus, a rise in labor productivity may be offset by a rise in the capital-labor ratio.

Nevertheless, one would expect that dramatic labor-productivity gains would increase total factor productivity quite sharply. This would be consistent with the rapid adoption of mechanized production after 1850 in almost every branch of industry. However, rather than focusing upon the narrower issue of mechanization's effects upon labor productivity, this study examines its effects upon total-factor productivity because of the ambiguous role played by changes in the capital-labor ratio. Indeed, we will show below that it is impossible to reconcile our estimates of the total-factor productivity gains with the labor-productivity gains quoted by Wright, even after allowing for large changes in the capital-labor ratio.

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[48] Although crude capital-labor ratios for mechanized plants were generally higher than those for the nonmechanized, there were occasional exceptions. For example, in 1900 the capital-labor ratio in boot and shoe factories was only $875, compared with almost $1,000 in the handicraft sector of the industry. See *U.S. Twelfth Census*, 1900, "Manufactures," vol. 7, pt. 1, p. 4.

[49] Goldin and Sokoloff, for example, show that the larger, mechanized plants consistently employed a higher percentage of female and child labor than smaller artisan shops. See C. Goldin and K. L. Sokoloff, "Women, Children and Industrialization in the Early Republic: Evidence from the Manufacturing Censuses," *Journal of Economic History* 42 (Dec. 1982), pp. 741–774. See also A. Field, "Skill Intensity in Early Industrialization: The Case of Massachusetts," *Journal of Human Resources* 15 (1980), pp. 149–175.

This may, however, have been partially offset by an increase in labor-intensity as a result of machines setting the pace for human operatives, but there is no means of measuring this with the available data.

[50] By dividing through by $\{Q/L\}^b$ and using the result that since $a + b = 1$, $L^a.L^b = L$ and $Q^a.Q^b = Q$.

## II

The relative total-factor productivity gains to be realized from changing the scale of operations and the organization of the plant are estimated by using the mean values of $Q$, $L$, and $K$ for medium and large establishments and factories in the relationship

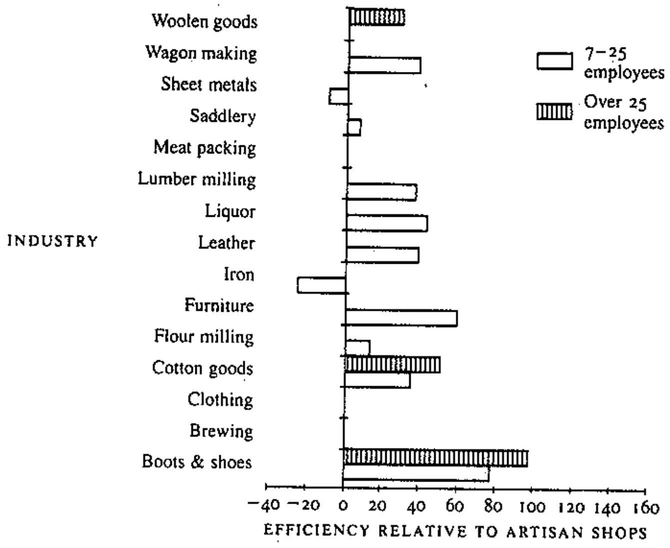
$$A = Q/(L^a K^b)$$

with productivity in artisan shops serving as numeraire.

For 1820, we estimate that larger plants were generally about 40 percent more efficient than the small artisan shops employing fewer than seven workers (Figure 9.1). This is similar to the result reported by Sokoloff.[51] No calculations of relative efficiency were made for tobacco in any year because of the small sample sizes.

Boot and shoe manufacturers, however, seemed to do much better than average. The largest boot and shoe shops were twice as efficient as small artisan shops in 1820 and about 12 percent more efficient than the midsize plants. One possible explanation for this would be that labor and capital might be understated in the larger boot and shoe manufactories if these relied heavily upon a "putting-out" system. Unfortunately, there is no means of ascertaining this from the census data.

Larger iron producers and sheet metal manufacturers, on the other hand, were less efficient than smaller ones. Their inferiority increased with size. Indeed, the very largest iron plants produced only about one-third as much value-added per unit of input (defined as the geometrically weighted average of labor and capital) as small plants with fewer than seven employees. Given the rural location of most iron works, the high transport costs for both raw materials and finished products, and the absence of technological economies of scale in furnaces, which might have offset these disadvantages at the time, rising unit costs for larger plants seem quite plausible. However, such plants could only continue to survive in the face of more efficient, smaller establishments if, for example, they produced a good that smaller plants would have been incapable of supplying. Unfortunately, the product descriptions are usually quite generic, and we have no information about cross-elasticities of substitution.



SOURCE: Calculated from Sokoloff's sample from the 1820 census.

FIGURE 9.1 Relative Efficiency by Industry, 1820

After 1820, no relative efficiency figures are calculated for cotton goods, since no establishments met the criterion of six or fewer employees and no power. All plants in this industry were either mills or factories. No calculations for woolen goods were made after 1850 for the same reason. Furthermore, although relative efficiency estimates for flour and lumber milling are reported, the representativeness of the artisan-shop data in these industries is suspect. Both industries made early and extensive use of power, and it is probable that those plants identified as artisan shops simply neglected to report their power use to the census enumerators.

The efficiency gains realizable by larger plants and through mechanization seem to have been smaller in 1850 than in 1820 (Figure 9.2). Where mechanized (i.e., powered) plants were more efficient than artisan shops, the efficiency gains seem to have been less than 20 percent. Notice, however, that factories (i.e., those mechanized plants employing more than twenty-five) were usually less efficient than mills, and only woolen factories managed to be more efficient than the artisan

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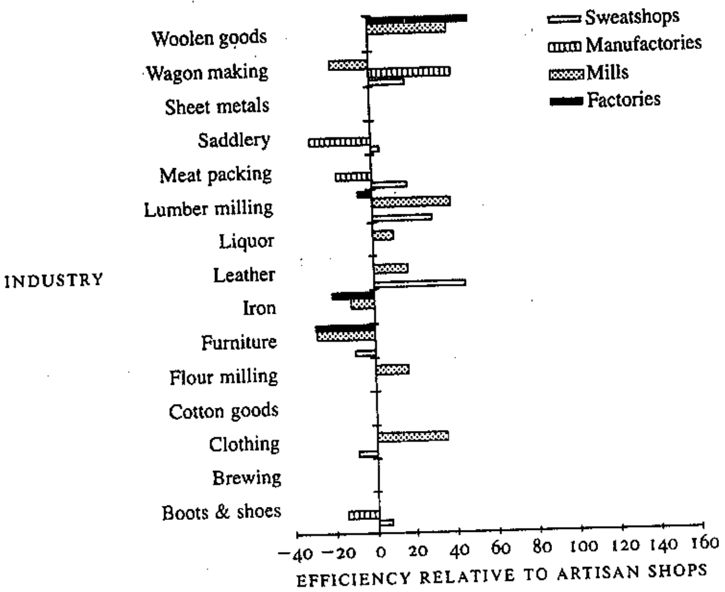
[51] Our assumptions differ slightly, notably in our treatment of child and female labor and the degree of aggregation in our results. The choices made here parallel those made in Atack, *Estimation*, especially Ch. 3. Whereas Sokoloff weighted women and children at 0.4 of an adult male equivalent, a weight of 0.5 for women and 0.33 for children was used here (see Sokoloff, "Transition from the Artisanal Shop," footnotes to Table 5, pp. 364–365). Second, whereas Sokoloff estimated a single production function across all industries except textiles and iron, separate production functions for each industry are made here (see Sokoloff, Table 6, p. 368). No effort has been made to replicate Sokoloff's results, but both our aggregate results and our estimates of labor's share in 1820 are similar. The differences, therefore, seem to be of little importance.



SOURCE: Calculated from the Bateman-Weiss samples from the 1850 census.

FIGURE 9.2 Relative Efficiency by Industry, 1850

shops in the industry. This finding seems to contradict Sokoloff's conclusion, but the difference is almost certainly attributable to the breakdown of establishments between powered and nonpowered here. It may also reflect differences in our size categories.

Except for clothing and wagon and carriage manufacture, medium-sized nonmechanized plants seem to have been more efficient than large ones, and they were also generally more efficient than artisan shops. By 1870, however, sweatshops, even in these two industries, were more efficient than the manufactories in those same industries, and consequently the importance of manufactories should have been declining in each industry. With a few notable exceptions, this was the case (see Table 9.2 above).[52]

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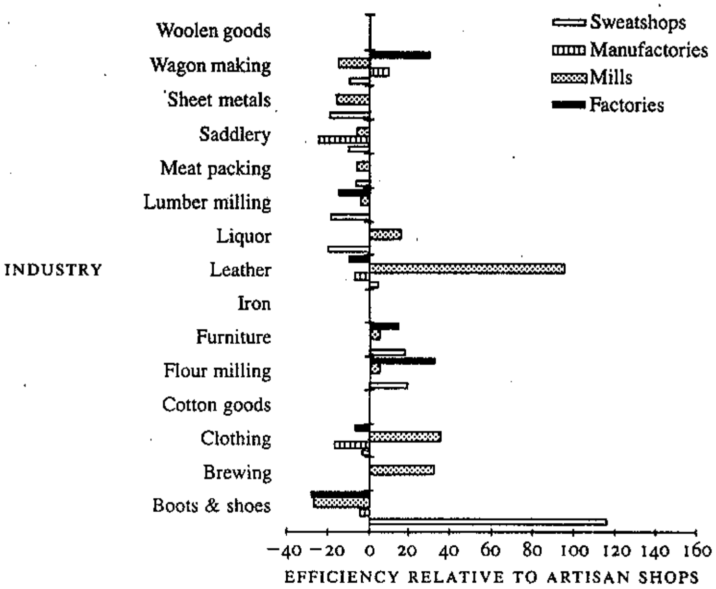
[52] There are two glaring exceptions—sheet metals and woolens. The former largely did remain a handicraft trade until the introduction of stamping machinery for sheet steel. See David A. Hounshell, *From the American System to Mass Production 1800–1932* (Baltimore: Johns Hopkins University Press, 1984), especially pp. 208–215 and n. 71, pp. 369–370. The results for woolens may reflect a coding or key-punch error whose seriousness is reinforced by the small sample size for this industry.

