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Optimal Plant Size and Industrial Structure Before the Modern Industrial Corporation

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Abstract

The transition from small, seasonal businesses meeting local needs to the large scale corporation serving a national market in America took less than a hundred years from 1840 to 1920. Alfred Chandler explains the change as a response to high-speed, continuous production processes and mass distribution (especially from 1880 onward) and the interaction between these two factors. This paper emphasizes the crucial role played by external economies of scale in the transition since production economies in many processes were rapidly exhausted. At the same time, the changes for many firms at this time stemmed from taking advantage of the factory system and more completely exploiting the production economies available from pre-Civil War techologies, post-1880, rather than from the adoption of the revolutionary mass production methods then being pioneered.

Optimal Plant Size and Industrial Structure before the Modern Industrial Corporation*

According to Alfred D. Chandler, Jr. (1977, esp. pp. 287-314), the modern industrial corporation evolved from the technological imperatives of the late nineteenth and early twentieth centuries. High-speed, continuous production processes and the ever-expanding markets needed to absorb their output demanded new and specialized management forms to oversee their operation. The small scale, individually owned and managed manufactory became economically obsolete and was replaced by the large scale, investor-owned and professionally-managed factory. The transition from the small, seasonal business, meeting local needs, to the large corporation serving a national market year-round took less than a hundred years, from 1840 to 1920 (Chandler, 1977).

This paper examines the extent and universality of this change by determining what scale of plant survived during the early stages of the transition and the implications that this had for the industrial structure in the latter half of the nineteenth century. In most industries, production economies were rapidly exhausted, but plants continued to benefit from mass distribution and it was the conjunction of mass production with mass distribution by a few firms that increased concentration and radically altered industrial structure. Nevertheless these changes were limited to relatively few firms and the small firm continued to survive and remained the typical producing unit in spite of these changes. Indeed, these changes may have even added to small firm vigor. Specifically, I will determine what size of plant survived during the period 1850-1870 before most of the new technologies were innovated and how many of these plants would have been needed to satisfy demand with no changes in technology or the extent of the market during the subsequent period.

I. Constraints on Factory Production

Faced by scarce labor and capital, limited power resources, and poor transport facilities, most manufacturing firms in the first half of the nineteenth century remained small (Bateman and Weiss, 1975 and 1981). The wage labor supply was small in a country with few large urban areas (Williamson and Swanson), and ample opportunities to set up as a yeoman farmer (Danhof, 1941). Large firms had to resort to various devices to create a captive labor force. The New England textile mills, for example, tapped the pool of unmarried farm girls by offering a supplementary source of income to the impoverished farm sector and education and strict moral guidance to their employees (Abbott, 1908-1909). In the South, slaves were often used, especially in the iron "plantations" (Bradford, 1959), or else manufacturers such as William Gregg or Daniel Pratt resorted to building model communities to tie labor to the mill (Mitchell, 1928; Miller, 1972). Capitalization, too, remained small so long as the investor's liability was unlimited.[1] Businesses had to rely upon the personal resources of the owners, their relatives, and friends and the good offices of their suppliers for investment funds.[2] It also meant that investors were unwilling to relinquish day-to-day supervision to professional managers, preventing the division of labor within firms and the division of talent between firms. Where power was needed, it was usually water. Yet the power capabilities of most water rights were quite small and usually seasonal; unusable in the winter's ice or summer's drought and flooded out in the freshets of spring. Even along the Fall line where quite large water powers were available and which were less plagued by seasonality, the demands for more power from growing firms exhausted the hydraulic potential of the site (Atack, Bateman and Weiss, 1980). Poor transport facilities compounded the problems of seasonality and more importantly, the high cost of transportation limited the distance over which goods could profitably be shipped to market.

Machines, particularly cheaply built machines, could be substituted for some of the scarce labor, but so long as work was seasonal and the geographic boundaries of the market were limited, there was little incentive to adopt the technology, improve it or adapt it to new applications. Although Oliver Evans' highly mechanized, continuous process flour mill was widely adopted by the industry, its principles were not applied to other activities during the antebellum period (Chandler, 1977). Similarly, although the New England textile mills had pioneered the integrated factory system, there were few imitators until just before the Civil War when the sewing machine began to be adopted by the boot and shoe industry (Ware, 1931; Hazard, 1921).

From 1840 onward these constraints were progressively eased by the railroad and the substitution of steam for water power. The spreading railroad network significantly reduced the costs of distribution and banished the seasonal dependency of other transportation media. By 1860 the east coast and midwest had a basic, albeit not fully integrated, network but which did include direct links between the midwest and major eastern cities, and, by 1870, 52,922 miles of track were in use nationwide (Poor, 1890).

The adoption of steam power, made possible and economic by new and cheaper supplies of coal, freed firms from the locational constraints of waterpower, its seasonality and the difficulty in expanding the power available.[3] Steam-powered plants could be located in towns and cities rather than alongside the nearest feasible water-right.[4] Labor supply problems were at once eased and the urban environment not only constituted a larger market for manufactured products, but was also usually a node in the railroad network. Lastly, the steam engine permitted the use of power intensive machinery on an extensive scale and the factory system came into being in more and more industries.

II. Economies of Scale and Factory Production

Factory production did not necessarily imply large scale operation; the technology of the day was not one that demanded high rates of output to realize lowered production costs. Indeed, what evidence we have suggests that the potential economies of scale were often realizeable by relatively small plants.[5]

The usual method of estimating production functions, ordinary least squares, disguises the rapid exhaustion of scale economies as it implies a linear cost function and scale economies independent of plant size. A number of alternative production function forms have been developed which have the property that scale elasticity varies with plant size.[6] Within certain parameter limits, these are consistent with a U-shaped long-run average cost curve. I do not, however, impose prior constraints upon the parameters.

Consider the following Cobb-Douglas version of the Zellner and Revankar (1969) function:

$$\ln(V^{\lambda}) = \ln A + \mu \cdot \ln L + \beta \cdot \ln (K/L) \qquad [1]$$

where: V = value-added

L = labor

K = capital

and $\ln(V^{\lambda}) = \ln V + \Theta V$, a monotonic transformation of V.

This production function is estimated using the Box and Cox (1963) non-linear maximum likelihood method.[7]

Returns to scale, ε, depend upon the parameter, Θ, the estimate, μ, and upon the level of value-added, V:

$$\varepsilon = \mu/(1 + \Theta V)$$

For $\Theta > 1$, returns to scale are decreasing with increasing plant size measured by value-added and, when $\mu > 1$ and $\Theta > 1$, at low levels of value-added, plants are subject to increasing returns to scale which eventually give way to a range of approximately constant returns followed by decreasing returns to scale as the value of V increases.

Production functions using this non-linear maximum likelihood method were estimated for plant data from the 1870 census of manufacturing.[8] Analysis focused upon twenty-four industries which in 1870 produced over 50 percent of all manufacturing value-added and represented about a quarter of the identifiable industries at the time.

The production function estimates of μ and the value of Θ which maximized the likelihood function are shown in Table 1.

