Capital Deepening in United States Manufacturing, 1850-1880

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Summary: Capital Deepening in United States Manufacturing, 1850-1880

We use establishment level data to study the process of capital deepening – increases in the amount of capital per unit of labor – in nineteenth century United States manufacturing, with a focus on the role of establishment size. A model is developed in which larger establishments ("factories") may, under certain conditions, use more capital per worker, and possibly per unit of output than smaller establishments ("artisan shops"). Regressions on a sample of establishments for 1880 show a strong positive gradient of capital use with respect to size. However, changes over time in the size distribution of establishments can explain only a small fraction of changes over time in capital intensity.

I.

In the early nineteenth century, most manufacturing in the United States was undertaken in small artisan shops. These typically employed the owner-operator and possibly a small number of assistants and produced goods that were designed and made to order. Consequently, workers in artisan shops were, on average, highly skilled. The capital which they used, however, was relatively modest and non-specific – a few general-purpose hand tools, a generic workshop, and credit extended to customers or tied up in goods in process.

Over the course of the century the American manufacturing sector expanded its share of total output and its use of productive resources.[1] This expansion was associated with a shift in production from these artisan shops to factories. As an organizational form, factories differed fundamentally from artisan shops in their reliance upon the division of labor and their use of inanimate power. Tasks that had once been performed by a single skilled artisan using simple tools were sub-divided and given to less skilled workers using more specialized machinery. This division of labor and the "lumpiness" associated with these capital goods required a certain minimum scale to be effective and, therefore, the factory had more workers, on average, than the typical artisan shop.

Direct evidence on the magnitude of the factory's impact on skill intensity during the nineteenth century is very scanty although the evidence suggests that they employed workers who were, on average, less skilled.[2] For example, it has been shown recently that the distribution of the average wage across manufacturing plants--the "establishment wage"-- became increasingly unequal after 1850 primarily because the portion of the wage distribution below the median wage became more unequal.[3] The low-wage establishments that emerged were generally larger in terms of employment than the high-wage establishments; that is, the establishment wage was a negative function of size. This is precisely the pattern that would be predicted if the factory were less skill intensive than the artisan shop.[4]

This "de-skilling" of the manufacturing labor force is one key feature of nineteenth century industrialization in the United States. Capital deepening is another. By "capital deepening," we mean increases in the amount of real capital per unit of labor—that is, more and/or better machines and facilities per employee. Although not a necessary outcome of the process, the extent of capital deepening might also be sufficient to cause an increase in the capital-output ratio.[5]

Just as a prima facie case can be made that the shift of employment towards larger establishments reduced the skill intensity of manufacturing labor, a case can be made that this same shift was a leading proximate cause of capital deepening. Specifically, the increased division of labor that more employees made possible could in principle be enhanced by more intensive use of capital. For example, in an 1899 report the United States Department of Labor compared the production of a standardized quantity of men's shirts (12 dozen white muslin shirts with attached collars and cuffs) in a factory in 1895 with that in artisan shop in 1853. The factory employed 230 workers performing 39 distinct operations whereas in the artisan shop a single worker performed all 25 operations required to make a shirt. In the artisan shop, workers used shears, patterns, needle, thimble and press iron to produce the shirts, performing such operations as "cutting out bodies, bosoms, collars, cuffs and gussets" and "turning and basting cuffs." The most specific tool mentioned in production by hand was "buttonhole shears." In machine production on the other hand, cutting presses, stamping machines, sewing machines, awls and press irons, shears, pleating machines, brushes, knives, and buttonhole cutters along with needles and thread were used. The presses, stamping, and sewing machines were driven by steam, the buttonhole cutter by foot. Production workers were also supported by a variety of helpers who ran errands and performed "general work"—probably sweeping and cleaning and delivering and taking away goods in process. Importantly, approximately half of the operations in the factory were assisted by steam-powered machinery while all operations in the artisan shop were hand-powered. The impact of the division of labor cum steam power on labor productivity in this case was enormous -- just 188 hours were required to produce the standardized quantity of shirts in the factory, compared with 1,439 hours in the artisan shop.[6] Most of these same characteristics—the sub-division of tasks performed by more and different employees, the use of specialized machinery and steam power, and a bifurcation in skills—are apparent in all of the hand versus machine production comparisons made by the Commissioner of Labor.