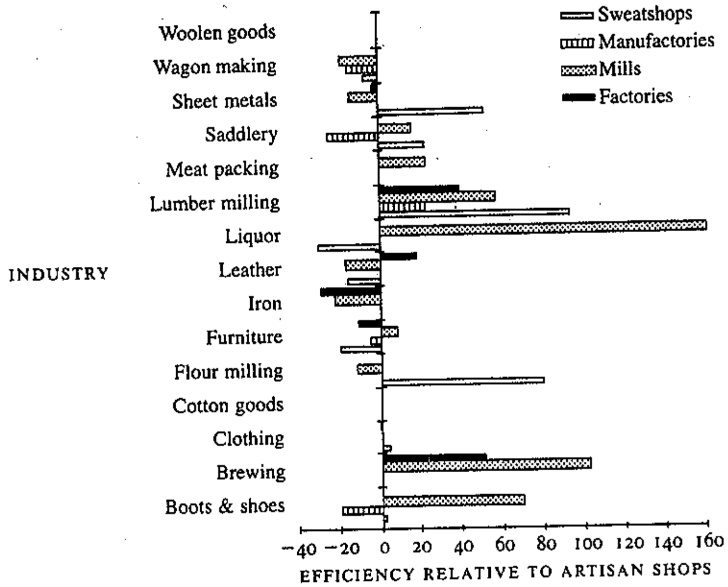


SOURCE: Calculated from the Bateman-Weiss samples from the 1860 census.

FIGURE 9.3 Relative Efficiency by Industry, 1860

In 1860, the potential efficiency gains, relative to artisan shops, to be realized from larger size and mechanization remained small, averaging less than 20 percent (Figure 9.3). Efficiency losses were also quite small, typically on the order of 5–10 percent. Plants in three industries, however, could have realized very substantial efficiency gains by changing organization and adopting mechanized production processes. Small mechanized tanneries, for example, were about 90 percent more efficient than very small nonmechanized leather tanneries; and very large, power-using meat-packing plants were some 220 percent more efficient than very small, nonpowered establishments. Whereas most sweatshops compared unfavorably with artisan shops in industry, in boot and shoe making they were the most efficient plants in the industry, producing about twice as much value-added per unit of input as artisan boot and shoe makers.

These estimates for 1860 present a much different picture than those for other years. About a quarter of the relative efficiency estimates in 1860 are in the opposite direction from results for 1850, and fully half of the results are counter to the 1870 results. On the other hand, there



SOURCE: Calculated from the Bateman-Weiss samples from the 1870 census.

FIGURE 9.4 Relative Efficiency by Industry, 1870

is a much higher degree of concordance between the 1850 and 1870 results, but the limited time-series observations with these data make such generalizations difficult.

By 1870, the efficiency gains to be made from a change in organization and structure were much more pronounced than in either 1850 or 1860 and were on a par with those for 1820 (Figure 9.4). Whereas for the 1850 and 1860 estimates it was hard to generalize about efficiency relative to that of artisan shops across industries, in 1870, as in 1820, the artisan shops were typically the least efficient producers. Furthermore, mechanized plants in 1860 and 1870 typically produced more output per unit of inputs of labor and capital than the nonmechanized establishment in the same industry.

If these data are reorganized within each industry by establishment type (between mechanized and nonmechanized and by the size of labor force) and by year, a different set of inferences can be drawn from them. First, the "manufactory" (i.e., a non-power-using establishment employing more than twenty-five) was clearly an inferior organization in terms of efficiency and should have been in decline. In most industries, the manufactory was less efficient than the artisan shop and this relative inefficiency grew over time. Labor supervision and control over management and entrepreneurial functions were perennial problems. In the artisan shop, the owner often labored alongside his employees and the intimacy of their physical location provided all the necessary control and supervision. Managerial and supervisory functions in larger businesses were usually delegated, with a resultant loss of some degree of control, but whereas in the mill and factory mechanization instilled discipline and interdependence and controlled the flow and pace of work, this element was lacking in the larger handicraft industries.

Second, relative efficiency declined in most sweatshops (nonmechanized establishments employing seven to twenty-five), although in many industries sweatshops were to remain as efficient, or somewhat more so, than artisan shops throughout the period. Sweatshop efficiency did, however, rise steadily in the one industry that was to become synonymous with this mode of production, namely, the needle trades, and by 1870 sweatshops in this industry were marginally more efficient (4 percent) than artisan shops.

Third, the relative efficiency of mechanized plants in virtually every industry grew over time, so that in many cases such plants had become more efficient than artisan shops by 1870. Where mills were more efficient than artisan shops, their advantage averaged about 40–50 percent. Where factories were more efficient, their advantage was considerably smaller, averaging perhaps 20 percent. These gains are similar to those reported by Sokoloff for more aggregated industry groups in 1820 and 1850.[53] There were thus some advantages to mechanization, although they seem to have been at least partially offset by other factors, perhaps managerial shortcomings, in larger plants. This pattern is most marked for furniture and lumber.

One particularly interesting pattern is apparent in these data: mechanized iron furnaces were uniformly less efficient than the very small nonmechanized producers, and their relative inefficiency grew over time. This result may well help explain the persistence in the United States of the small charcoal iron producer in competition with larger coke iron smelters. It is also consistent with Temin's argument that the cost differential between the two production techniques was not great

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[53] Sokoloff, "Transition from the Artisanal Shop," pp. 368 and 377, shows productivity gains from larger plants of 30–35% in 1820 and 27–29% in 1850. The overall figures here are on the same order of magnitude, although, of course, there are some efficiency losses too, whereas Sokoloff found none with his more aggregated data.

enough to compensate for the lower market price commanded by coke-smelted pig iron, since the larger producers generated less value-added per unit of input.[54]

These estimates of total factor productivity change cannot be reconciled with Wright's estimates of the labor-productivity gains, even allowing for changes in the capital-labor ratio.[55] Consider, for example, the case of the boot and shoe industry. Mechanized producers in this industry had 25 percent higher capital-labor ratios in 1870 than artisan shops ($750/male equivalent versus $600/male equivalent).[56] We estimate that the output elasticity with respect to capital in the boot and shoe industry was 0.29 and that the switch from shop to factory led to a 5-percent gain in efficiency.[57] These data, then, imply a 40-percent gain in labor productivity from mechanization.[58] This is very small when compared with the ninefold increase shown in Table 9.3 above. Results for the other industries were similar. A partial explanation may be that capital quality, measured by its productivity per unit cost, improved with mechanization and/or that its quantity increased in real terms due to a decline in capital goods prices, and these changes were not captured in the capital estimates from the census.[59]

Small as the gains seem to have been, they still potentially overstate the benefits because of our treatment of entrepreneurial labor, which is biased against smaller plants.[60] One adult male equivalent has been added to each firm's labor force to represent the input of managerial and entrepreneurial labor. The figure is arbitrary but, as entrepreneurial and managerial labor contributes to output, it should be included, but the censuses omitted it.[61] The same adjustment was made in each year. This addition represents a proportionately greater increase in the labor input for very small establishments, many of which also probably only worked part-time or were only part-time interests of the owner, than for larger establishments. Consequently, small-firm value-added per unit of "inputs" is reduced relative to that of the larger producer, thereby lowering the small firm's relative efficiency.

The efficiency estimates, particularly those for factories, may also be biased downward by regional price variations. Value-added has not been deflated by local or regional product prices, and there may have been significant differences in these prices between regions. Certainly, the available price indexes show marked variations.[62] Average firm size was also correlated with regions, with smaller plants in the South and Midwest. As a result, western value-added may well be overstated, raising the relative efficiency of all small artisan shops, since these shops predominated in that region. Similarly, regional variations in competition would also bias estimates of value-added in favor of establishments in the less competitive markets. This would again favor plants in the West. The use of state dummy variables to account for such factors and any other unique differences was inconclusive.

The failure to realize the huge gains in labor productivity that contemporaries expected may have discouraged universal adoption of mechanized production. Certainly, in the boot and shoe industry, the changeover to factory production was leisurely, so that it is unlikely that the gains, whatever their absolute magnitude, were large. Nevertheless, although the gains may have been less than entrepreneurs anticipated, they should have been sufficiently attractive to ensure that

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[54] See Peter Temin, *Iron and Steel in Nineteenth Century America: An Economic Inquiry* (Cambridge, Mass.: MIT Press, 1964), Ch. 3.

[55] Inability to reconcile total and partial factor productivity estimates seems to be fairly common. See, for example, the Parker-Klein estimates of labor-productivity growth in American agriculture and compare with Robert Gallman's estimates of agricultural total factor productivity. William N. Parker and Judith L. V. Klein, "Productivity Growth in Grain Production in the United States, 1840–1860 and 1900–1910," in *Output, Employment, and Productivity in the United States After 1800*, Studies in Income and Wealth, vol. 30, pp. 523–582; Robert E. Gallman, "Changes in Total U.S. Agricultural Factor Productivity in the Nineteenth Century," *Agricultural History* 46 (Jan. 1972), pp. 191–210.

[56] Bateman-Weiss sample data.

[57] The output elasticity is estimated from a restricted Cobb-Douglas production function where the output elasticities were constrained to sum to unity: $\ln(Q/L) = \ln A + b\ln(K/L)$.

[58] Using the relationship $\{Q-L\}^* = A^* + b\{K-L\}^*$, where the variables are logged and * indicates rates of change. On the other hand, if one were to accept Wright's estimate of the labor-productivity gain and my estimate of the overall productivity gain and output elasticity with respect to capital, then the capital-labor ratio would have had to increase by a factor of 27, or my estimate of overall productivity gains is grossly in error, being less than one-eighth its true value.