Table 1

Interpretation of the results was not, however, straightforward. In approximately a third of the twenty-four cases, the value of Θ which maximized the likelihood function was <u>negative</u>. This would imply scale economies that increased with plant size, a notion generally contrary to our theory of the firm. However, in none of these instances was the estimate of Θ significantly different from zero suggesting that the variable scale elasticity production function methodology was not a significant improvement over fixed scale elasticity forms. Indeed, only two estimates (woolen mills and steam engine manufacturer) yielded values for Θ that were significantly different from zero.[8]

Although none of the scale parameters, Θ, was estimated to be significantly less than zero, negative values for Θ should not be dismissed as a statistical irregularity. Other researchers using different data sets have encountered similar results but have not investigated the phenomenon more closely (Ringstad, 1974). The problem appears to be that not only is the scale elasticity parameter, ε, a function of plant size but also Θ itself is a function of plant size. A simple verification of this can be made. If the data are dichotomized by plant size into two mutually exclusive groups, "small" and "large" plants in each industry, and equation [1] re-estimated for the separate groups, then θ is often significantly positive (and never negative) for "small" plants and negative, often significantly so, for

Table 1

Parameters of the Variable Scale Elasticity Production Function, 1870

Industry Code	Industry Description	Variable Scale Elasticity Parameters		Industry Code	Industry Description	Variable Scale Elasticity Parameters	
		μ	$\theta(x\ 10^3)$			μ	$\theta(x\ 10^3)$
2011	Meat Packing	1.59^a (.225)	.0122 [-.0203]	2511	Wood Furniture	0.95 (.056)	.0023 [-.0095]
2041	Flour Milling	1.05 (.080)	-.004 [-.007]	2700	Printing and Publishing	0.96 (.094)	.0035 [.0216]
2051	Bread and Other Baked Goods	1.50^a (.226)	.062 [-.115]	3111	Leather Tanning	1.06 (.102)	.0005 [-.027]
2082	Malt Liquors	1.21^a (.101)	-.0001 [-.0104]	3131	Boots and Shoes	1.02 (.035)	.0026 [-.0028]
2085	Distilled Liquors	1.26 (.180)	.0002 [-.018]	3199	Saddlery and Harness	0.75^b (.074)	-.008 [-.0786]
2100	Tobacco	0.85^b (.076)	-.002 [-.020]	3251	Bricks	0.87 (.107)	-.0065 [-.0725]
2211	Cotton Textiles	1.00 (.127)	0 [-.0011]	3312	Pig Iron	1.14 (.127)	.0045 [-.0015]
2231	Woolen Textiles	1.47^a (.132)	.0059^c [.0008] [.582]	3321	Iron Foundries	1.03 (.074)	-.0015 [-.0083]
2321	Men's, Youth's and Boy's Clothing	0.96 (.046)	.023 [-.0013]	3444	Sheet Metal Work	1.06 (.075)	.0059 [-.0028]
2351	Millinery	1.03 (.086)	-.0001 [-.0295]	3511	Steam Engines	1.13 (.071)	.005^a [.00001] [.136]
2421	Sawmills	1.13^a (.034)	.001 [-.0013]	3522	Farm Machinery	1.10 (.087)	-.002 [-.0029]
2431	Millwork	1.37^a (.108)	.0098 [-.0032]	3799	Wagons and Carriages	0.68^b (.032)	-.002 [-.009]

Figures in parentheses are standard errors. Bracketed numbers indicate the conditional lower and upper bounds for θ at the 5 percent level, assuming θ is the true θ. For those estimates of θ not significantly different from zero at the 5 percent level, only the conditional lower bound is shown. These are subject to error over the search interval.

[a] Significantly greater than 1.0 at the 5 percent level.

[b] Significantly less than 1.0 at the 5 percent level.

[c] Significantly different from zero at the 5 percent level.

"large" plants.[9] The hypothesis that θ was the same for both "small" and "large" plants in an industry was almost always rejected.

For "small" plants, scale elasticity decreases rapidly, so that even quite modest growth by "small" plants exhausts the potential scale economies available to such firms. For "large" firms the puzzle is why scale economies appear to increase for larger and larger firms. The answer, I believe, lies in unidentified cost curve shifts which invalidate the results based on the estimation of a single production function. The source of such shifts may have been technological discontinuities between "small" and "large" plants.

Production function estimates assume technological homogeneity across the observations and although the period up to 1870 was not characterized by significant or rapid technological change, except for the sewing machine, subtle changes did take place at differential rates between plants on the basis of size. One important change, for example, was the adoption of steam power. Steam-driven plants, in virtually every industry, were larger on average than waterpowered plants. For example, steam driven saw mills produced an average of $5,400 (1860 dollars) value-added in 1870 compared with only $1,400 for waterpowered mills and in iron blast furnaces and rolling mills, the averages were $56,700 and $4,700 respectively for steam and water powered plants. These differentials were preserved in each region including New England which had abundant, large waterpower resources.[10] The importance of steam power for the embodied technology in the machines is not very well documented but we do know, for example, that steam-powered spindles operated at higher speeds and produced a different quality of yarn (Montgomery, 1840, pp. 69-71). Similarly, in saw mills, the switch to steampower was often accompanied by a switch to a circular or band saw with dramatic decreases in the kerf and sharp increases in the throughput of lumber (Reynolds, 1957). Under this general heading of technological change too, one can also include the transition from workshop to factory and the organizational changes contingent upon that change. The switch lowered unit costs at larger output levels and factory production was sufficiently different and distinct from workshop/artisan manufacture to warrant classification as a separate technology. We cannot, however, distinguish the workshop from the factory using the data in the manuscript censuses.

A second factor may also have generated cost curve shifts for large firms, most of which were to be found in New England or the Middle Atlantic states. Higher population and transport densities, a more skilled labor force, more sophisticated capital markets and a superior supply of ancilliary and support services and products may well have placed the plants in those areas on a different family of cost curves and at the same time have contributed to their larger relative size.

Within a given technology, however, there is good reason to suppose that unit costs were lower for larger plants. The large manufacturer may have been able to exercise some monopsony power to purchase inputs at lower prices than smaller competitors. Poor transport facilities would have reinforced this power as raw materials with a low value-to-weight would not be able to absorb the transport costs to distant markets. At the same time, any cost savings to large firms were apparently passed along to consumers in lower prices as the return on investment in large firms was often less (but more stable) than that for small firms (Bateman and Weiss, 1980). Large firms also had access to the imperfect captial market of the time at preferential rates (Davis, 1960). For very large plants, cost could rise if only from managerial difficulties in overseeing such a large operation and controling costs with so imperfectly developed management tools.

Although the results in Table 1 do not lend much support for a variable scale elasticity production function form in preference to a homogeneous function, nevertheless we can use the results from Table 1 for these industries for which $\theta > 0$ and $\mu > 1$ to estimate the output level for which average costs were a minimum, and the range of outputs embraced by costs within 5 and 10 percent of the minimum. These can then be compared with the average size of plant in the industry. The results are shown in Table 2. Value-added has been adjusted using the

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Table 2

Warren-Pearson price index to express the results in 1860 dollars. This step is essential for the later results as the lingering effects of the Civil War inflation were still apparent in the 1870 data and prices generally fell over the period to the mid-1890s (U.S. Bureau of the Census, 1975, Series E52-63).

The relationship between decreasing scale elasticity and the average cost curve for woolen textiles is graphed in Figure 1.

Figure 1

Table 2

Value-Added for Minimum Average Costs and the Range of Plant Sizes with Average Costs within Five and Ten Percent of the Minimum, 1870 (1860 Dollars)[a]

Industry Code (SIC)	Industry Description	Value-Added for Minimum Average Costs	Range of Plant Sizes Within: 5% of Minimum	10% of Minimum	Average Value-Added Per Plant[b]	Average Costs of Mean Plant as a Percent of Minimum
2011	Meat Packing	33,400	19,000 - 53,500	14,700 - 63,600	5,900	140.2
2051	Bread and Other Baked Goods	5,600	3,000 - 9,200	2,300 - 10,900	2,500	109.1
2085	Distilled Liquors	377,000	174,000 - 710,500	118,900 - 870,000	5,700	194.0
2231	Woolen Textiles	52,600	28,700 - 87,800	21,500 - 104,300	4,700	102.4
2421	Sawmills	91,000	30,100 - 203,000	17,500 - 262,500	3,800	129.0
2431	Millwork	26,400	13,500 - 45,900	9,900 - 55,300	7,100	117.2
3111	Leather Tanning	96,000	18,000 - 280,000	6,800 - 396,000	3,700	113.9
3131	Boots and Shoes	6,200	200 - 32,000	0 - 49,200	2,700	100.5
3312	Pig Iron	23,300	8,200 - 51,000	4,800 - 66,000	8,900	100.3
3444	Sheet Metal Work	7,600	1,400 - 22,500	600 - 31,500	4,200	100.8
3511	Steam Engines	19,500	6,500 - 43,500	3,800 - 56,600	4,900	100.4