In this paper we use establishment-level data from the 1850-80 manuscript censuses of manufacturing to study the relationship between establishment size and capital use—something that is impossible using the published aggregate data.[7] Our analysis of these data is guided by a variant of the simple model of manufacturing developed by Claudia Goldin and Lawrence Katz.[8] In this model, there are two types of firms (artisan shops and factories) that differ in size as measured by employment. Artisan shops are small. Factories are large. Both types of establishments use capital and skilled, and unskilled labor to produce output. The model implies that the share of skilled labor will be lower in the factory than in the artisan shop. Whether or not the factory uses more capital per total amount of labor (skilled plus unskilled) hinges upon whether capital or unskilled labor is more substitutable with skilled labor, as well as the degree to which skill intensity is affected overall. Capital per effective amount of labor – that is, adjusting for skill intensity – will be higher in the factory provided capital per total amount of labor is a non-decreasing function of size. Finally, the capital-output ratio may be higher or lower in the factory depending on the differences in capital intensity and labor productivity.

Our analysis reveals that capital-labor and capital-output ratios were much higher in 1880 than in 1850. Cross-sectional regression analyses reveal that larger establishments used significantly more capital both per total amount of labor and per effective unit of labor, and more capital per unit of output, than smaller establishments. Moreover, these patterns are robust when we control for industry and location. Despite the strongly positive gradient between capital and size, shifts in employment toward large establishments account for a very modest portion of capital deepening over the period from 1850 to 1880. Rather, the more intensive use of capital appears to have been a widespread phenomenon occurring in establishments of all sizes, industries, and locations, albeit in varying degrees.

II.

Our theoretical framework extends that used in our analysis of wage dispersion and is based upon the model developed by Claudia Goldin and Lawrence Katz. It guides our empirical work which links capital use to establishment size, measured by employment.

In the model, establishments are of two sizes: small (=artisan shops (A)) and large (=factories (F)) where small and large are defined in terms of the number of workers. Conditional on size, the manufacture of a finished product occurs in two stages. In the first stage of production, skilled labor (S) is combined with "raw" capital (K_R) to produce an intermediate input, which is called "operating" capital (K_O). This process is assumed to be described by a Leontief production function which we may write without loss of generality as follows[9]

$$K_O = \min(\alpha S, K_R)$$

In the second stage of production, less skilled labor (U) is combined with operating capital to produce a finished good, Q:

$$Q = f(U, K_O).$$

The ratio of less skilled labor to operating capital is $\varphi = U/K_O$. It is assumed that φ is selected optimally so as to minimize costs.

In artisan shops, both α and φ are small. When α is small, a relatively large amount of skilled labor is needed to produce operating capital from any given amount of raw capital. This might be the case, for example, if operating capital largely consists of inventories of partially (or nearly) completed goods, on which the finishing touches are made by a less skilled assistant or two—for example, polishing and buffing and the final assembly of fitted parts. In such an interpretation it follows naturally that φ would be small in the artisan shop.

In the factory, however, the values of α and φ are large. When α is large, a small amount of skilled labor is needed to produce operating capital from any given amount of raw capital. This might be the case, for example, if the operating capital was a specialized machine that complemented the work of unskilled laborers. Such machines are built, installed, and maintained by highly skilled workers although they are operated by much less skilled labor. The parameter φ is expected to be larger because the factory uses relatively more unskilled labor to actually fabricate the product.

Because $\alpha_F > \alpha_A$ it follows by definition that $(S/K_R)_F < (S/K_R)_A$. That is, for any amount of operating capital produced, the factory uses less skilled labor per unit of raw capital than does the artisan shop. In this sense, the factory "substitutes" (raw) capital for skilled labor. It is also straightforward to show that s, the share of skilled labor in total employment [$s = S/(U + S)$], is lower in the factory than in the artisan shop.[10] Because both α and φ are larger in the factory than in the artisan shop, s will be smaller in a factory than in an artisan shop.

Although skill intensity will be lower in a factory, the amount of operating capital per total amount of labor may be higher or lower. The amount of operating capital per total amount of labor, k, is

$$(K_O/(S+U)) = k = \frac{1}{2} \times [(K_O/S) \times s + (K_O/U) \times (1 - s)] = \frac{1}{2} \times [\alpha s + (1 - s)/\varphi]$$

The value of k is increasing in both α and $(1 - s)$. These tendencies make k larger in factories than artisan shops, but they can be offset because s is lower and φ is higher in the factory. In other words, capital per worker, might be higher or lower in the factory relative to the artisan shop depending on (a) how much skilled labor is substitutable for raw capital in the first stage; (b) the relative amounts of unskilled labor and capital used in this second stage (which is dependent on the division of labor and whether it is assisted by capital (see below)); and lastly, (c) the overall effect of the shift to factory production on skill intensity.