[59] Some evidence consistent with this hypothesis is to be found in the movement of price indexes which generally fell during the period up to 1900, except for the Civil War interlude, but if Gallman's interpretation of the census capital estimates is right, then the hypothesis can be rejected. See *Historical Statistics*, Series E52–E134 for price data. See also Robert E. Gallman, "Investment Flows and Capital Stocks: U.S. Experience in the Nineteenth Century," Ch. 7 in this volume.

[60] See Atack, *Estimation*, especially pp. 77–78 and 133–135. Also Sokoloff, "Transition from the Artisanal Shop," pp. 367–370.

[61] Sokoloff's 1820 sample offers a superior method of dealing with the omission because he coded whether or not the firm was a partnership, sole proprietorship, or corporation and, if a partnership, how many partners, but comparable data were not coded for the other censuses.

[62] See, for example, Anne Bezanson, *Wholesale Prices in Philadelphia, 1852–1896* (Philadelphia: University of Pennsylvania Press, 1954), and compare with Thomas Berry, *Western Prices before 1861: A Study of the Cincinnati Market* (Cambridge, Mass., Harvard University Press, 1943). See also Philip R. P. Coelho and James F. Shepherd, "Differences in Regional Prices: The United States, 1851–1880," *Journal of Economic History* 34 (Sept. 1974), pp. 551–591.

mills and factories would have become relatively more dominant in industry structure through time.

## III

The measurement of total factor productivity involved a strong assumption that the sum of output elasticities with respect to factor inputs sum to 1. This assumption is necessary so that factor payments exhaust the product. (Sometimes, authors have disguised it by asserting that market conditions are assumed to be perfectly competitive or that factors are paid the value of their marginal products.[63]) Making this assumption, we then compare the value-added per geometrically weighted average unit of factor inputs across different methods of organizing production. Although it is in the background and implicit in our separate identification of artisan shops, sweatshops, and manufactories and of mills and factories, scale as such plays no role in total factor productivity differences. Indeed, we go even further and assert, if only by default, that there are no scale economies, since they would be measured by the sum of the output elasticities with respect to inputs.

Estimates of the unconstrained production function indicate, however, that there were returns to scale to be realized in a growing number of industries.[64] The arbitrary restriction to constant returns to scale may therefore bias the output elasticities of the inputs, unless the monopoly elements were approximately equal in each market.

Total factor productivity and scale-economy arguments are thus theoretically incompatible with one another. On the one hand, constant returns to scale are assumed in order to exhaust the product; on the other, there is strong evidence that there were returns to scale for larger plants at least up to some output level. Indeed, the argument will be made that in a number of industries, nothing but increasing returns to scale are observed, and that in the absence of external constraints or internal nontechnological constraints, such as managerial control, the optimum firm in these industries would have been a natural monopoly.[65]

Economists typically assume that well-behaved average costs are U-shaped, with returns to scale for small plants, then a range of constant returns, which eventually gives way to decreasing returns in very large plants. However, empirical studies of cost functions have not been particularly successful in validating this assumption. Most of the studies in a survey of cost functions by A. A. Walters suggest that the cost curve is perhaps better described as L-shaped than U-shaped; that is, average costs decline at first and then become constant over a wide range of alternative plants and ultimately begin to rise slowly.[66] Walters therefore concluded that "for 'competitive' industries, the U-shaped hypothesis does not inspire great confidence . . . [but] at least there is no large body of data which convincingly contradicts the hypothesis . . . and the fruitful results which depend upon it."[67]

The standard critique of the hypothesis that average costs are L-shaped is that a firm's output is a random variable. Consequently, the firm has no means of controlling its variation about the average value and the firm responds by searching for the best means to produce this distribution of outputs.[68] This has the effect of blurring the distinction between fixed and variable factors and, if there are no variable costs, then "a cross section study would show sharply declining average costs. When establishments are classified by actual output, essentially this kind of bias arises. The plants with the largest output are unlikely to be producing at an unusually low level; on average, they are clearly likely to be producing at an unusually high level, and conversely for those which have the lowest output."[69]

This argument is potentially devastating to the results presented here; for given the uncertainties of the time and the enumeration process, reported output probably did contain large random elements, and my data are cross-sectional. Further, we found precisely what Friedman

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[63] The Cobb-Douglas production function may thus be rewritten as

$$Q = AL^aK^{(1-a)}$$

This is linear in logarithmic transformation, and the restriction upon the output elasticity with respect to capital was forced by regressing ln $(L/K)$ on ln $(Q/K)$ to obtain an estimate of $a$. The output elasticity with respect to capital was then estimated as $(1 - a)$.

[64] In 1820, cotton goods, flour, leather, and lumber exhibited increasing returns to scale. As the century wore on, increasing returns came to characterize more and more industries and, by 1870, the following industries had significant increasing returns to scale: lumber, beer, cotton, flour, liquor, meat, and woolens.

[65] The results reported by James from aggregate translog production-function estimates corroborate this conclusion. See James, "Structural Change," especially pp. 437–449.

[66] This argument is forcefully made by J. Johnston, *Statistical Cost Functions* (New York: Wiley, 1960).

[67] A. A. Walters, "Production and Cost Functions: An Econometric Survey," *Econometrica* 31 (Jan.–Apr. 1963), pp. 1–66, especially p. 52.

[68] Ibid., p. 48.

[69] Milton Friedman, "Comment," in *Conference on Business Concentration and Price Policy*, quoted by Walters. Note that the thrust of Friedman's argument is that unit costs for the "large" establishments are biased downward because of their unusually large output, while those of "small" establishments are, conversely, biased upward.

predicted would be found as a result of the regression fallacy, namely, average costs that were sharply declining, more closely approximating an L-shape than a U-shape. However, our interpretation of this result differs.

## IV

The census questionnaires do not provide sufficient information from which to estimate a cost function directly. Data on capital costs, rents, incidental expenses, and so forth are missing. Instead, we estimate two nonhomogeneous production-function forms, as discussed in Appendix B at the end of this chapter. These have variable returns to scale and are consistent with unit costs dependent upon the size of the firm.

The full set of economically meaningful and statistically significant production-function estimates appears in Appendix C. Attention here is focused, for convencience, upon a subset. This subset was chosen so as to illustrate the salient points in all of the estimates.

Consider first the results from estimating translog production functions. The econometric results were mixed. They were not always statistically significant or economically meaningful. About half of the translog production-function estimates were rejected because none of the variables were significantly different from zero at the 10-percent level in a two-tailed test.[70] A number of other translog production-function estimates exhibited perverse behavior in the returns-to-scale parameter, which increased with firm size. Scale elasticity behaved similarly in most of the variable scale-elasticity estimators (VSE) estimates (see Appendix C at the end of the chapter), but the ability to interpret those results in terms of the "normal" behavior of unit costs via duality mitigated my concern with the phenomenon.

In all cases for which the translog results were statistically significant and economically sensible, scale elasticity declined along a constant capital-labor ratio expansion path. Returns to scale were quite large for small plants and decreased rapidly as firm size increased. Scale economies eventually disappeared and decreasing returns set in for larger plants. Establishments that were two or three times larger than the average were often producing under constant returns to scale. In a number of industries, however, scale economies were such that constant returns were realizable only by the very largest of plants. In 1870, for example, the estimates predict that lumber mills producing less than $3,250,000 value-added would have been operating in the range of increasing returns to scale. No lumber mills that large existed then.

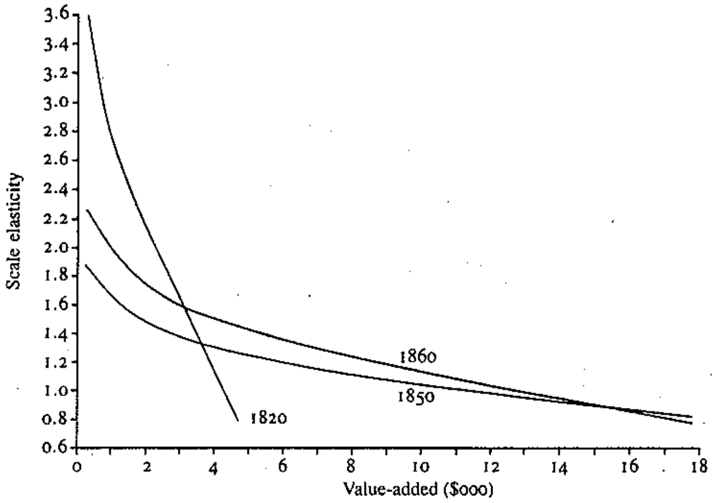

FIGURE 9.5 Translog Production Functions: Flour

Where the scale elasticity estimates from the translog function for an industry could be examined over time, the scale elasticity curves for successive years lay above and to the right of those for earlier years (Figure 9.5). In 1820, for example, flour mills producing less than about $4,400 value-added were producing under increasing returns to scale. By 1850, flour mills had to be almost three times as large to produce under constant returns, and in 1860 those producing $12,600 or less were producing under increasing returns to scale. Returns to scale in 1860 were diminishing more rapidly than they had in 1850. Consequently, whereas small to medium-sized mills producing less than $16,000 value-added in 1860 had returns to scale greater than comparable plants in 1850, those producing over this amount had smaller returns to scale. In both cases, however, mills that large were producing in the range of decreasing returns to scale.[71]

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[70] Changing the critical $t$-value to ± 1.28 (20% confidence interval) would result in 14 more regressions having one or more variables that were significantly different from zero. For an extended note on the unreliability of standard statistical tests (i.e., the $t$-test) on the squared terms in the equation, see Z. Griliches and V. Ringstad, *Economies of Scale and the Form of the Production Function* (Amsterdam: North-Holland, 1971), pp. 77–79.

[71] The estimate for 1870 was discarded, as scale elasticity was increasing with firm size.

In his study, John James found that the optimum size for flour mills before 1870 was very small, indeed close to zero; but in the estimates given here, flour mills had to be three to four times larger than the average to produce at about constant returns.[72] After 1870, James argues that there was a dramatic upward shift in the returns to scale. Our estimates show a similar upward movement, but from a much earlier date.