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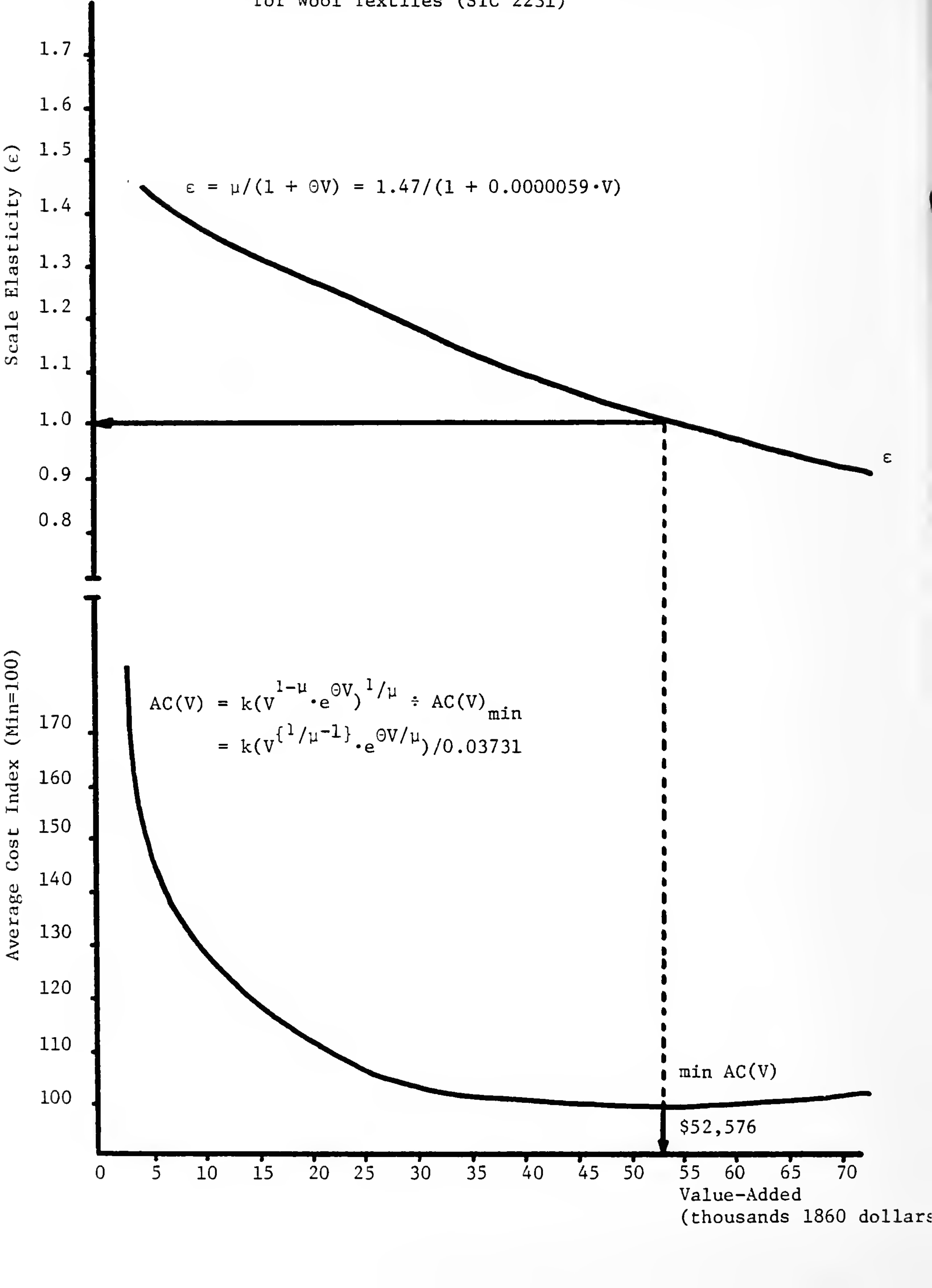
[a] Industries from Table 1 for which $\mu > 1$ and $\theta > 0$. Figures rounded to nearest $100.

[b] From the sample.

Figure 1

Economies of Scale and Index of Average Cost by Value-Added (1860 dollars) for Wool Textiles (SIC 2231)



Average costs are defined by:

$$AC(V) = k(V^{1-\mu} \cdot e^{\theta V})^{1/\mu}$$

where μ and θ are from the variable scale elasticity production function estimates, V is value-added and k is a function of input prices. Assuming competitive markets (as we must for our production function estimates), k is a constant.

In general, the range of plant sizes with average costs within five or ten percent of the minimum average costs is quite broad except for bread and other baked goods. In some instances, the average cost curve is very flat, as, for example, with sawmills, leather tanning or boots and shoes. A wide range of plants of different sizes could thus be cost competitive with one another. Unfortunately, we do not know what magnitude of cost differences would make firms non-competitive with one another. In part,this would depend upon transport costs and the firms' juxtaposition *vis a vis* the transport network and markets; it would also depend upon the rate of return each owner-investor demanded for the level of risk being borne. Unfortunately, production functions do not address the issue of the costs of distribution, although Chandler's (1977) thesis that the modern corporation emerged from the conjunction of mass production with mass distribution assigns them a critical role.

A relatively narrow range for low cost firms in the bakery industry makes sense. Product perishability and the comparatively undeveloped state of the market for commercially baked goods would limit the growth of firms in the industry. The other products were non-perishable and transportable, though given the ease of their manufacture and the sometimes low value-to-weight ratio, there was probably little point in producing more than necessary to supply the market in the immediate vicinity. Nevertheless, since not all markets were the same size and scale economies remained more or less constant over a fairly wide range, the industries supported a variety of different sizes of plant.

The average size plant producing boots and shoes, pig iron, sheet metal work, steam engines and woolen textiles was operating at a scale very close to that which minimized average costs. Indeed, I would argue that in only three of the industries in Table 2 were plants of average size producing at a scale where costs were dramatically greater than the minimum: meat packing, distilled liquers and sawmills. In each case, the average plant in the sample (and also in the population) was too small. With comparative statics analysis we cannot, however, say anything about what happened to these small plants in the long-run: Some may have grown and expanded into the range of constant returns becoming cost competitive; some may have been driven out of business; and others may have continued to survive if their (small) markets were somehow protected, as, for example, by high transport costs.

III. The Survivor Technique

The static nature of the production function analysis and the problems associated with the estimates which we have outlined above limit the usefulness of that methodology for analyzing changes in industrial structure and addressing the Chandler thesis of the conjunction of mass production and mass distribution in the rise of big business. Fortunately, there is an alternative means to determine what size of plant was most efficient in 1870. We can examine changes in the distribution of industry value-added (in constant 1860 dollars) by size of plant over time. This approach is called the "survivor technique." The survivor technique seeks to identify those size classes of plant that not only survived the rigors of market competition and the test of time, but also succeeded in increasing their share of total industry value-added (Stigler, 1958; Saving, 1961; Weiss, 1964; Shepherd, 1967). That is, it seeks to identify those plant sizes that grew in relative importance in an industry through the long-run competitive adjustment process.

A number of assumptions are implicit in the technique and while these have been discussed in detail by others, notably by Shepherd (1967), there still appears to be some confusion about them. Shepherd (1967), for example, argues that "survivor estimates for firm sizes are likely to be more valid for atomistic industries...than for highly concentrated ones," presumably because the assumptions of atomistic competition insure that, in the long-run, market pressures force all plants to operate at minimum long- and short-run average cost if they are to survive. Profit maximizing behavior, however, also ensures the survival of lower cost plants even under conditions of monopolistic competition (Stigler, 1958). Moreover, demand changes under conditions of atomistic competition affect only the number of firms in the industry while such changes for monopolistically competitive industries will permanently alter the market solution, including the optimum plant size. Similarly, the assumptions of atomistic competition presuppose no technological change and yet the movement towards a deterministic surviving plant size may be most pronounced when technological charge is greatest.