Although k could be higher or lower in the factory than in the artisan shop, it is more likely that k^*, the amount of operating capital per <u>effective</u> unit of labor, will be higher. Let us define the effective quantity of labor $L^* = S + \gamma U$, where $\gamma < 1$; that is to say each skilled worker is the equivalent of more than one unskilled worker. Because $\gamma < 1$, $L^* < L$. Therefore it follows that if $k_F = k_A$, then $k^*_F > k^*_A$ because $s_A > s_F$. That is, if capital per total amount of labor is non-decreasing when comparing the factory with the artisan shop, capital per <u>effective</u> unit of labor will be greater in the factory than in the artisan shop.

If k and k^* are higher in the factory than in the artisan shop, K_O/Q, the ratio of operating capital to output, may also be higher. Suppose, for example, that production in the second stage follows a Cobb-Douglas function: $Q = AK_O^{\beta}U^{1-\beta}$. The capital-output ratio may be written

$$K_O/Q = A^{-1}(\varphi)^{1-\beta}$$

After taking logarithms of both sides, the total differential of this expression is

$$d(\ln K_O/Q) = (1-\beta)d(\ln \varphi) + \ln \varphi d(1-\beta) - d\ln(A)$$

Comparing the factory with the artisan shop, the first term on the right hand side of this expression will be negative, because $d(\ln \varphi) < 0$. The third term will also be negative, provided that total factor productivity is higher in the artisan shop than in the factory. However, the second term will be positive, because the factory is more reliant on unskilled labor in the second stage $[d(1-\beta) > 0]$. Put another way, if output per effective unit of labor is higher in the factory, whether because k^* or A (or both) are higher, the capital-output ratio will also be higher, provided that any gains in total factor productivity, A, are sufficiently small relative to the increase in k^*.[11] Note, as well, that when $d(A) > 0$, the difference in the capital-output ratio between the factory and the artisan shop will be smaller, percentage-wise, than the difference in k^*.

The productivity of unskilled labor is enhanced by the use of powered machinery. In the equation for k, the use of powered machinery will affect both α and φ, and hence, s.

With respect to the proportion of skilled labor in the first stage of production, powered machinery and associated millwork had to be installed which might require delicate and extensive modification of the physical plant. After installation, it also required periodic maintenance. Both factors will raise the value of α. In the second stage of production, however, powered machinery complements unskilled labor and φ will be smaller. Therefore, in establishments using powered machinery, it is likely that k will be higher than in establishments relying on hand power.

During the early stages of industrialization in the United States, machinery was powered by water wheels. The use of water power particularly before the development of water turbines, however, was limited to certain industries and, most importantly, required that the establishment locate near a suitable site. Such sites were more common in the Northeast than elsewhere in the country. Steam power, on the other hand, was more versatile than water power, and with design improvements it eventually became a "general-purpose technology" that could be adapted for a wide range of industrial applications, one far less dependent on geography than was the situation with water power.[12] Prior to 1850 the diffusion of steam in the United States was relatively limited. After 1850, however, steam power diffused quite rapidly, particularly in regions where usable water power sites were relatively limited such as in the South and Midwest. Although water power declined in importance the diffusion of steam was sufficiently rapid that the proportion of workers employed (and value-added produced) in plants using powered machinery increased over the period 1850-80.[13]

III.

Our empirical analysis uses random samples drawn from the manuscript schedules of the 1850-80 federal censuses of manufactures for the United States.[14] These schedules record the responses of manufacturers (or their knowledgeable representatives) to the questions posed by the census enumerators. The samples are nationally representative of the surviving manuscripts. In this paper, for reasons given below, we focus primarily upon the 1880 sample.

The censuses reported the value of "real and personal" capital invested in the establishment, along with information about each plant's outputs and inputs. The specifics of what was reported varied somewhat from census to census. All of them reported the value of outputs and raw materials, but only the pre-1880 censuses reported physical quantities of outputs and inputs. In 1850 and 1860, the number of male and female employees was reported but child workers were not separately identified. In 1870 and 1880, the number of adult males (over age 16), adult females (over age 15), and children were given. Information was also given on the source of power although the actual horsepower used was not regularly reported until 1880.[15]