It is possible to make too much of these differences. Instead, the focus of attention should be on the similarity in the implications of our results. If the problem of increasing scale elasticity with plant size in the 1870 flour-milling estimate is overlooked, all of our scale-elasticity-curve estimates follow the same pattern that James describes, lying above and to the right of those for earlier years. The scale-elasticity estimate for flour mills in 1870 suggests that the most efficient plant would be one of infinite size, while in 1860 a mill producing only $12,600 value-added would have been most efficient. The scale differences that James noted between 1860 and 1880 in flour milling are on the same order of magnitude, given the size of the market.

Confirmation of James's finding of upward shifts in the returns to scale with the passage of time is significant. James's original results were not conclusive because he used aggregate state data in a pooled time-series–cross-section model in which time acted as a shift parameter. Hence, his results were in part forced by the particular form of the estimating equation. The estimates presented here, on the other hand, are independent of one another. Nevertheless, the same general pattern emerges from them, although without the symmetry that characterizes James's estimates. Plants grew larger over time partly because they had to if they wished to realize potential scale economies.

Many of the translog production functions were rejected because they contained no statistically significant regression coefficients.[73] No variable scale-elasticity estimates were rejected for this reason. Indeed, in the VSE equations, the regression coefficients and the conditional parameter, $c_o$, were usually significantly different from zero.[74] Just over half of the estimates were rejected because they implied unit costs that rose first and then fell, or that rose at a decreasing rate. These results arise because the equation predicts decreasing returns to

scale for even the very smallest plants.[75] Rejection of them is a denial that the average-cost-curve behavior that they imply is economically reasonable and plausible, rather than a rejection of the idea that there may be decreasing returns for very small plants. There is nothing to prevent production of a good under conditions of decreasing returns to scale, but we would not expect to observe plants growing under such circumstances, beyond the absolute minimum scale for production, unless and until conditions changed.

The conditional parameter, $c_0$, in the equation

$$\ln Q + c_0(\ln Q)^2 = b_0 + b_1 \cdot \ln K + b_2 \cdot \ln L$$

allows scale elasticity to vary with plant size. It was almost always significantly negative, regardless of the year, industry, or magnitude of the regression coefficients for labor and capital. As a result, scale elasticity was not well behaved and increased with plant size over the observed range.

Consequently, we have interpreted these estimates in terms of the average-cost curve that is derived from the dual of the production function. Where the sum of the capital and labor coefficients was greater than unity and $c_0$ was negative, unit costs were declining across the entire observed range of plant sizes. The most efficient plant in the industry for a particular year was consequently larger than the largest plant in the data set, but there is no way of knowing how much larger.

In just two cases was $c_0$ positive.[76] Both were in 1870. Since the sum of the capital and labor coefficients was greater than one, these estimates imply an average-cost curve that was U-shaped. However, given the small (although significantly positive) values for $c_0$ and the magnitude of the sum of the labor and capital coefficients, the minimum point on the average-cost curves occurred at output levels in the billions of dollars. The estimates thus still imply that the optimum plant in these industries was one that supplied the entire market.

The level of each average-cost curve relative to the others gives no information about the relative cost between them from year to year. Absolute costs are determined by the magnitude of the constant, $k$, in each equation. It changed from year to year. Thus, although the curve

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[72] James, "Structural Change," pp. 445–446.

[73] See Griliches and Ringstad, *Economies of Scale*, pp. 77–79.

[74] The distribution ($\ln L - \ln L_{max}$), where $\ln L$ is the estimated value of the log likelihood function, follows the a chi-square distribution such that ($\ln L - \ln L_{max}$) $< 0.5\chi^2$. The critical value of $\chi^2$ for the 95% confidence interval is $-1.94$. See Ringstad, "Some Empirical Evidence," p. 93.

[75] When $m < 1$ and $c_0 < 0$, then the implied average-cost curve has an inverted U-shape, with rising unit costs for very small establishments, eventually decreasing for large establishments. For $m < 1$ and $c_0 > 0$, unit costs are increasing throughout, but at a decreasing rate for larger plants.

[76] Cotton goods and meat packing. See Appendix C at the end of the chapter.

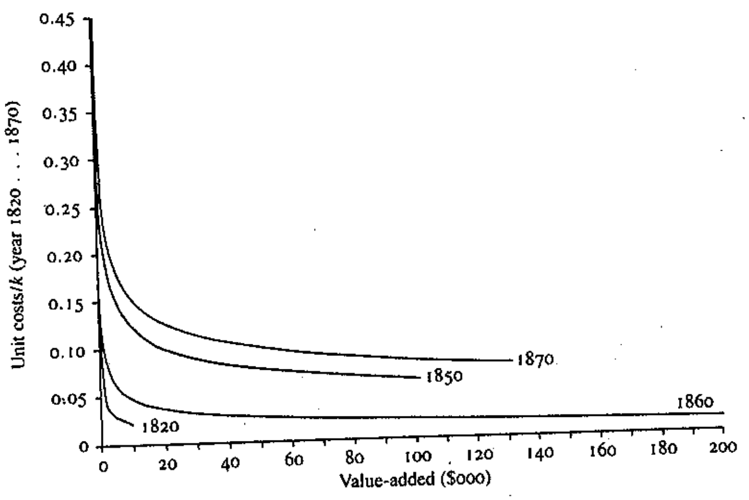

FIGURE 9.6 Flour-Milling Unit Costs, 1820–1870

for 1870 lies above the others, this does not imply that costs in 1870 were the greatest or that 1820 costs were lowest. Furthermore, since output is measured by value-added, not physical units, these results must be interpreted cautiously and the reader should recognize that product prices will affect the relative "unit" costs.

The estimates for flour milling in 1820, 1850, 1860, and 1870 (Figure 9.6) show the indeterminacy of the cost-minimizing scale of plant quite clearly. The unit-cost curves are declining throughout, and plant size was therefore theoretically bounded only by the size of the market. In practice, however, this was probably not the case. Plant size determinacy is restored by positive transport costs. This is discussed at length below. Moreover, although unit costs declined very steeply at first, the curve eventually flattened out. As a result, the average-cost curve had a very pronounced L-shape. The sharpest decreases in unit costs per unit increase in output were realized by the smallest plants. Further declines in unit costs once a certain scale had been attained were much smaller. Small plants beyond this critical point may therefore not have been placed at a serious cost disadvantage relative to those that were somewhat, or even much, larger.

The largest flour mill in the 1820 sample was quite small, producing less than $10,000 value-added, compared with the largest mill in the

1870 sample, which produced about $130,000 value-added.[77] In 1820, a flour mill half as large as the largest would have had unit costs some 40 percent higher. A mill of the same relative size in 1870 would have experienced costs only about 22 percent higher. A mill one-tenth the size of the largest would have unit costs almost three times greater than those for the largest in 1820. In 1870, the margin would have been about 80 percent.

These results are broadly consistent with those from the translog production function. Whereas the translog estimates predict that plant size, for constant returns to scale, was increasing over time, the cost functions derived from the VSE estimates imply falling average costs that did not begin to flatten as quickly over time, exhausting scale economies, as plant size increased.

Both the translog and VSE estimates lead to estimates of the optimum plant size (defined as that plant size with constant returns to scale, or minimum average cost) that are considerably larger than the average plant size by industry. In every industry for which sensible variable scale elasticity estimates were obtained, the optimum-sized plant would have enjoyed a natural monopoly. The translog estimates were somewhat more conservative. Optimum plant size was less than infinite, but with the exception of sheet metals in 1850 and the two estimates for 1820 (flour milling and wagon and carriage making), plants that were large enough to be producing at constant returns were more than twice the size of an average plant in the industry.

## V

Another check upon these results was made using heuristic estimates, from the survivor technique of the optimal plant size.[78] The survivor technique uses the economic theory of long-run equilibrium adjustment to identify which plant sizes not only survived the rigors of market competition over time but also succeeded in increasing their share of total industry value-added. Competition guarantees that only the

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[77] The average-cost curves in Figure 9.6 cover the range of observed plant sizes, from smallest to largest in the sample for each year. Note, however, that the largest firm in these samples was not the largest flour mill in the country in that year. In 1870, for example, the largest flour mill was the firm of Blecker Brothers, which produced $569,500 value-added.

[78] *Optimality* in this context is defined in terms of adjustment to market conditions rather than simple cost minimizing. Although the fundamental notion embodied in the survivor technique may be traced back to John Stuart Mill and Willard Thorp, it owes its modern revival to George Stigler. See George Stigler, "Monopoly and Oligopoly by Merger," *American Economic Review* 40 (May 1950), pp. 23–34, and "The Economies of Scale," *Journal of Law and Economics* 1 (Oct. 1958), pp. 54–71.

efficient plants survive in the long-run. Survival, through evolution if necessary, is the ultimate "market test" of efficiency.

A number of assumptions are implicit in the technique.[79] Shepherd, for example, argues that "survivor estimates for firm sizes are likely to be more valid for atomistic industries . . . than for highly concentrated ones," because the assumptions of atomistic competition ensure that, in the long run, market pressures force all surviving plants to operate at minimum long- and short-run average cost.[80] In perfect competition in a constant-cost industry, demand shifts affect only the number of establishments in the industry, but such changes under other market structures permanently alter the market solution, including the optimum plant size. The available evidence on market structure in the nineteenth century suggests that American industry was not perfectly competitive, but consisted of spatially separated local monopolies that were protected from competition with each other by high transportation costs.[81] As a result, the survivor results reflect both supply and demand changes, but to the extent that there were sharp discontinuities in the pattern of plant survivorship these will be attributed to supply-side changes, including changes in transport costs.

Profit-maximizing behavior ensures the survival of lower-cost plants regardless of market structure. Survivorship under imperfect competition, monopolistic competition, or oligopoly, however, no longer carries the implication of cost minimization. To avoid confusion between survivorship and the economic concept of optimum plant size, Leonard Weiss coined the term "minimum efficient scale" (MES) to characterize the smallest range of surviving plants.[82] This terminology is appropriate regardless of market structure, and it is used here.