Under certain circumstances, survivor technique results may lead to erroneous conclusions. Consider, for example, the problems posed by the existence of monopoly elements. Under conditions of monopolistic competition, long-run equilibrium is reached at some output less than that which minimizes long-run average cost. Weiss (1964) avoids this problem by emphasizing the "minimum efficient" scale of operation rather than the range of optimal plant sizes emphasized by others (Stigler, 1958; Saving, 1961). However, if the range of surviving firms continues to be identified with minimum long-run average cost then the results will be inconsistent with production or cost function estimates which would show increasing returns to scale and decreasing unit costs. Similarly, the presence of externalities in distribution which alter the cost minimizing level of output for the product delivered to the consumer will lead to inconsistent results between the survivor technique estimates which take such factors into account as a matter of course and those based upon production functions which focus purely upon the production process internal to the firm.

There is no universal agreement on how plant size should be measured, yet alternative measures such as value-added, output, employment or capital can lead to quite different conclusions during periods of technological change. Consider a (Hicks) neutral technological change (a homothetic shift of isoquants towards the origin) in an industry whose production function is consistent with a U-shaped long-run average cost curve. Such a change leaves the shape of the long-run average cost curve unchanged, it merely results in lower costs at each level of output. Under these circumstances, if plant size were measured by labor or capital, the survivor technique would show smaller plants surviving because of the shift of the isoquants towards the origin (Δ% less labor and capital are needed to produce the same level of output), while on an output basis, the optimal (or minimum efficient) plant size would be unchanged. If, instead, the technological change had been labor-saving, then the apparent reduction in the size of the optimal plant would be greater if size is measured by employment rather than by capital and *vice versa* if the technological change were capital-saving.[11] These scenarios are shown in Figure 2. We have elected to use value-added as a measure of plant size.

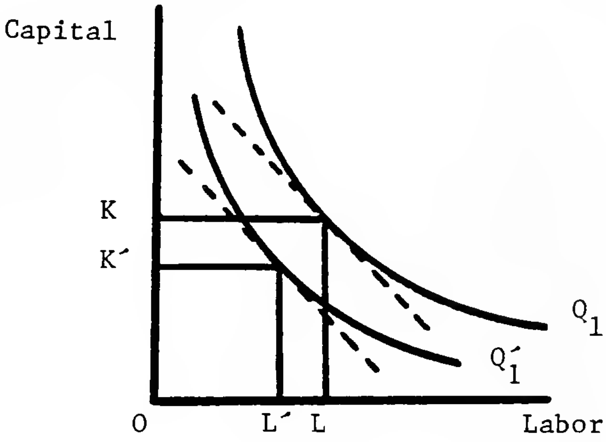
Figure 2

The survivor technique implications for an optimal range of plant sizes (classified by value-added) over the 1850, 1860 and 1870 samples from the manuscript censuses of manufacturers for the 24 industries in Table 1 are shown in Table 3.[12] The results generally reveal a wide

Figure 2

Effect of Neutral, Labor-Saving, or Capital-Saving Technological Change on Various Measures of Plant Size.

A. Neutral Technological Change:

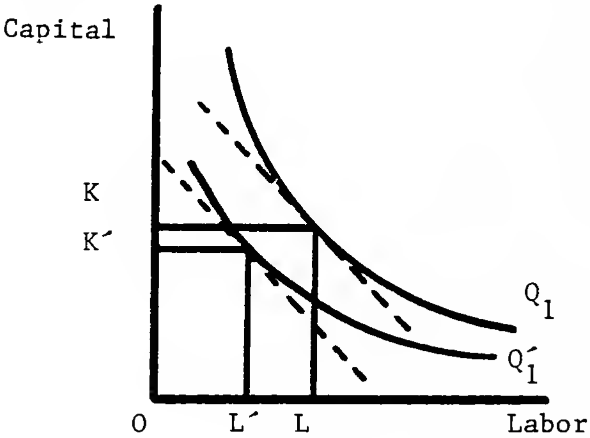


$$Q_1 = Q_1'$$

$$\frac{OK}{OL} = \frac{OK'}{OL'}$$

$$\frac{KK'}{OK} = \frac{LL'}{OL}$$

B. Labor-Saving Technological Change:

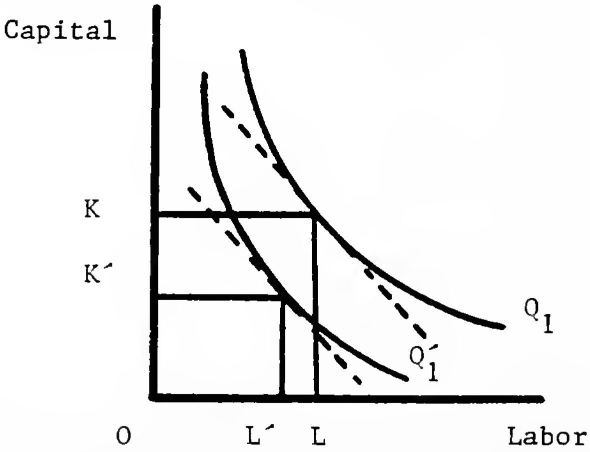


$$Q_1 = Q_1'$$

$$\frac{OK}{OL} < \frac{OK'}{OL'}$$

$$\frac{KK'}{OK} < \frac{LL'}{OL}$$

C. Capital-Saving Technological Change:



$$Q_1 = Q_1'$$

$$\frac{OK}{OL} > \frac{OK'}{OL'}$$

$$\frac{KK'}{OK} > \frac{LL'}{OL}$$

Table 3
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range of optimally-sized plants in almost every industry and suggest that a considerable portion of the long-run average cost curve may have been flat. This finding is consistent with the twentieth century cost function studies reported in Walters (1963), the survivor technique results reported by Saving (1961) and production function estimates for the nineteenth century (Atack, 1976; Atack, 1977; Sokoloff, 1981; James, 1982). There were five industries, flour-milling, bread and bakery products, tobacco manufacture, saw and planning mills, and brick works, in which the range of surviving plants embraced less than $16,000 value-added. All were locally produced and traded goods. Plants producing these goods typically supplied markets limited by product perishability, by localized brand loyalties, or by a low value-to-weight ratio in the presence of high transport costs.

Estimates of the minimum efficient scale of operation are also given in Table 3. The minimum efficient scale of plant is the smallest size of plant which increased its share of total industry value-added over the period. In industries suspected of not being perfectly competitive, this measure is to be preferred to the range of optimal plant sizes because long-run equilibrium is reached at some output less than that which minimizes long-run average cost (Weiss, 1964). The minimum efficient scale in many industries was often quite

Table 3

Plant Survival in the United States, By Industry, 1850-60-70[a] (1860 dollars)