Although these records are a valuable and under-utilized data source, there is no question that some of the information is problematic, none more so that the capital estimates which were frequently criticized by officials at the time.[16] For example, census enumerators were given no written guidance as to whether "value" meant book value or market value.[17] However, the leading authority on the United States capital stock in the nineteenth century, Robert Gallman, argued that book value was uncommon at the time and that the capital figures refer typically to market value.[18]

It is also unclear how—if at all—the censuses treated working capital. Although there is both circumstantial and direct evidence that working capital was not wholly omitted in 1880, it is possible that, on average, working capital was under-reported.[19] Working capital, however, was definitely enumerated and its value reported separately in 1890. We have used these data to impute estimates of working capital based upon ratios of working capital to the gross value of outputs as reported in 1890, with the ratios varying by industry-state cells. By definition, these adjustments assume that working capital was wholly omitted, an assumption that is no doubt extreme in 1880 but may be more reasonable in other years. Regardless, these are useful for sensitivity analysis and we report estimates based upon both the capital figures given in the census as well as those based upon the sum of fixed capital and our imputed working capital.

There have also been questions raised regarding whether or not the employment figures recorded by the census enumerators included the owner-operator or not. The earlier censuses instructed enumerators to include the owner in the count of workers if she or he contributed materially to production. In 1880, however, the census instructions contain no such cautionary note, and there is internal evidence to suggest that the entrepreneurial labor input may not have been adequately enumerated.[20] To allow for the possible under-reporting of the labor of owner-operators we follow previous work by Sokoloff and add one person to the number of workers employed at the establishment in certain calculations (see below).[21]

Although the samples analyzed in this paper are nationally representative of the surviving manuscript schedules, they are not necessarily nationally representative of all manufacturing establishments. Some establishments were missed by careless enumerators. Some schedules have not survived. In general such failures were random and, hence, do not bias the results. However, some losses in 1880 were the result of a deliberate decision. At the Tenth Census, in recognition of the growing technical complexity of manufacturing activities, certain industries were assigned to special agents who were more knowledgeable about the industry than the average census enumerator. For example, James Swank, the Secretary of the American Iron and Steel Association, was appointed to supervise the collection of data on steel producers. These enumerations were not deposited with the other census data—perhaps they were retained by the enumerators as they wrote their reports (many of which appear in the 1880 census volume on manufacturing)—and the records have never been found.[22] Comparing the sample industry proportions with those of the population reported in the 1880 census volume, it is clear that establishments in these expert industries are under-represented in our sample. Some, however, do appear in our sample— perhaps collected by overly-eager enumerators—and we have used these to re-weight the 1880 sample.[23]

Dollar amounts were reported in nominal terms. To adjust for changes in prices we constructed price deflators for capital goods and for output. Although crude, we believe that these deflators capture the salient movements in prices over the period 1850-80. The deflators are reported in Panel A of Table 1. Product prices spiked during the Civil War and then generally fell but were still (slightly) above their pre-war levels by the time of the 1880 census while capital prices were lower in 1880 than at any of the earlier censuses.

Panel B of Table 1 reports sample sizes and real capital-labor ratios, expressed in index form (1850 = 100). Depending upon whether or not adjustment is made for the possible exclusion of working capital and entrepreneurial labor, the sample data imply increases in real capital-labor ratios of between 75 and 94% from 1850 to 1880 -- or average annual rates of between 1.9 and 2.2% per year over the 30-year period. Capital-labor ratios rose especially rapidly during the 1870s at an average rate of between 2.7 and 3.0% per year. They grew most slowly during the Civil War decade. Capital-output ratios, measured here by value added (Table 1, Panel C), also grew between the Seventh and the Tenth Censuses, at rates averaging between 1.4 and 1.6% per year depending upon whether our imputation for working capital is excluded or included. The real capital-to-value-added ratios grew most slowly during the 1850s and most rapidly during the 1870s.

In the regression analysis that follows we imposed a number of data selection criteria. To be included establishments must have had (1) positive employment (2) positive reported value of capital (3) positive value added (value of outputs – value of raw materials) (4) positive value of raw materials. Moreover, we excluded those firms at the very top and the very bottom of the distribution of rates of return on capital, as estimated by an accounting procedure, trimming the distribution to the 1-99 percentile range, on the grounds that these had data that were most suspect.[24]

Table 2 reports the coefficients on establishment size from cross-sectional regressions for 1880. We use the 1880 sample because this sample contains information useful for sensitivity analysis not contained in the other samples (see below). The count of workers is adjusted using the entrepreneurial labor imputation because, as noted earlier, there is reason to believe that in 1880 the labor input of owner-operators may not have been recorded properly. We experimented with a variety of ways of measuring size but, for simplicity, settled on three dummy variables: 6-15 workers, 16-100, and 100+ (the left-out dummy is 1-5 workers).