Estimates of the range of surviving plants are consistent with the L-shape of the average-cost curve implied by the VSE production-function estimates and suggest that a considerable portion of the long-run average-cost curve may have been flat, or almost so. The ranges of surviving plants also generally overlapped the translog estimate of

plant size for unit scale elasticity.[83] A wide range of plants survived in almost every industry. In most, the MES plants were larger than average, and the upper range was usually many times greater than the mean establishment size. In only six industries (flour and lumber milling, saddlery, sheet metals, tobacco, and woolens) did the range of surviving plants include plants that were of average size. Plants in four of these industries, flour and lumber milling, saddlery, and sheet metal, were ubiquitous. These were local establishments that produced locally consumed goods. Surviving plants in the other ten industries were much larger than average.

There is, therefore, abundant evidence of increasing returns to scale and declining unit costs. The translog estimates suggest that to realize constant returns to scale, establishments had to be at least twice as large as average and sometimes much larger. Estimates of the unit-cost curve implied by the variable scale-elasticity results indicate continuous cost advantages for ever-larger plants. Both techniques, however, show the greatest gains would be realized by small establishments growing somewhat larger. Nevertheless, large plants could enjoy quite substantial cost advantages over smaller competitors. Similarly, the survivor results show that large plants, particularly factories, contributed ever-greater proportions of total industry production as time passed. They not only survived but prospered and grew even larger.

## VI

Our empirical work, regardless of any inconsistencies between efficiency estimates and those for economies of scale, indicates persistent supply-side incentives for increasing plant size during America's industrialization. Sometimes the changes in the average scale of operation caused by the rise of the factory were quite dramatic. For example, whereas iron furnaces in 1820 had generally employed fewer than twenty workers and produced less than $6,000 value-added, by 1870 such establishments typically employed sixty or more workers and produced $45,000 value-added. Even cotton mills, which had been the first big business in American industry, underwent extraordinary growth. From establishments employing perhaps twenty adult equivalents and producing about $7,000 value-added on average in 1820, by 1870 the average mill employed more than a hundred and produced perhaps $100,000 value-added.

The dominant picture in the literature is one of increasing average

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[79] William A. Shepherd, "What Does the Survivor Technique Show About Economies of Scale," *Southern Economic Journal* 34 (July 1967), pp. 113–122. See also Thomas R. Saving, "Estimation of Optimum Plant Size by the Survivor Technique," *Quarterly Journal of Economics* 75 (Nov. 1961), pp. 569–607.

[80] Shepherd, "Survivor Technique," p. 115.

[81] See Fred Bateman and Thomas J. Weiss, "Comparative Regional Development in Antebellum Manufacturing," *Journal of Economic History* 35 (March 1975), pp. 182–208, and "Market Structure Before the Age of Big Business: Concentration and Profit in Early Southern Manufacturing," *The Business History Review* 49 (Autumn 1975), pp. 312–336.

[82] See Leonard W. Weiss, "The Survival Technique and the Extent of Sub-Optimal Capacity," *The Journal of Political Economy* 72 (June 1964), pp. 246–261.

[83] See Appendix B at the end of the chapter.

plant size, with particular emphasis being given to the emergence of industrial behemoths. This began quite early, but the pace accelerated later in the century, and there was a sharp increase in the number of establishments producing a million dollars of output or more between 1820 and 1870. There were no plants this large in Sokoloff's 1820 sample. In 1850, there were 16 plants that produced more than a million dollars worth of output. By 1860, 56 plants produced this much, and by 1870, at least 138 plants were producing goods valued at more than a million dollars.[84] These data suggest an accelerating trend toward bigness in American industry.

Furthermore, big establishments were to be found in an increasingly wide range of industries. Whereas in 1850, million-dollar plants were confined to just four industries—cotton mills (11), sugar refineries (3), woolen mills (1), and steam engine factories (1)—by 1870, they were to be found in thirty-eight industries. Cotton mills and sugar refineries still dominated, but industries such as sewing machines, agricultural implements, iron, nails, clothing, boots and shoes, liquor, brewing, leather tanning, lumber milling, and flour milling, to name but a few, had representatives among the million-dollar-plus plants by 1870.

Given our results that show larger, mechanized plants to be economically superior to smaller, nonmechanized plants, the rise of very large plants is not surprising.[85] Nevertheless, average plant size remained small despite the establishment of more and bigger establishments in every industry. In some industries, scale differences were barely perceptible over the interval between 1820 and 1870. The ubiquitous lumber and flour mills, for example, changed hardly at all, except perhaps in switching from water to steam power. In 1820 the average flour mill employed 3.25 adult equivalents and generated about $2,000 value-added.[86] In 1870, the average mill in the sample employed 2.8 people to produce about $2,300 value-added.[87] The average boot and shoe establishment in 1870 was in fact only about half the size (in terms of employment and output) of its predecessor of 1820.[88]

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[84] These figures are from the Bateman-Weiss large-firm samples. I believe that they are comprehensive, since each state sample that contained million-dollar plants also contained plants producing less than that. After adjusting output values by the Warren-Pearson price indexes, there would be 19 million-dollar plants in 1850, 57 in 1860, and 78 in 1870.

[85] Mechanized plants were larger in terms of value-added or output for comparable labor forces than nonmechanized plants in the same industry.

[86] Sokoloff sample data.

[87] Bateman-Weiss sample data. Average employment in flour mills in the published census is a little lower, 2.57 employees, and value-added a little higher, $3,400.

[88] Regardless of whether sample or published census statistics are used.

TABLE 9.4

Firms Producing Less than $1,000 Value-Added, by Industry, in 1850 and 1870, as a Percentage of All Firms in the Industry from the Samples and the Implied Number of Such Firms in the Population

(Rounded to nearest 10)

| | 1850 | | 1870 | |
|---|---|---|---|---|
| Industry | Percent of firms in sample | Number of firms in population[a] | Percent of firms in sample | Number of firms in population[a] |
| Boots & shoes | 35% | 3,960 | 60% | 14,060 |
| Brewing | 14 | 60 | 65 | 1,280 |
| Clothing | 25 | 1,070 | 48 | 3,760 |
| Cotton goods | 2 | 20 | 0 | 0 |
| Flour milling | 43 | 5,110 | 68 | 15,350 |
| Furniture | 44 | 1,870 | 44 | 2,290 |
| Iron | 3 | 10 | 27 | 90 |
| Leather | 36 | 2,350 | 56 | 4,100 |
| Liquor | 47 | 460 | 51 | 370 |
| Lumber milling | 45 | 8,050 | 51 | 13,170 |
| Meat packing | 23 | 40 | 31 | 80 |
| Saddlery | 31 | 1,090 | 54 | 4,110 |
| Sheet metals | 23 | 520 | 34 | 2,260 |
| Tobacco | 42 | 600 | 31 | 1,600 |
| Wagon making | 41 | 1,730 | 52 | 6,160 |
| Woolen goods | 24 | 440 | 13 | 250 |

SOURCE: Percentages are computed from the Bateman-Weiss samples.

[a] Numbers are computed by applying these percentages to the published census estimates for the number of firms by industry.

Moreover, the median establishment in almost every industry (except textiles) was very small. To at least 1870, small-firm populations decreased in only three industries (cotton and woolen textiles and tobacco) that are considered here (Table 9.4).[89] These industries were overwhelmingly concentrated in cities and were confined to fairly narrow geographic areas. New England, for example, contained more than half of all the nation's cotton mills and accounted for about two-thirds of the production.[90]

In the other industries the fraction of very small plants seems to have been increasing. In particular, the percentage of plants producing less than $1,000 value-added increased and, in a majority of cases, the median plant size fell within this range. These populations, however, were not only increasing in relative frequency, they were increasing in absolute number. Between 1850 and 1870, for example, over 10,000 small

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[89] Among the industries I study here. I have not yet examined the results for all industries.

[90] Francis A. Walker, *Statistics of Wealth & Industry*, p. 430.

boot and shoe establishments, 10,000 small flour mills, and 5,000 small lumber mills were established, not to mention perhaps 2,500 needle-trade establishments, 1,200 small breweries, and 1,000 cigar and tobacco establishments.[91] In aggregate, in the sixteen industries that are considered here, perhaps as many as 41,000 new small establishments, each producing less than $1,000 value-added, were established. As the increase in the entire population of business establishments between the two dates was only 130,000, between a quarter and a third of all new entrants were small plants in just these few industries.

Despite their overwhelming numbers in virtually every industry, small plants contributed relatively little in terms of total industry output, and although they were an increasing majority, they generally failed to maintain their share of industry production.[92] By simple arithmetic, one plant producing a million dollars of output contributes as much to total production as one thousand plants each producing a thousand dollars of output. The 122 additional large establishments with outputs exceeding a million dollars in 1870, over the number in 1850, thus probably generated a greater output value than the 41,000 new small plants in the sixteen industries studied here.

## VII

This situation raises a potential economic paradox: If small plants were inefficient and uneconomic, how could they survive within a competitive environment? The answer, it is argued, lies in the role that transportation played in the development of the structure and location of industry in America.

First, consider the case of the very large-scale enterprise. According to our production-function estimates, plants faced monotonically decreasing average costs. As a result, optimum (that is, cost-minimizing) plant size was indeterminate. However, positive transport costs can make plant size determinate even under these conditions. Market boundaries for competing establishments are defined by equality in price to the consumer. That price covers not only production but also distribution costs. Internal production costs are therefore only part of the story, and it can be shown that the sum of a monotonically decreasing average-cost curve and a monotonically rising transport-cost function may be U-shaped.

Consider now the situation that might have faced a small plant, say a typical flour mill. In 1820, such a mill, producing about $2,000 value-added, would have experienced unit costs that were about double those of the largest mills. In 1870, an average-sized mill (generating $2,300 value-added) would have been at an even worse competitive disadvantage. Its costs would have been about three times higher than those of the largest mills around then. With cost differentials of these magnitudes, mills of radically different size were unlikely to be located in close proximity to one another.