SIC Industry Code	Industry Description	MES[b] ($000 1860 dollars)	Range of Optimal Plant Sizes[c] ($000 1860 dollars)	Value Added 1870 / Value Added 1850 in Optimally Sized Plants (1860 dollars)	Percentage of Industry Value Added produced in Optimally Sized Plants 1870	Chi-square value for Goodness of Fit test between 1850 and 1870 distributions of Value Added
2011	Meat Packing	32	32-64	3.79	69.0	196.46
2041	Flour Milling	0.1	0.1-8	1.53	54.0	33.54
2051	Bread and Other Bakery Products	0.5	0.5-16	1.81	87.1	135.36
2082	Malt Liquors	32	32-128	∞	44.3	85.54
2085	Distilled, Rectified and Blended Liquors	32	32-128	2.39	52.4	27.77
2100	Tobacco Manufacture	2	2-16	1.63	49.4	19.30
2211	Cotton Textiles	128	128-*	∞	63.2	46.51
2231	Woolen Goods	32	32-256	2.45	86.8	50.52
2321	Men, Youths' and Boys' Clothing	16	16-256	1.59	58.6	30.92
2351	Millinery	64	64-128	∞	39.6	19.34
2421	Sawmills and Planning Mills	0.5	0.5-16	1.46	50.2	59.38
2431	Millwork	2	2-64	1.40	74.9	70.73
2511	Wood Household Furniture	32	32-128	2.74	43.9	24.96
2700	Printing, Publishing and Allied Industries	2	2-64	1.87	99.3	82.00
3111	Leather Tanning and Finishing	8	8-128	1.83	68.2	27.36
3131	Boots and Shoes	16	16-256	1.36	52.9	36.13
3199	Saddlery and Harness	0.5	0.5-64	1.20	99.7	41.29
3251	Brick and Structural Clay Tile	1	1-8	1.05	39.9	14.87
3312	Pig Iron	64	64-256	2.04	68.1	30.29
3321	Gray Iron Foundries	4	4-128	1.12	96.3	78.17
3444	Sheet Metal Work	2	2-32	1.08	48.6	93.77
3511	Steam Engines	8	8-128	1.89	87.6	100.82
3522	Farm Machinery and Equipment	32	32-*	∞	66.4	48.65
3799	Wagons and Carriages	32	32-128	4.33	22.5	24.17

Footnotes

[a] The following plant sizes were used, where size is measured by plant value-added in 1860 dollars: $0-249, $250-499, $500-999, $1,0000-1,999, $2,000-3,999, $4,000-7,999, $8,000-15,999, $16,000-31,999, $32,000-63,999, $64,000-127,999, $128,000-255,999, and $256,000 or more.

[b] MES=Minimum Efficient Scale; or the smallest size class of plant increasing its share of total industry value-added (Weiss, 1964).

[c] Range of size classes of plant increasing their share of total industry value-added.

*Upper-bound is open-ended and maximum size of surviving plant cannot be specified.

†Significantly different distribution of industry value-added in 1870 than in 1850.

Source: Computed from the Bateman-Weiss samples. Values were adjusted by the Warren-Pearson price index for the appropriate industrial category (U.S. Bureau of the Census, 1975, Series E52-63).

small.[13] In flour milling, for example, firms producing as little as \$100 (1860 dollars) value-added in 1870 could still be efficient. At the opposite end of the scale, the minimum efficient scale in cotton textiles was apparently \$128,000. Small textile mills could not survive.

The ratio of value-added in 1870 produced in optimally sized plants to the value-added produced in those plants in 1850 (expressed in constant 1860 dollars) shown in Table 3 is an attempt to capture the movement towards the concentration of value-added in optimally sized plants over the period. In most cases, the increase in the proportion of output produced in optimally sized plants was quite large; in 17 of the 24 cases, there was better than a 50 percent increase. Moreover, in all but seven cases more than half of 1870 value-added originated in optimally sized plants. In some cases the increase was exceptionally dramatic. In 1850, no farm machinery manufacturer produced more than \$32,000 value-added, but by 1870, two-thirds of industry output was produced by plants larger than that; among them would number firms such as McCormick (\$407,000 (1860 dollars) value-added in 1870) and Case (\$283,000 value-added).

With only two exceptions the range of plant sizes with costs within 10 percent of the minimum average costs given in Table 2 overlap the range of optimal plant sizes in Table 3. In some cases the overlap was quite extensive. In the meat packing industry, the range of surviving plants, \$32,000-64,000, compares favorably with the range of meat packing plant sizes with costs within 10 percent of the minimum, \$14,700-63,600. In other cases, the intersection of the two was much less. In the boot and shoe industry, for example, the ranges were \$16,000-256,000 and \$0-49,200 respectively. The range of surviving plants did not intersect with the lower portions of the estimated average cost curve in sawmilling and in pig iron production.

In the former case, surviving plants were "too small," though even today sawmilling is classified as a local monopoly protected by transport costs, while in the latter case, surviving plants were "too large." The iron industry was one of the few industries which underwent rapid technological change between 1850 and 1870 with hard driving, improved heat recovery in the blast furnace and the introduction of the Bessemer process in the 1860s. The survivor techniques correctly identifies integrated blast furnaces and Bessemer plants as surviving.[14]

Seven of the 11 estimates of the size of plant which minimized average costs in Table 2 also fall within the range of optimally sized plants in Table 3. In two of the "failures," distilled liquors and sawmills, the cost minimizing plants in Table 2 were larger than the optimal range, while the cost minimizing plants in the boots and shoe industry and iron manufacture were smaller than the range of surviving plants.

From what has been said already, inconsistencies such as these between the production function approach to identify long-run equilibrium plant size and the survivor technique are to be expected. On the one hand, transport costs for a relatively homogeneous product which is as easily and cheaply produced in one location as another would cause the cost minimizing plant to be smaller than that based purely upon production factors. On the other hand, mass distribution lowering unit distribution costs for larger producers would cause the cost minimizing scale of plant to be larger than that determined solely by production consideration. The survivor technique takes both production and marketing distribution costs into account; production function analysis doesn't.

IV. 1870 Optimal Plants and Industrial Structure 1870-1900

We have used the range of optimal plant sizes from Table 3 as the basis for estimating the number of optimal plants which industry value-added could have sustained with no changes in technology, externalities or the costs of transport between 1870 and 1900. These estimates are shown in Table 4. The figures indicate the number of plants that would have been in the industry if all plants had been the same size as either the minimum efficient scale of plant in 1870 or the largest surviving plants in 1870.

Table 4

In 1870 the number of plants in more than half of selected industries; meat packing, flour milling, bread and bakery products, tobacco, lumber milling, millwork, printing and publishing, saddlery and harness, brick, pig iron, iron castings, and steam engine and machinery industries fell within the range defined by the surviving plants. The distribution of plants could, therefore, be consistent with the majority of plants having adjusted their scale of operation into the optimal range. However, a glance at Table 3, which shows the

Table 4

Number of Optimal 1870 Plants that Industry Value-Added Could Support, 1870-1900[a]