The regressions also include controls for industry and location. Average capital intensity and size might have differed across industries but, controlling for industry, size may have been independent of capital intensity. The industry dummies are measured at Standard Industrial Classification (SIC) 3-digit level—the finest detail available in the sample.[25] Despite the absence of tariff barriers between states, the United States in 1880 was far from a "common market" in goods or factors of production. Distance and high transport costs impeded the free flow of mobile factors and products. If firms were choosing factor ratios optimally, then geographic variation in wages relative to rental rates of capital should have affected capital intensity. Geography may also have affected the size distribution of establishments because, to borrow a (well-known) phrase, the division of labor was limited by the extent of the market. We control for location effects by including dummy variables for the state in which the establishment was located and for urban status.

Panel A of Table 2 reports regressions of the log of the capital-worker ratio. We observe a strong positive gradient between size and capital intensity, up to 100 workers. Above 100 workers there was a slight decline in capital intensity but, even in the largest establishments, capital-worker ratios were far higher than in artisan shops (the omitted size category). The size-capital gradient was slightly attenuated when we included the imputation for working capital but any difference in this regard was small and does not affect our substantive conclusion.

The model in section II predicted that, if capital per total amount of labor were higher in factories, then capital per effective unit of labor – that is, adjusting for skill intensity – would be even higher. None of the samples directly reported the number of workers by skill level. Instead, the best we can do to construct a proxy for the effective amount of labor is to follow the previous literature and use the information on gender and age. Specifically, we define the effective amount of labor to be $L^* = 1 + M + \lambda_1 W + \lambda_2 C$, where both values of λ are less than one.[26] The logic of using gender and age in this manner is that, on average, woman and (especially) children were less skilled than men.[27]

Panel B of Table 2 reports the size coefficients in regressions of the log of our proxy for capital per effective unit of labor. Not only are the size coefficients again positive but, as required by our model, they are larger in value than the coefficients in Panel A. For example, when the imputation for working capital is made, the coefficient of the third size class (100+) is 0.510, compared with a value of 0.357 in Panel A.

Panel C of Table 2 reports the coefficients of the size class dummies in regressions of the log of the capital-output ratio. Output is measured by value added (value of outputs – value of inputs). Our model predicts that, if capital intensity was increasing in establishment size and if labor productivity was increasing at a smaller rate than capital intensity, then the capital output ratio would be higher in larger establishments, but proportionately less than the increase in capital intensity. This is exactly what we observe: The capital-value added ratio was significantly higher in larger establishments, particularly when we control for industry and location but the increase was proportionately smaller than the increase in capital intensity.

We conducted three sensitivity analyses (not shown).[28] First, we adjusted the labor input to take account of variations across establishments in annual hours of operation. This analysis is possible in 1880 (and only in 1880) because the census in that year reported daily hours and months of operation, so that annual hours can be estimated.[29] When this is done the positive gradient between capital intensity and size is slightly flatter but our substantive conclusions are not affected.[30] Second, we re-estimated the regressions in Table 2 including a dummy variable for the use of inanimate power. The issue here is whether the positive relationship between capital and size were entirely due to the use of powered machinery or were more general in nature. Establishments using powered machinery were more capital intensive and had higher capital-output ratios than firms relying on hand power. However, controlling for the use of powered machinery, there still was a positive gradient between capital use and size. Third, we estimated capital-labor and capital-output regressions using the 1850-70 samples. These show that the positive relationship between size and capital use is evident in the 1850-70 samples and suggest that the relationship between capital use and size became steeper over time, although such change was relatively modest in scope.

IV.

Larger establishments – "factories" – used more capital per unit of labor, and more capital per unit of output, than small establishments – "artisan shops". The size effect, as estimated for 1880, was impressive in magnitude. According to the regression in column 1, Panel A of Table 2, establishments in the largest size category (100 + workers) used 52 percent more capital [= exp(0.416) – 1] per worker than establishments in the smallest category, controlling for industry and location. Per effective worker, the differential was even larger: 76% (Panel B) because larger firms generally substituted less skilled workers for the more skilled workers employed in artisan shops.