Positive transport costs, however, created protected markets for high-cost producers by providing a measure of protection to less efficient plants. A high-cost producer—provided it located at sufficient distance from a low-cost producer, such that the cost of transport exceeded the production-cost differential between them—could always survive.[93] This situation generates some interesting dynamics in the distribution of plant sizes, especially in a developing country.

Consider a large business located on a featureless plain in a developing economy. The situation is shown in Figure 9.7. The large plant is located at point *C*. Consumers are distributed across the plain, but population density decreases as we move away from *C*. Transportation costs are positive and equal in all directions. Let us examine the dynamics of competition along a radius, *CD*, from *C*. This is shown in the *xy* graph in the lower half of Figure 9.7. Distance from *C* is measured along the *x*-axis. The *y*-axis represents production and distribution costs per unit. The large plant at *C* produces a homogeneous good at a price of *CA* per unit. Adding to this the cost of transportation (a function of distance) represented by the line *AB* determines the selling price of the good at any location along the radius *CD*. Thus, at *D*, the good is available at price *DB*.[94]

Suppose now that small plants have higher unit-production costs

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[91] Estimated by applying the percentages in Table 9.4 to the number of plants reported by the census in those industries in 1850 and 1870.

[92] This might be inferred from the results shown in Table 9.2 above, which shows mills and factories gaining at the expense of other organizational forms.

[93] Whether or not the measure of protection afforded by transport and information costs extended to cover costs that were two or three times greater is a different matter. One should not be too dogmatic about the specific cost ratio estimates presented here, provided that the existence of a "substantial" differential is recognized. How significant such cost differences were in affecting the competitiveness of establishments of varying size and location would depend upon transport costs.

[94] For similar ideas in the industrial organization literature, see Steven C. Salop, "Monopolistic Competition with Outside Goods," *The Bell Journal of Economics* 10 (Spring 1979), pp. 141–156; William J. Baumol, John C. Panzer, and Robert D. Willig, *Contestable Markets and the Theory of Industry Structure* (New York: Harcourt, Brace Jovanovich, 1982).

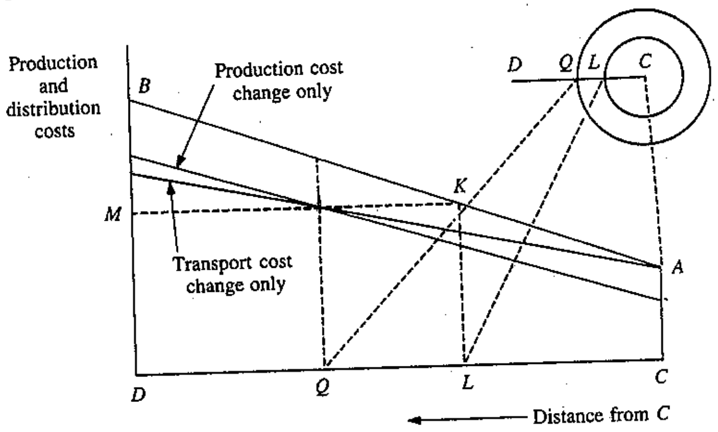

FIGURE 9.7 The Spatial Distribution of Competition

than large plants, say *LK*. Their cost levels are higher because of their inability to realize scale economies and because of the relative inefficiency of their handicraft organization. These costs, then, become the upper limit of the price that the larger enterprise can charge for its product. Assuming homogeneity, consumers will buy the cheapest product. Thus at distance *CL* from the large plant, consumers will be indifferent between the good sold by the large plant and distributed from *C* and that produced by a small enterprise located at *L*. To the extent that not many sales are required to realize unit costs of *LK*, the price of this product to any consumer will be given by the line *AKM*.

The circumference, *L*, around *C* represents the market boundary for the product made by the large-scale enterprise located at *C*. All consumers within this boundary purchase the good from *C*; all those without, purchase the good from a smaller plant located on or beyond the circumference. Sales for the larger-scale enterprise are determined by the number of consumers within the market boundary, which is a function of the area of the circle radius, *CL*, given the population density. Because population density decreases with distance from *C*, markets for the smaller plants are quite limited geographically, and market density is greatest closest to the circumference, *L*, of the large plant's market boundary. Most smaller establishments will therefore try to locate on or close to this circumference. Their number, given the volume of sales they needed to realize unit costs of *LK*, will be a function of the circumference of this market boundary centered on *C*. Other small establishments will locate beyond this boundary.

Over time, a number of changes took place that affected this situation. First, market density increased through population growth, migration, and rising incomes. Second, transport costs fell as transportation media improved. These two forces affect the transport costs for any given level of sales and hence alter the effective slope of *AB* as shown in Figure 9.7. Third, new production technologies were developed that were better suited to large-scale than small-scale production. Moreover, there is evidence of a quality differential between factory and handicraft goods that favored the former over the latter, thereby reducing the relative price of factory goods, adjusted for quality. Machine-made cloth, for example, was finer than the hand-loomed kind, and machine-made boots and shoes were more durable.

As a result, the market boundary for the large plant at *C* expanded to, say *Q*. Its sales expand as a function of the market area, that is at the rate of the square of the change in the market radius. This would further accelerate if population densities and income levels were to rise within the market boundary. Small establishments on the old market boundary, *L*, would be driven out of business by low-cost competition from the large producer. But there would now be a new, larger market boundary represented by the circumference *Q* around *C*. There might therefore be *more* small establishments than before, even after the exit of those establishments in the area between circumferences *L* and *Q*.

It is unlikely, however, that lowered transport costs would immediately lead to the displacement by factory products of rural handicraft production in the market between *L* and *Q*. Handicraft workers were often willing to squeeze their income levels to stay in business in competition with more efficient producers. To the extent that they were successful, the artisan shop represented an impediment to the spread of the factory by limiting the scope of market and the desirability of further investments. Alexander Hamilton in his "Report on Manufactures" clearly thought that this would be the case. In his opinion,

> the spontaneous transition to new pursuits, in a community long habituated to different ones, may be expected to be attended with proportionally greater difficulty. When former occupations ceased to yield a profit adequate to the subsistence of their followers; or when there was an absolute deficiency of employment in them . . . changes would ensue; but these changes would be likely to be more tardy than might consist with the interest either of individuals or of the society. In many cases they would not happen, while a bare support could be insured by an adherence to ancient courses, though resort to a more profitable employment might be practicable.[95]

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[95] Alexander Hamilton, "Report on Manufactures, Communicated to the House of Representatives, December 5, 1791," in *American State Papers*, Finance, I, as re-

The lumpiness of factory investment compounded these problems. Each new factory or machine represented a significant, finite increase in industry supply. This increased pressure upon prices and was felt keenest in times of depression when factories were kept operating because of their relatively high ratio of fixed to variable costs. On the other hand, artisans either switched to part-time work or temporarily closed up shop.

Nevertheless, the long-term effects of such behavior seem to have been minimal as large establishments grew very rapidly. This growth seems to have been much faster than warranted by demand-side factors such as price and income elasticity and the growing number of potential consumers. Furthermore, to the extent that small establishments located in more remote rural markets,[96] which grew increasingly less remote, it is unlikely that the growth in their numbers might be attributed to complementarity between most handicraft and factory production.[97] Markets were segmented by heterogeneous access to transportation and by nonuniform transport costs, and as a result, there were areas where small establishments not only survived but prospered. Competition between producers with disparate costs took place on the boundaries of these markets.

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printed in John C. Hamilton, ed., *The Works of Alexander Hamilton* (New York: Charles S. Francis, 1851), vol. 3, pp. 192–284. The quotation is from p. 217.

[96] Sokoloff has done some work mapping firm location in 1832 and 1850 and found that more large plants are located in urban areas and that plants tended to shun locations in close proximity to competitors. See Sokoloff, "Transition from the Artisanal Shop," pp. 359–362. More work on this topic, however, needs to be done.

[97] In this situation the handicraft sector would serve as a buffer for the factory, supplying extra goods beyond the factory's capacity in boom times and absorbing unemployment to maintain factory employment in times of slump. The scenario is akin to the microeconomic model of price leadership by a dominant firm in which the dominant "firm" is the group of low-cost factory producers and the smaller plants are the artisan shops. In that model, the dominant plants set price at a level that maximizes their profits and then permit the small artisan shops to sell as many units as they wish at the prevailing price. The factories act as monopolists, the artisan shops behave like perfect competitors. See John S. Lyons, "Competitiveness or Complementarity in the Survival of Protoindustry?" (unpublished manuscript, Northwestern University, 1984), for a discussion of these scenarios in the case of British industrialization.

Another way in which the factory and handicraft shop may have been complementary is if the existence of the factory cheapened inputs for the artisanal shop, thereby making artisan shops located in close proximity to factories more efficient.

In either complementarity scenario, however large and small plants would be located in close proximity to one another, whereas when factories and handicraft production are substitutes, they will be located at a distance from one another.

## VIII

The rise of the factory thus seems to have been helped by persistent, but small, productivity gains over more traditional production methods. These gains are similar to those estimated by Sokoloff for 1820 and 1850 but they are much smaller than one would have anticipated from the narrative literature. The mill and factory compared particularly favorably with sweatshops and manufactories, and competition between them led to the disappearance, or sharp economic decline, of these larger, nonmechanized producers. The smaller artisan shops also declined in relative importance, but many consumers still remained dependent upon them. They persisted despite substantial scale economies that became progressively larger as the nineteenth century progressed. These economies of large-scale production led to rapid increases in the number of large plants in every industry, consistent with Chandler's identification of the origins of modern large-scale production in the technological imperatives of new production methods.