Industry SIC	Industry Description	1870 Number of 1870 Optimal Plants	1870 Actual[b]	1880 Number of 1870 Optimal Plants	1880 Actual[c]	1890 Number of 1870 Optimal Plants	1890 Actual[d]	1900 Number of 1870 Optimal Plants	1900 Actual[e]
2011	Meat Packing	106-212	206	560-1,119	872	1,426-2,852	1,367	3,041-6,082	1,134
2041	Flour Milling	6,689-424,124	22,573	7,955-636,405	24,338	11,138-891,005	18,470	19,975-1,597,908	25,258
2057	Bread and Other Bakery Products	633-20,270	3,550	1,451-46,426	6,396	3,900-124,831	10,484	10,209-326,503	14,917
2082	Malt Liquors	63-254	1,972	96-383	2,191	288-1,153	1,248	833-3,335	1,509
2085	Distilled, Rectified and Blended Liquors	38-151	719	29-115	844	217-867	440	367-1,467	967
2100	Tobacco Manufacture	1,599-12,795	5,204	3,300-26,399	7,622	8,096-64,770	11,351	20,117-160,935	14,976
2211	Cotton Textiles	41-324	819	89-706	1,005	129-1,021	905	359-2,837	1,055
2231	Woolen Goods	151-1,206	1,938	217-1,736	1,990	232-1,852	1,311	416-3,327	1,035
2321	Men, Youths' and Boys' Clothing	160-2,564	7,838	284-4,543	6,166	284-12,412	5,067	1,897-30,352	5,880
2351	Millinery	16-33	1,668	n.a.	n.a.	165-329	5,999	584-1,168	16,151
2421	Sawmills and Planning Mills	4,847-155,099	26,930	4,378-140,105	25,758	9,450-302,397	22,617	21,982-703,440	33,035
2431	Millwork	192-6,143	1,605	353-11,297	2,491	952-30,471	3,670	1,511-48,337	4,204
2511	Wood Household Furniture	202-809	5,423	352-1,406	6,008	809-3,234	5,973	1,669-6,678	7,972
2700	Printing, Publishing and Allied Industries	499-15,980	2,159	981-31,398	3,468	3,554-113,743	16,566	3,906-124,997	22,312
3111	Leather Tanning and Finishing	144-2,310	4,237	309-4,951	5,628	529-8,475	1,787	797-12,760	1,306
3131	Boots and Shoes	275-4,403	23,428	224-3,588	1,959	548-8,775	2,082	737-11,798	1,600
3199	Saddlery and Harness	208-26,627	7,607	255-32,699	7,999	609-78,006	7,931	960-122,829	12,934
3251	Brick and Structural Clay Tile	1,743-13,945	3,114	2,313-18,503	5,631	5,333-42,661	5,828	7,081-56,649	5,423
3312	Pig Iron	129-516	396	369-1,476	1,005	640-2,559	645	1,673-6,689	668
3321	Gray Iron Foundries	217-6,954	2,328	662-21,172	4,984	2,289-73,238	6,500	4,260-136,317	9,324
3444	Sheet Metal Work	503-8,048	6,646	665-10,647	7,693	1,341-21,463	7,002	2,377-38,025	12,466
3511	Steam Engines	313-5,009	2,400	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
3522	Farm Machinery and Equipment	46-713	2,076	65-1,041	1,943	118-1,880	910	170-2,721	715
3799	Wagons and Carriages	254-1,016	11,847	289-1,156	3,841	556-2,225	8,614	487-1,947	7,632

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[a] Industry Value-Added (in 1860 dollars) at time t: Value-Added of Minimum Efficient Scale of Plant in 1870 or Value-Added of Upper-bound optimally-sized plants in 1870. See Table 3.

Sources: [b] U.S. Census Office (1873).
[c] U.S. Census Office (1883).
[d] U.S. Census Office (1893).
[e] U.S. Census Office (1902).

percentage of value-added originating in optimal plants in 1870, shows that this is not necessarily the case; a combination of plants that were "too small" and "too large" could produce a total value-added and number of plants consistent with an optimal range. In a number of other industries (malt and distilled liquors, cotton and wool textiles, clothing, millinery, wooden furniture, leather tanning, boots and shoes, farm machinery and carriages and wagons) the number of establishments in 1870 was greater than the number of minimum efficient scale plants, suggesting that relatively few establishments in those industries had achieved an efficient scale in 1870. Except for textiles, these industries in 1870 were still dominated by small-scale artisan shops. Most agricultural implements manufacturers, for example, were little more than village blacksmiths and handmade shoes still had not been displaced by the mass produced factory product.

By 1900, the number of establishments and the distribution of value-added had changed so that only in millinery, wooden household furniture, and wagons and carriages was the number of establishments in an industry greater than the predicted range. In four industries there were fewer establishments in the industry than predicted: Three of these were ones in which there had been rapid technological change; meat packing, tobacco, and blast furnaces. The other industry, brickmaking, is one of the lowest value-to-weight products and, hence, one on which cheaper transportation is most likely to have the greatest effect.

The nature, timing and extent of technological change influences how the hypothetical number of 1870 optimal plants compared with the number of plants actually in an industry at any moment. Consider the case of meat packing. In 1870 and 1880, the number of plants in the industry lay within the range of the numbers of optimal 1870 plants, but, by 1890, there were fewer plants in the industry than we predict on the basis of no changes in technology or externalities from 1870. Yet this is precisely when the industry was revolutionized by the introduction of the refrigerator car with a nationwide distribution network and the conversion of meat-packing to a high volume, continuous disassembly process making full use of by-products. Firms such as Swift and Company, P. D. Armour and the Cudahy Packing Company drove smaller firms out of business as they integrated vertically and spread out horizontally into cities other than Chicago (Swift and Armour) or Omaha (Cudahy) (Chandler, 1977, pp. 300-301; Yeager, 1981).

A similar story can be told for the tobacco industry which was revolutionized by Duke's adoption of Bonsack's continuous-process cigarette-making machine in 1885 and his national advertising campaign to promote the product (Chandler, 1977, pp. 290-291; Tennant, 1950). As a result, in 1890, the number of tobacco plants was closer to the lower-bound number of optimally-sized 1870 plants than had been the case in 1880. By 1900, with the American Tobacco Company dominating the industry by merger and predatory practices, the industry had been transformed to one with fewer plants than we would have predicted had those changes not taken place since 1870.

This pattern is repeated in industry after industry although in some industries, such as agricultural implements, it is difficult to point to specific innovations other than the adoption of factory production, superior machine tools and more reliable supplies of low cost metals to account for the marked change in the number and size of plants. The data in Table 5 reveal the magnitude of industry

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Table 5
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adjustment towards optimal plant sizes by 1900. They do not, however, necessarily measure the extent, degree and significance of technological progress. Some changes came about because of widespread adoption of factory production to take advantage of improvements in transportation and distribution but using pre-Civil War technology. The most rapid relative adjustment was in the boot and shoe industry in which the artisan producer was virtually driven out of business, except in the repair of shoes, in favor of factory-made products (Hazard, 1921; Clark, 1929). One would add in passing that the switch to mass-produced shoes was accompanied not only by a decline in price but by improvements in fit and durability (Keir, 1920). Leather tanning also underwent a marked change as a result of improvements in the chemical industry and the effects of concentration in the meat-packing industry which confer a degree of monopoly power on the packers. In the brewing industry, brewmasters, led by Pabst, established vertically integrated plants to supply far-flung markets via temperature-controlled tank cars. The clothing industry, revolutionized by the sewing machine and the adoption of standard sizes, underwent the fourth most rapid transition. The agricultural machinery industry which experienced the fifth most dramatic relative change

Table 5

Actual Number of Plants in an Industry as a Fraction of the Minimum Number of Optimal 1870 Plants
1870-1900

Industry SIC	Industry Description	1870	1880	1890	1900	Ranked Relative Adjustment 1870-1900
2011	Meat Packing	1.9	1.6	0.9	0.4	12
2041	Flour Milling	3.4	3.1	1.7	1.3	20
2057	Bread and Other Bakery Products	5.6	4.4	2.7	1.5	15
2082	Malt Liquors	31.3	22.8	4.3	1.8	3
2085	Distilled, Rectified and Blended Liquors	18.9	29.1	2.0	2.6	7
2100	Tobacco Manufacture	3.3	2.3	1.4	0.7	13
2211	Cotton Textiles	20.0	11.3	7.0	2.9	8
2231	Woolen Goods	12.8	9.2	5.7	2.5	10
2321	Men, Youths' and Boys' Clothing	49.0	21.7	17.8	3.1	4
2351	Millinery	104.3	n.a.	36.4	27.7	14
2421	Sawmills and Planning Mills	5.6	5.9	2.4	1.5	15
2431	Millwork	8.4	7.1	3.9	2.8	17
2511	Wood Household Furniture	26.8	17.1	7.4	4.8	9
2700	Printing, Publishing and Allied Industries	4.3	3.5	4.7	5.7	21
3111	Leather Tanning and Finishing	29.4	18.2	3.4	1.6	2
3131	Boots and Shoes	85.2	8.7	3.8	2.1	1
3199	Saddlery and Harness	36.6	31.4	13.0	13.5	19
3251	Brick and Structural Clay Tile	1.8	2.4	1.1	0.8	23
3312	Pig Iron	3.1	2.7	1.0	0.4	6
3321	Gray Iron Foundries	10.7	7.5	2.8	2.2	11
3444	Sheet Metal Work	13.2	11.6	5.2	5.2	21
3511	Steam Engines	7.7	n.a.	n.a.	n.a.	--
3522	Farm Machinery and Equipment	45.1	29.9	7.7	4.2	5
3799	Wagons and Carriages	46.6	13.3	15.5	15.6	18

Source: Computed from Table 4.

finally broke with its blacksmithing origins to become a mass-produced, factory product. At the opposite end of the scale, industries such as brick making, sheet metal and printing underwent remarkably little change by way of transforming the industry. Nor is there evidence of revolutionary change in the flour milling industry; despite the adoption of reduction milling and the development of national brands such as Pillsbury and Gold Medal, the small flour mill continued in existence. Other "laggard" industries such as wagons and carriages or saddlery and harness, are less surprising as these underwent no technological change nor probably did they benefit from the development of a national market.