This movement towards concentrating production in larger establishments was a marked and general phenomenon during the nineteenth century, occurring in almost every industry everywhere. Panel A in Table 3 shows that artisan shops had employed about a quarter of the industrial labor force in 1850 but had little more than an eighth by 1880 and, whereas less than 30 percent of the work force had been employed in establishments with a hundred or more workers in 1850, 45 percent worked in such places in 1880. The share of manufacturing employment in plants with more than 15 workers went from less than 60 percent to almost 74 percent over the same period. Moreover, the very largest plants increased their share of manufacturing value-added from 1850 by about half to more than 38 percent by 1880. Panel B shows the shares of employment by industry in plants employing more than 15 workers in 1850 and 1880. In almost every industry (the one exception shown being machinery), the employment share in larger establishments grew—often sharply—between 1850 and 1880. Moreover, in almost all of these industries, the log capital-labor ratio in larger plants (those employing more than 15) was higher than in smaller plants, and usually significantly larger.

Although impressive in magnitude, the pronounced shifts in the size distribution of firms in favor of larger establishments were relatively unimportant in explaining capital deepening at least over the period 1850-80. According to the estimates in Table 1 (Panel A, with entrepreneurial labor imputed), real capital-labor ratios increased by 84.5 and 94 percent between 1850 and 1880, depending upon whether we adjust for the possible omission of working capital. If we estimate the predicted change based upon our regression coefficients (from Table 2, Panel A) and the changes in the size distribution of firms shown in columns 1 and 2 of Panel A in Table 3, our empirical work suggests that the capital-labor ratio would have grown by just 4.7-6.4 percent, again depending on whether or not we impute working capital. Shifts in the size distribution of establishments explain somewhat more of the increase in the capital-output ratio from 1850 to 1880 – between 7.3 and 10.1 percent, depending on how working capital is treated.

If changes in the size distribution of firms do not explain capital deepening then it must have occurred primarily because of the increased use of capital within all size classes. It is, of course, possible that changes in one or more establishment level characteristics not included in the regression could account for the capital deepening within size classes. But it is difficult to identify plausible omitted characteristics on a priori grounds – the most relevant establishment characteristics it seems to us, are industry and location, and these are controlled for in the regression.[31] Rather, it appears that capital deepening was a widespread phenomenon. Simply put, manufacturing establishments of all different sizes, industries, and locations became more capital intensive over time.

Why should capital deepening have been a broad rather than a narrow process? One possible reason is that certain technological advances were "general purpose" in nature. The diffusion of steam power is an example. Steam engines could be varied in horsepower and adapted for use in a wide array of industrial contexts. Even very small establishments could, and did, re-design production to make use of steam powered machinery.[32] Beginning in the late nineteenth century, electricity – an even better general purpose technology – would diffuse widely and, in the process, lead to even greater and more widespread capital deepening.[33]

More generally, the best explanation may be the simplest – a pervasive decline in the relative price of capital, where "relative" means relative to wages and to the price of output. As the (rental) price of capital fell relative to wages and to output, the capital labor and capital-output ratios increased.[34] Although the evidence is not as detailed as one might like, post-1850 decreases in the relative price of capital appear to have been the continuation of trends the originated well before, rather than just prior to, 1850.[35]

As the British economic historian H. J. Habbakuk noted some time ago, an abundance of land in the United States may have raised wages relative to the rental price of capital and thus promoted greater capital intensity in non-farm sectors, such as manufacturing.[36] Following Habbakuk's logic, improvements in internal transportation and other factors that promoted the westward movement of population may have raised wages in the East where manufacturing predominated, thereby leading to capital deepening. Although recent scholarship has not been particularly favorable to Habakkuk's story, the general notion that resource "endowments" in the United States – absolutely and relative to other countries -- may have influenced factor prices and factor accumulation in ways that were conducive to capital deepening is still quite plausible.[37] "Tinkering" with existing production processes, along with a well-functioning patent system contributed to a high rate of innovation, some of which was manifested in new or improved versions of existing capital goods.[38] By world standards, the United States possessed reasonably effective financial markets by the early nineteenth century.[39] Although most of the investment in capital goods in manufacturing was probably financed through savings or retained earnings, or by pooling the funds of a small number of "insiders", over time an increasing share at the margin was financed by borrowing from financial intermediaries especially as the commercial paper market developed, or by issuing debt or equity, particularly for the larger establishments.[40]

Our empirical account of capital deepening ceases with the 1880 census year because there are no census manuscript data are available for 1890 or 1900. However, establishment size began to increase sharply after 1880. Further, as previously noted, the development and eventual diffusion of electricity led to substantial increases in capital per worker as well as fundamental changes in the skill composition of the manufacturing labor force. It is likely, therefore, that if we had analogous establishment level data for 1900, they would reveal not only a positive association between size and capital use but possibly a somewhat greater role for shifts in establishment size than is observed for the period 1850-80.