Artisan shops, however, not only appear to have persisted but their numbers continued to increase until at least 1870, despite the emergence of more efficient and seemingly better-adapted larger plants. In many industries, this trend may have continued to the end of the century.[98] Although more work is needed on plant location, this pattern of increasing numbers of both seemingly uneconomic small plants and much more efficient large plants is consistent with a model in which competition between them is constrained by transport costs. The eventual triumph of big business and large-scale plants in many industries, then, is attributable to transportation improvements, despite scholarly efforts over the past two decades to downplay the contribution of the transportation revolution.

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[98] This conjecture is based upon my claim that the structure of industry in 1900 does not seem to be different in most industries from the trends that were apparent in 1870. See Atack, "Industrial Structure," especially pp. 42–50.

## Appendix A

TABLE 9.5
Sample Sizes by Industry and Year

| Industry | 1820 | 1850 | 1860 | 1870 |
|---|---|---|---|---|
| Boots & shoes | 25 | 478 | 471 | 389 |
| Brewing | n.a.[a] | 11 | 29 | 43 |
| Clothing | n.a. | 120 | 135 | 154 |
| Cotton goods | 70 | 41 | 35 | 14 |
| Flour milling | 44 | 420 | 627 | 542 |
| Furniture | 23 | 213 | 170 | 115 |
| Iron | 24 | 30 | 25 | 22 |
| Leather | 121 | 371 | 251 | 106 |
| Liquor | 168 | 30 | 75 | 24 |
| Lumber milling | 27 | 865 | 1,061 | 622 |
| Meat packing | n.a. | 39 | 67 | 10 |
| Saddlery | 15 | 181 | 157 | 159 |
| Sheet metals | 27 | 109 | 129 | 105 |
| Tobacco | n.a. | 66 | 72 | 84 |
| Wagon making | 20 | 205 | 270 | 227 |
| Woolen goods | 39 | 63 | 38 | 30 |

[a] n.a. = no observations in the sample.

## Appendix B: Estimating Nonhomogeneous Production Functions

Currently the most popular form of nonhomogeneous production functions is the translog production function. In log-linear form, this may be written as[99]

$$\ln Q = b_0 + b_1 \cdot \ln L + b_2 \cdot \ln K + b_3 \cdot (\ln L)^2 + b_4 \cdot \ln K \cdot \ln L + b_5 \cdot (\ln K)^2$$

which has returns to scale,

$$b_1 + b_2 + (2b_3 + b_4) \ln L + (2b_5 + b_4) \ln K$$

This production function is both nonhomogeneous and nonhomothetic. As a result, returns to scale are usually evaluated for the different output levels generated by labor and capital in proportions equal to the mean capital-labor ratio. To the extent that different modes of production had different capital-labor ratios, they would also have had different patterns of scale economies by output. Unfortunately, the translog function is not self-dual; that is, estimation of a translog production function gives no information about the cost function. The two formulations represent different specifications of the underlying technology. This is a serious drawback for the intended use of the results.[100] Nevertheless, at times, economically nonsensical results from the preferred estimator led to the use of the translog production functions as a substitute. In general, however, the translog results were no more robust and could not be preferred on any econometric or theoretical grounds to those arrived at by other methods.

There exists a class of homothetic, nonhomogeneous production functions that are self-dual and yet have scale economies solely dependent upon the level of output. Estimators of this class will be referred to as variable scale-elasticity (VSE) estimators. These represent our preferred estimators. Functions of this class have been developed by Nerlove:[101]

$$\ln Q + c_0 (\ln Q)^2 = b_0 + b_1 \cdot \ln K + b_2 \cdot \ln L$$

which has returns to scale:

$$(b_1 + b_2)/(1 + 2c_0 \ln Q)$$

and by Zellner and Revankar:[102]

$$\ln Q + c_0 Q = b_0 + b_1 \cdot \ln K + b_2 \cdot \ln L$$

which has returns to scale:

$$(b_1 + b_2)/(1 + c_0 Q).$$

Experiments with both formulations have led to the selection of Nerlove's model because the returns-to-scale parameter is better behaved for negative values of $c_0$ and the estimates of $c_0$ are less subject to computational inaccuracy.

Regardless of formulation, the equation is estimated using a conditional maximum likelihood estimator. The parameter $c_0$ is free to vary within certain bounds and is chosen so as maximize the likelihood of the ordinary least-squares regression of the independent variables on the transformed dependent variable. The bounds on $c_0$ are such that the returns to scale are defined. That is, in Nerlove's model,

$$c_{0_{\min}} = -1(2 \ln Q_{\max})$$

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[99] See Laurits Christensen, Dale Jorgensen, and Lawrence Lau, "Transcendental Logarithmic Production Functions," *Review of Economics and Statistics* 55 (Feb. 1973), pp. 28–45; Ernst Berndt and Laurits Christensen, "The Translog Function and the Substitution of Equipment, Structures, and Labor in U.S. Manufacturing, 1929–1968," *Journal of Econometrics* 1 (March 1973), pp. 81–113, for a discussion of the methodology. See James, "Structural Change," or Louis P. Cain and Donald Paterson, "Factor Biases and Technical Change in Manufacturing: The American System, 1850–1919," *Journal of Economic History* 41 (June 1981), pp. 341–360, for examples of the application of the methodology.

[100] See James, "Structural Change," pp. 443–460, especially pp. 453–456, for an elaboration of this point.

[101] M. Nerlove, "Returns to Scale in Electricity Supply," in *Measurement in Economics,* Carl F. Christ, ed. (Stanford: Stanford University Press, 1963). See also V. Ringstad, "Some Empirical Evidence on the Decreasing Scale Elasticity," *Econometrica* 42 (Jan. 1974), pp. 87–102.

[102] A. Zellner and N. S. Revankar, "Generalized Production Functions," *Review of Economics Studies* 36 (April 1969), pp. 241–250.

while for the Zellner and Revankar model,

$$c_{0_{\min}} = -1/Q_{\max}$$

There is no upper-bound constraint on the parameter in either formulation. The cost function implied by Nerlove's model is that given by

$$\text{min.: } C = wL + rK$$

$$\text{subject to: } Qe^{c_0(\ln Q)^2} = K^{b_1}L^{b_2}$$

Solving yields

$$C_{\min} = K\,[Qe^{c_0(\ln Q)^2}]^{(1/(b_1 + b_2)}$$

where *k* is a constant determined by the relative factor shares and relative factor prices. The average-cost curve corresponding to this is:

$$AC = K\,[Q^{-m}Qe^{c_0(\ln Q)^2}]^{(1/m)}$$

where $m = (b_1 + b_2)$.

For $m > 1$ and $c_0 > 0$, this average cost curve is U-shaped. If $m > 1$ and $c_0 < 0$, then average costs are declining at least through $Q_{\max}$, the largest plant observed. Results for $m < 1$ (i.e., diseconomies of scale for even the very smallest plants) are inconsistent with economic theory. In the case of $m < 1$ and $c_0 < 0$, the implied average-cost curve has an inverted U-shape; that is, unit costs are increasing for very small plants, reach a maximum, and then decrease for large plants. For $c_0 > 0$, unit costs are increasing throughout but at a decreasing rate for larger plants.[103]

Where initial results were inconsistent with accepted economic theory, the data that generated them were scrutinized. Particular attention was paid to those observations with large positive residuals. By definition, plants can produce an output less than that specified by the production function (i.e., be inefficient), but they cannot produce more output, given their resources, than that defined by it.[104] That is,

$$Q_{\text{actual}} < Q_{\text{predicted}}, \quad \text{so} \quad Q_{\text{actual}} - Q_{\text{predicted}} < 0$$

Nevertheless, in some instances, $Q_{\text{actual}} > Q_{\text{predicted}}$, in which case the residuals will be positive. Plants with positive residuals were superefficient and producing beyond the production-possibilities curve, and those with the largest positive residuals were the most efficient of all.[105]

This result arises only because of my reliance upon least-squares estimation. By the Gauss-Markov conditions, $E(e_i) = 0$, so that except in the case of a perfect regression fit, observations will lie both above and below the predicted regression plane. There were positive residuals only because there were negative ones, and vice versa.

Of far greater concern was that the pattern of positive and negative residuals indicated a degree of autocorrelation that seemed related to the state from which the observations were drawn. A series of contiguous observations would have large positive residuals and be followed by a larger number of smaller negative residuals; that is, the production function seriously underpredicted output and productivity in some states. This raises some serious questions with respect to either the way in which the data were collected by census enumerators or the assumption of homogeneity between states.[106]

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[103] Note that in this case, the curve is not simply the right-hand half of a "normal" U-shaped average-cost curve.

[104] See Arthur S. Goldberger, "The Interpretation and Estimation of Cobb-Douglas Functions," *Econometrica* 36 (July–Oct. 1968), pp. 464–472.

[105] See M. J. Farrell, "The Measurement of Productive Efficiency," *Journal of the Royal Statistical Society*, series A, 120, part 3 (1957), pp. 253–281; M. J. Farrell and M. Fieldhouse, "Estimating Efficient Production Under Increasing Returns to Scale," *Journal of the Royal Statistical Society*, series A, 125, part 2 (1962), pp. 252–257; D. J. Aigner and S. F. Chu, "Estimating the Industry Production Function," *American Economic Review* 58 (Sept. 1968), pp. 826–839. There is a technique, known as a Minimum Absolute Deviation estimator (MAD), that permits us to constrain residuals to be of one sign, but this is not widely used, is inefficient, and prevents our reliance on standard statistical tests such as hypothesis testing. See E. M. L. Beale, "On Minimizing a Convex Function Subject to Linear Inequalities," *Journal of the Royal Statistical Society*, series B, 17 (1955), pp. 173–184; George G. Judge and T. Takayama, "Inequality Restrictions in Regression Analysis," *Journal of the American Statistical Association* 61 (1966), pp. 49–61. MAD is not used here.

[106] The use of state dummy variables (both slope and intercept) and filter rules to weed out those observations exhibiting unusually high or low labor or capital productivity failed.