Conclusion

In aggregate terms, few industries showed a dramatically different structure in 1900 than had been present in 1870. Some of the most pronounced changes were in those industries which had successfully moved from the workshop or small factory serving local needs to factories serving a wider clientele; industries such as boots and shoes, leather tanning, brewing, clothing and agricultural implements. With few exceptions, these were not the industries undergoing rapid technological change after the Civil War.[15] For the most part they were taking advantage of pre-Civil War technology and the post-War revolution in transportation and distribution. The typical plant in these industries in 1900 was no larger than an efficient plant in 1870 would have been.

In some industries, however, the average scale of operation by 1900 was much larger than that of an efficient plant of 1870. These were generally industries which had experienced technological change permitting high-speed, continuous-production processes and had also taken advantage of mass marketing and distribution for their product. However, only a few establishments in each industry took advantage of these opportunities. Their output level was often many times greater than that of even the largest 1870 efficient plants and, for the most part, they survived. The rest of the plants in these industries remained small. They were the typical producing units but they are generally ignored. Certainly, they do not appear in Chandler's model. Bigness is better documented; more heroic and although big firms made their mark, the successful coexistence of small producers is at least as deserving of study. Their survival seems to stem from the rapid exhaustion of production economies in many activities and the ability of the small firm to carve out a niche catering to local tastes and needs not met by a mass-marketed, homogenized product.

Footnotes

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[1] The difficulties of raising impersonal capital were a frequent lament of nineteenth century industrialists, particularly in the South and West. The issues are discussed in Livermore (1935). Various studies have been made of the progress of limited liability and the granting of corporate charters to business. None, however, is comprehensive. See, for example, Evans (1948), Kuehnl (1959), Wilson (1964) and Wolfe (1965).

[2] Daniel Pratt, for example, raised the $110,000 for his Prattville Manufacturing Company No. 1 from personal resources, friends and relatives (Miller, 1972, p. 17). The large New England textile mills were, however, able to attract institutional funds for operating capital and expansion, and sell equity to finance the initial construction (Davis, 1957; Davis, 1958; Davis, 1960).

[3] Even in cities such as Lowell or Lawrence centered upon large developed water rights, future expansion could only be met by improvements in the use of the available water or the adoption of supplementary steam power (Atack, Bateman and Weiss, 1980). Pressure upon existing water rights led to the pioneering research and development

work of the Locks and Canal Company at Lowell and its chief engineer, James B. Francis, inventor of the Francis turbine (Francis, 1868).

[4] For an attempt at measuring the geographic spread of steam power as coal became available, see Atack and Bateman (1983).

[5] See, for example, Atack (1976; 1977) and Sokoloff (1981) for the antebellum period and Ringstad (1974) for comparable results for modern industry.

[6] See, for example, Nerlove (1963); Soskice (1968); Zellner and Revankar (1969); Ringstad (1974); Christensen, Jorgensen and Lau (1973); Christensen and Greene (1976).

[7] The logarithm of the likelihood function corresponding to equation [1] is:

$$\ln\ell = \text{constant} - \frac{n}{2}\ln\sigma^2 + \ln J(\lambda;V) - \frac{1}{2\sigma^2}\left[\sum_{i=1}^{n} \ln\,(V^\lambda)_i - \ln A - \mu\cdot\ln L_i - \beta\cdot\ln\left(\frac{K_i}{L_i}\right)\right]^2 \qquad [2]$$

where σ^2 is the variance of the normally and independently distributed random error term with mean zero, n is the number of observations and $J(\lambda;V)$ is the Jacobian of the monotonic transformation. $J(\lambda;V) = \sum_i \ln(1+\theta V_i)$. Ordinary least squares minimizes the last term of equation [2] for any predetermined value of Θ, yielding a conditional maximum for the likelihood function. By varying Θ and evaluating $(\ln\ell - \text{constant})$ the estimate of $\Theta,(\hat{\Theta})$, follows a chi-square distribution such that:

$$\ln\ell(\hat{\Theta}) - \ln\ell(\Theta)_{\max} < 1/2\ \chi^2(\eta)$$

where η is the confidence interval. Using $\eta = .05$ yields a value for $1/2\ \chi^2$ of 1.94. Thus $\ln\ell(\hat{\Theta})_{\max} < 1.94$ in the test for the confidence interval around the value of Θ, the global maximum likelihood function can be determined.

[8] The data are from the samples drawn from the manufacturing census of 1850, 1860 and 1870 by Fred Bateman and Tom Weiss. Sokoloff (1981) also reports relatively slight support favoring a variable scale elasticity production function in 1820 and 1850 data. Similar findings of increasing scale elasticity with plant size have been noted by Sokoloff (private communication) and James (1982).

[9] For analogous results for the pre-Civil War period, see Atack (1977).

[10] Manuscript census data. The higher value-added produced in steam-powered factories as compared with that produced in water-driven plants holds across virtually every industry, in each region and in each of the three years exasmined: 1850, 1860 and 1870. It is also greater than can be accounted for by the elimination of seasonality. Steam-driven factories were larger and the machinery was probably driven longer and harder than that in water-powered plants.

[11] Similarly a technological change which reduces raw material waste would increase value-added for the same level of output.

Evidence favoring substantial biased technological change over the period 1850-1919 is given in Cain and Paterson (1981) and in James (1982) for the period 1850-1900. The bias was generally in favor of labor-saving technological change, and although it was not necessarily capital-using, there is evidence of material-using and capital-using biases. James' (1982) work suggests much of the biased technological change occurs from 1880 onward, except in iron, leather tanning and cotton textiles. However, 10 of the industries in this study (bread and other baked goods; malt liquors; tobacco; millinery; millwork; household furniture; saddlery and harness; sheet metal work; farm machinery; and transportation equipment) are not included in James' work.

[12] The theory gives no guidance over the appropriate size categories, probably because modern studies applying the survivor technique have to rely upon census size classifications. I elected to use a logarithmic progression of size categories; the limits of each category are double those of the next smaller category. Because of the large numbers of small firms in many industries I selected $0-249 value-added (1860 dollars) as the smallest category. The largest size groups is $250,000 or more value-added (1860 dollars) and is open-ended. An upper bound on plant value-added for plants falling in this group is not specified. No size distribution of firms/plants was published before 1900 (U.S. Census Office, 1902).

[13] James (1982) also notes the generally small scale of optimal size plants though his results suggest some significant increases in size between 1860 and 1870.

[14] Only one integrated blast-furnace and Bessemer plant was in the sample and its inclusion in the \$128,000-255,990 category resulted in that size class surviving. On the other hand, there were only three Bessemer plants in operation in 1870 (Jeans, 1880). Nevertheless, there was a marked shift in favor of larger blast furnaces to economize on fuel and recycle heat otherwise lost in the process. See also Allen (1967).

[15] In these industries the only technical changes of consequence in the production process were the McKay welting machine in boot and shoe manufacture and the pneumatic malting process in brewing (Hazard, 1921; Chandler, 1977).