Table 1 Capital Deepening, Real Estimates: Atack-Bateman Samples

Panel A: Price Deflators (1850 = 100)

	Capital	Output
1850	100.0	100.0
1860	97.4	103.6
1870	131.1	165.2
1880	83.0	109.2

Panel B: Real Capital-Labor Ratios (1850 = 100)

	Number of Establishments		Real Capital-Labor Ratios			
		Imputation for Working Capital?	No	Yes	No	Yes
		Imputation for Entrepreneurial Labor Input?	No	No	Yes	Yes
1850	4,906		100.0	100.0	100.0	100.0
1860	4,971		125.5	128.0	126.2	129.4
1870	3,832		134.4	138.1	141.3	145.0
1880	7,178		175.4	183.9	184.5	194.0

Panel C: Real Capital-Value Added Ratios (1850 = 100)

Imputation for Working Capital?	No	Yes
1850	100.0	100.0
1860	106.0	108.6
1870	122.2	125.5
1880	152.6	160.6

Source: 1850-80 Atack-Bateman establishment-level samples from manuscript censuses of manufacturing; see Atack and Bateman (1999).

General Notes to Table 1: to be included in the calculations, an establishment has to have positive values of capital, number of workers (= male + female employees, 1850-60, or adult male + adult female + child employees, 1870-80), inputs, value added (value of outputs – inputs), and the log (capital/labor). Observations in SIC 999 (miscellaneous or industry unknown) or SIC 492 (gas works) are deleted as are observations with extremely high or extremely low ex-post rates of return to capital (see Atack, Bateman, and Margo, 2003). Indices are based on weighted averages of establishment estimates; weights equal to the establishment's share of aggregate employment or value added. Imputation for Working Capital: the imputation assumes that working capital was used in fixed proportion (δ) to the reported gross value of output. The value of δ is assumed to vary across state-industry (3 or 4-digit SIC level) cells, but not across years; these are estimated from figures reported in the 1890 Census of Manufactures. Imputation for entrepreneurial labor input: one is added to count of workers (see text and Sokoloff 1984). 1880 re-weighting: The 1880 sample must be re-weighted to correct for under-sampling of so-called "special agent" industries. Sample is re-weighted so that special agent industry share of total reported employment (Panel B) or value added (Panel C) in the sample matches the aggregate share reported in the 1880 census and distribution of employment or value-added by establishment size class in expert industry establishments matches that in the 1870 Atack-Bateman sample. For establishment size class categories, see Table 2.

Notes to Panel A: Capital price deflator is a weighted average of price index numbers for equipment, structures, and working capital (see Sokoloff 1986). Weights: equipment, 0.412; structures, 0.275; working capital, 0.313. Working capital is assumed to be divided equally between finished output and raw materials. Weights are computed from the 1890 Census of Manufactures. Equipment capital price is from Brady (1966, pp. 110-111, "Machine-shop products"). Structures capital price is from Brady (pp. 110-111, "Factors, Office-Buildings") with imputation for 1859 based on change in construction costs for "Houses, Churches, Schools" (Brady, op. cit.) between 1854 and 1859, and imputation for 1869 based on change in construction costs from 1869 to 1879 implied by Riggleman building cost index (see U.S. Department of Commerce 1975, series N138, p. 629). Price index for finished products component of working capital is set equal to Warren-Pearson wholesale price index. Output price deflator computed by taking the ratio of Gallman's (1961, Table A.13) estimates of aggregate nominal and real value added in manufacturing, 1850-80, and re-scaling so that 1850 = 100.

Table 2: Coefficients of Size Dummies, Regressions of Log (Capital/Labor), Log (Capital/Effective Labor), and Log (Capital/Value Added) Ratios: 1880 Sample

Panel A: Log (Capital/Labor)

Working Capital Imputation?	No	Yes
6-15 Workers	0.192 (0.030)	0.193 (0.025)
16-100 Workers	0.450 (0.046)	0.425 (0.036)
100+ Workers	0.416 (0.104)	0.357 (0.092)
Adjusted R^2	0.335	0.426

Panel B: Log (Capital/Effective Labor)