# Appendix C

TABLE 9.6

Statistically Significant and Economically Sensible Translog Production-Function Estimates, by Year and Industry, 1820–1870

(K/L rounded to nearest $10. Value-added rounded to nearest $100)

| Year and Industry | $b_0$ | $b_1$ | $b_2$ | $b_3$ | $b_4$ | $b_5$ | K/L | Value-added for constant returns |
|---|---|---|---|---|---|---|---|---|
| 1820 | | | | | | | | |
| Flour milling | 5.367 | 11.315 | −2.138 | −0.387 | −1.005 | 0.238 | 1,600 | 4,400 |
| (S.E.) | | 5.520 | 1.722 | 0.520 | 0.654 | 0.119 | | |
| Wagon making | −0.067 | −0.099 | 1.905 | −0.679 | 0.524 | −0.186 | 190 | 2,000 |
| (S.E.) | | 2.557 | 0.724 | 0.547 | 0.559 | 0.111 | | |
| 1850 | | | | | | | | |
| Boots & shoes | 1.712 | 1.039 | 0.674 | −0.005 | −0.051 | −0.007 | 300 | 4,400 |
| (S.E.) | | 0.427 | 0.388 | 0.058 | 0.077 | 0.033 | | |
| Flour milling | 5.578 | 2.950 | −0.915 | −0.038 | −0.257 | 0.117 | 3,250 | 11,100 |
| (S.E.) | | 0.810 | 0.384 | 0.161 | 0.112 | 0.025 | | |
| Furniture | 5.832 | 2.798 | −0.989 | 0.152 | −0.398 | 0.159 | 500 | 2,800 |
| (S.E.) | | 0.812 | 0.622 | 0.125 | 0.151 | 0.053 | | |
| Lumber milling | 4.517 | −0.127 | −0.175 | −0.237 | 0.150 | 0.049 | 1,070 | 208,600 |
| (S.E.) | | 0.42 | 0.317 | 0.072 | 0.070 | 0.023 | | |
| Sheet metals | 6.328 | 6.189 | −1.646 | 0.700 | −1.001 | 0.245 | 1,150 | zero |
| (S.E.) | | 1.329 | 0.696 | 0.381 | 0.272 | 0.054 | | |
| Wagon making | −3.319 | −1.686 | 2.505 | −0.179 | 0.339 | −0.159 | 420 | 1,309,800 |
| (S.E.) | | 0.927 | 0.947 | 0.188 | 0.183 | 0.070 | | |
| Woolen goods | −5.211 | −2.551 | 2.934 | −0.716 | 0.738 | −0.226 | 1,220 | 25,700 |
| (S.E.) | | 2.790 | 2.055 | 0.348 | 0.466 | 0.166 | | |
| 1860 | | | | | | | | |
| Boots & shoes | 5.426 | 1.333 | −0.298 | −0.068 | −0.044 | 0.050 | 620 | 12,800 |
| (S.E.) | | 0.608 | 0.464 | 0.082 | 0.112 | 0.042 | | |
| Flour milling | 3.928 | 3.280 | −0.402 | −0.128 | −0.224 | 0.076 | 2,880 | 12,600 |
| (S.E.) | | 1.153 | 0.499 | 0.211 | 0.173 | 0.037 | | |
| Iron | 13.594 | 6.113 | −3.356 | 0.406 | −0.793 | 0.308 | 1,590 | 9,900 |
| (S.E.) | | 4.147 | 6.559 | 0.306 | 0.438 | 0.361 | | |
| Lumber milling | 2.757 | 2.288 | −0.080 | −0.021 | −0.185 | 0.063 | 1,290 | 11,200 |
| (S.E.) | | 0.458 | 0.380 | 0.057 | 0.070 | 0.028 | | |
| Saddlery | −0.616 | 0.843 | 1.366 | 0.032 | −0.014 | −0.059 | 830 | 38,600 |
| (S.E.) | | 1.168 | 0.681 | 0.193 | 0.212 | 0.061 | | |
| Woolen goods | 14.859 | 7.055 | −3.613 | 0.432 | −0.856 | 0.315 | 1,610 | 33,200 |
| (S.E.) | | 3.868 | 3.248 | 0.380 | 0.587 | 0.238 | | |
| 1870 | | | | | | | | |
| Brewing | −1.511 | −2.161 | 1.838 | −0.881 | 0.669 | −0.131 | 2,990 | 31,000 |
| (S.E.) | | 2.115 | 1.287 | 0.382 | 0.365 | 0.103 | | |
| Lumber milling | −2.101 | 1.137 | 1.258 | 0.125 | −0.122 | −0.019 | 1,300 | 3,281,800 |
| (S.E.) | | 0.412 | 0.367 | 0.053 | 0.061 | 0.026 | | |
| Saddlery | 1.693 | 1.780 | 0.532 | 0.124 | −0.202 | 0.022 | 900 | 5,000 |
| (S.E.) | | 0.871 | 0.480 | 0.163 | 0.155 | 0.041 | | |
| Tobacco | 0.019 | −1.176 | 1.351 | −0.319 | 0.292 | −0.064 | 1,110 | 12,200 |
| (S.E.) | | 0.975 | 0.810 | 0.184 | 0.173 | 0.062 | | |
| Woolen goods | −14.540 | −2.016 | 4.365 | −0.154 | 0.326 | 0.221 | 2,410 | 94,800 |
| (S.E.) | | 3.436 | 2.555 | 0.333 | 0.487 | 0.180 | | |

NOTE: (S.E.) = Standard error.

EQUATION: $\ln VA = b_0 + b_1 \cdot \ln L + b_2 \cdot \ln K + b_3 \cdot (\ln L)^2 + b_4 \cdot (\ln L \cdot \ln K) + b_5 \cdot (\ln K)^2$

## TABLE 9.7
### Statistically Significant Variable Scale-Elasticity Production-Function Estimates Implying Well-Behaved Average Costs, 1820–1870

| Year and industry | $c_0{}^a$ | $b_0$ | $b_1$ | $b_2$ |
|---|---|---|---|---|
| 1820 | | | | |
| Cotton goods | −0.00832 | 2.834 | 0.292 | 0.809 |
| (S.E.) | | | 0.069 | 0.115 |
| Flour milling | −0.01188 | 1.417 | 0.452 | 1.087 |
| (S.E.) | | | 0.137 | 0.348 |
| Furniture | −0.00995 | 3.363 | 0.278 | 0.887 |
| (S.E.) | | | 0.125 | 0.449 |
| Leather | −0.01096 | 2.935 | 0.308 | 0.811 |
| (S.E.) | | | 0.061 | 0.123 |
| Lumber milling | −0.01161 | 1.441 | 0.504 | 0.764 |
| (S.E.) | | | 0.128 | 0.253 |
| Saddlery | −0.00264 | 4.959 | 0.145 | 0.871 |
| (S.E.) | | | 0.126 | 0.434 |
| Sheet metals | −0.00857 | 3.697 | 0.310 | 0.713 |
| (S.E.) | | | 0.142 | 0.344 |
| Wagon making | −0.00571 | 3.635 | 0.368 | 0.669 |
| (S.E.) | | | 0.122 | 0.309 |
| 1850 | | | | |
| Flour milling | −0.00752 | 0.339 | 0.518 | 0.688 |
| (S.E.) | | | 0.109 | 0.041 |
| Leather | −0.00944 | 2.139 | 0.559 | 0.479 |
| (S.E.) | | | 0.074 | 0.034 |
| Liquor | −0.00788 | 1.363 | 0.352 | 0.656 |
| (S.E.) | | | 0.242 | 0.102 |
| Lumber milling | −0.00639 | 0.288 | 0.302 | 0.779 |
| (S.E.) | | | 0.050 | 0.031 |
| Woolen goods | −0.00720 | 2.390 | 0.845 | 0.379 |
| (S.E.) | | | 0.158 | 0.114 |
| 1860 | | | | |
| Brewing | −0.00264 | 0.226 | 0.139 | 0.869 |
| (S.E.) | | | 0.193 | 0.101 |
| Flour milling | −0.00666 | 1.048 | 0.811 | 0.591 |
| (S.E.) | | | 0.098 | 0.038 |
| Leather | −0.00698 | 2.314 | 0.657 | 0.461 |
| (S.E.) | | | 0.104 | 0.055 |
| Lumber milling | −0.00628 | 1.188 | 0.502 | 0.620 |
| (S.E.) | | | 0.043 | 0.029 |
| Saddlery | −0.00792 | 2.781 | 0.582 | 0.441 |
| (S.E.) | | | 0.100 | 0.057 |
| Sheet metals | −0.00839 | 1.710 | 0.496 | 0.588 |
| (S.E.) | | | 0.126 | 0.066 |
| Woolen goods | −0.00494 | 2.986 | 0.677 | 0.400 |
| (S.E.) | | | 0.198 | 0.159 |
| 1870 | | | | |
| Brewing | −0.00626 | 1.666 | 0.616 | 0.592 |
| (S.E.) | | | 0.194 | 0.098 |
| Cotton goods | 0.00592 | 2.656 | 0.903 | 0.435 |
| (S.E.) | | | 0.308 | 0.251 |
| Flour milling | −0.00720 | 0.718 | 0.520 | 0.652 |
| (S.E.) | | | 0.104 | 0.032 |
| Liquor | −0.00548 | 1.399 | 0.630 | 0.612 |
| (S.E.) | | | 0.286 | 0.128 |
| Lumber milling | −0.00549 | 0.706 | 0.416 | 0.705 |
| (S.E.) | | | 0.047 | 0.031 |
| Meat packing | 0.01000 | −2.362 | 0.197 | 1.262 |
| (S.E.) | | | 0.372 | 0.235 |
| Woolen goods | −0.00520 | 0.894 | 0.455 | 0.634 |
| (S.E.) | | | 0.218 | 0.175 |

TABLE 9.7 (*continued*)

NOTE: (S.E.) = standard error.

EQUATION: $\ln VA + c_0 \cdot (\ln VA)^2 = b_0 + b_1 \cdot \ln K + b_2 \cdot \ln L$

[a] All estimates significantly different from zero at the five percent level. As the likelihood function is asymmetric, confidence intervals or pseudostandard errors are not reported.