Bibliography

Abbott, Edith (1908/9), "History of the Employment of Women in the American Cotton Mill," Journal of Political Economy, 16 No. 10 (December 1908) pp. 680-92 and 17 No. 1 (January 1909), pp. 19-35.

Allen, Robert C. (1977), "The Peculiar Productivity History of American Blast Furnaces, 1840-1913," Journal of Economic History, 37, No. 3 (September), 605-33.

Atack, Jeremy (1976), "Estimation of Economies of Scale in Nineteenth Century United States Manufacturing and the Form of the Production Function," Unpublished Ph.D. thesis, Indiana University.

Atack, Jeremy (1977), "Returns to Scale in Antebellum United States Manufacturing," Explorations in Economic History, 14 No. 3 (October) 337-359.

Atack, Jeremy and Bateman, Fred (1983), "The Development of Industrial Steam Power in the Midwest with Special Reference to Indiana," The Old Northwest (forthcoming).

Atack, Jeremy; Bateman, Fred and Weiss, Thomas (1980), "The Regional Diffusion and Adoption of the Steam Engine in American Manufacturing," Journal of Economic History, 40 No. 2 (June), 281-308.

Atack, Jeremy; Bateman, Fred and Weiss, Thomas (1982), "Risk, the Rate of Return and the Pattern of Investment in Nineteenth Century

American Manufacturing," Southern Economic Journal 49, No. 1 (July), pp. 150-163.

Bateman, Fred and Weiss, Thomas (1975), "Comparative Regional Development in Antebellum Manufacturing," Journal of Economic History, 35 No. 1 (March), pp. 182-208.

Bateman, Fred and Weiss, Thomas (1981), A Deplorable Scarcity: The Failure of Industrialization in the Slave Economy, Chapel Hill: University of North Carolina Press.

Box, G. E. P. and Cox, D. R. (1963), "An Analysis of Transformations," Journal of the Royal Statistical Society, Series B, 26, 211-252.

Bradford, S. S. (1959), "The Negro Ironworkers in Antebellum Virginia," Journal of Southern History, 25, No. 2 (May) 194-206.

Cain, Louis P. and Paterson, Donald G. (1981), "Factor Biases and Technical Change in Manufacturing: The American System, 1850-1919," Journal of Economic History, 41 No. 2 (June), 341-360.

Chandler, Alfred D. (1977), The Visible Hand: The Managerial Revolution in American Business, Cambridge, Mass.: Harvard University Press.

Christensen, L.; Jorgenson, D. and Lau, L. (1973), "Transcendental Logarithmic Production Functions," Review of Economics and Statistics, 55 No. 1 (February) 28-45.

Christensen, L. R. and Green, W. H. (1976), "Economies of Scale in U.S. Electric Power Generation," Journal of Political Economy, 84 No. 4 (August), 655-676.

Clark, Victor (1929), History of Manufactures in the United States, New York: McGraw-Hill Co., Volume II.

Danhof, Clarence (1941), "Farm-Making Costs and the 'Safety Valve'" 1850-1860," Journal of Political Economy, 49, No. 3 (June), 317-59.

Davis, Lance E. (1957), "Sources of Industrial Finance: The American Textile Industry, A Case Study," Explorations in Entrepreneurial History, 9 No. 2 (April) 190-203.

Davis, Lance E. (1958), "Stock Ownership in the Early New England Textile Industry," The Business History Review, 32, No. 2 (Summer) 204-222.

Davis, Lance E. (1960), "The New England Textile Mills and the Capital Markets: A Study of Industrial Borrowing, 1840-1860," Journal of Economic History, 20, No. 1 (March), 1-30.

Evans, George H. (1948), Business Incorporations in the United States, 1800-1943, Baltimore: Waverly Press for the National Bureau of Economic Research.

Francis, James B. (1868), Lowell Hydraulic Experiments, New York: D. Van Nostrand.

Hazard, Blanche E. (1921), The Organization of the Boot and Shoe Industry in Massachusetts Before 1875, Cambridge, Mass.: Harvard University Press.

Keir, Malcolm (1920), Manufacturing Industries in America, New York: The Ronald Press.

Kuehnl, George J. (1959), The Wisconsin Business Corporation, Madison: University of Wisconsin Press.

James, John (1982), "Structural Change in American Manufacturing, 1850-190," unpublished manuscript, University of Virginia (mimeo).

Jeans, J. S. (1880), Steel: Its History, Manufacture, Properties and Uses, London: Spon.

Livermore, Shaw (1935), "Unlimited Liability in Early American Corporations," Journal of Political Economy, 43, No. 5 (September), 674-687.

Miller, Randall (1972), "Daniel Pratt's Industrial Urbanism: The Cottom Mill Town in Ante-Bellum Alabama," Alabama Historical Quarterly, 34 No. 1 (Spring), pp. 5-35.

Mitchell, Broadus (1928), William Gregg, Factory Master of the Old South, Chapel Hill: Univeristy of North Carolina Press.

Montgomery, James (1840), The Cotton Manufacture of the United States Contrasted and Compared with that of Great Britain, Glasgow: John Niven.

Nerlove, M. (1963), "Returns to Scale in Electricity Supply," in C. F. Christ (ed.), Measurement in Economics, Stanford: Stanford University Press.

Poor, Henry V. (1890), Manual of the Railroads of the United States, New York: Poor.

Reynolds, A. R. (1957), The Daniel Shaw Lumber Company, New York: New York University Press.

Ringstad, V. (1974), "Some Empirical Evidence on Decreasing Scale Elasticity," Econometrica, 42 No. 1 (January), 87-102.

Saving, T. R. (1961), "Estimation of Optimum Plant Size by the Survivor Technique," Quarterly Journal of Economics, 75, 4, 569-607.

Shepherd, William A. (1967), "What Does the Survivor Technique Show About Economies of Scale," Southern Economics Journal, 34, No. 1, (January) 113-122.

Sokoloff, Kenneth L. (1981), "Was the Transition from the Artisanal Step to the Small Factory Associated with Gains in Efficiency?: Evidence from the U.S. Manufacturing Censuses of 1820 and 1850," unpublished manuscript, University of California, Los Angeles (mimeo).

Soskice, David (1968), "A Modification of the CES Production Function to Allow for Changing Returns to Scale over the Function," Review of Economics and Statistics, 50, No. 4 (November), 446-448.

Stigler, George J. (1958), "The Economies of Sale," Journal of Law and Economics, 1, 3, 54-71.

Tennant, Richard B. (1950), The American Cigarette Industry, New Haven: Yale University Press.

U.S. Census Office (1873, 1883, 1893, 1902). Ninth-Twelfth Census, Washington, D.C.: Government Printing Office.

U.S. Bureau of the Census (1975), Historical Statistics of the United States, Colonial Times to 1970, Washington, D.C.: Government Printing Office.

Ware, Caroline (1931), The Early New England Cotton Manufacture, New York: Houghton Mifflin Co.

Weiss, Leonard W. (1964), "The Survival Technique and the Extent of Suboptimal Capacity," The Journal of Political Economy, 72, 2, 246-261.

Williamson, Jeffrey and Swanson, Joseph A. (1966), "The Growth of Cities in the American Northeast, 1820-1870," Explorations in Economic History, 4, No. 1 Supplement, pp. 1-101.

Wilson, Livy T. (1964), "Florida Business Corporatons 1838-1885," unpublished Ph.D. thesis, University of Illinois.

Wolfe, Arthur D. (1965), "Ohio Business Incorporations, 1803-1851," unpublished M.A. thesis, University of Illinois.

Yeager, Mary (1981), Competition and Regulation: The Development of Oligopoly in the Meat Packing Industry, Greenwich, Conn.: JAI Press.

Zellner, Arnold and Revankar, N. S. (1969), "Generalized Production Functions," Review of Economic Studies, 36 No. 2 (April) 241-250.