Working Capital Imputation?	No	Yes
6-15 Workers	0.222 (0.032)	0.223 (0.025)
16-100 Workers	0.514 (0.046)	0.489 (0.035)
100+ Workers	0.568 (0.095)	0.510 (0.079)
Adjusted R^2	0.339	0.437

Panel C: Log (Capital/Value Added)

Working Capital Imputation	No	Yes
6-15 Workers	0.077 (0.031)	0.078 (0.02)
16-100 Workers	0.212 (0.042)	0.187 (0.027)
100+ Workers	0.351 (0.080)	0.293 (0.052)
Adjusted R^2	0.284	0.377

Source: see Table 1. The sample size is 7,178 establishments. Notes to Panels A, B, and C: All regressions include dummy variables for urban status, state, and 3-digit SIC code. Unit of observation is the establishment. Size distribution classification is based on reported count of workers. The sample is re-weighted; see Table 1. Effective Labor = adult males + 0.5*adult females + 0.33*children; see text.

Table 3 Changes in the Distribution of Establishment Size and Use of Inanimate Power, 1850-80: Atack-Bateman Samples

Panel A: Distribution of Establishment Size: Proportion of Workers

	1849	1879	1849	1879
Weight?	Workers	Workers	Value Added	Value Added
<6 Workers	0.235	0.132	0.210	0.113
6-15 Workers	0.173	0.129	0.224	0.142
16-100 Workers	0.301	0.289	0.327	0.359
100+ Workers	0.290	0.450	0.239	0.386
>15 Workers and inanimate power	0.591	0.739	0.566	0.745

Panel B: Proportion of Workers in Factories (Employment > 15 Workers), by 3-digit Industry

3-digit SIC code	Industry	1850	1880	Difference in log (K/L): >15 workers vs. <=15 (absolute t-stat in parentheses)
201	Meat Packing	0.610	0.620	1.134 (3.26)
204	Flour Milling	0.014	0.139	0.694 (3.16)
205	Bakeries	0.071	0.533	0.145 (0.51)
208	Liquor	0.058	0.477	0.358 (0.53)
212	Cigars	0.319	0.681	0.189 (1.02)
231	Men's Clothing	0.787	0.932	0.425 (2.51)
235	Millinery	0.628	0.739	0.061 (0.14)
242	Saw Milling	0.187	0.473	0.478 (3.14)
243	Sashes, doors and blinds	0.377	0.554	0.617 (3.54)
244	Cooperage	0.113	0.500	0.423 (1.39)
251	Furniture	0.428	0.732	0.203 (1.50)
262	Paper	0.702	0.898	0.961 (3.18)
284	Soap	0	0.189	-0.472 (3.37)
311	Leather Tanning	0.197	0.740	0.476 (0.22)
314	Boots and Shoes	0.650	0.678	0.449 (3.21)
325	Brickworks	0.470	0.538	0.621 (0.22)
326	Pottery	0.153	0.516	0.401 (2.09)
328	Stone products	0.326	0.607	-0.955 (3.47)
332	Iron foundries	0.668	0.914	-0.274 (1.07)
342	Tools	0.653	0.901	0.552 (1.62)
344	Boilers	0.141	0.516	0.189 (0.91)
351	Machinery	0.919	0.848	0.388 (2.45)
352	Agricultural implements	0.657	0.664	0.573 (4.71)
379	Wagons and Carriages	0.245	0.462	0.652 (2.14)

Source: see Table 1. 1880 sample is re-weighted; see Table 1. For an industry to be included in Panel B there must be at least 20 observations (establishments) in both 1850 and 1880.

Table 4: Explaining Change in Real Capital-Labor and Real Capital-Value Added Ratios, 1850-80: The Role of Changes in the Size Distribution of Establishments

	K/L	K/L	K/Q	K/Q
Working Capital Imputation	No	Yes	No	Yes
Predicted Percent Change	5.4%	4.4%	5.3%	4.4%
Actual Percent Change	84.5%	94.0%	52.6%	60.6%
Percent Explained	6.4%	4.7%	10.1%	7.3%

Source: see Table 1.
Notes to Table 4: Predicted Percent Change: size coefficients from regressions in Table 2 multiplied by change in size class distribution from Table 3. Actual Percent Change: from Table 1, panels B, C; Percent Explained: Predicted Change/Actual Change. 1880 sample is re-weighted; see Table 1.

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Notes

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[1] For a general discussion of the growth of manufacturing in the United States in the nineteenth century, see Engerman and Sokoloff, “Technology and Industrialization”.

[2] The fundamental reason is that none of the federal manufacturing censuses prior to 1890 collected data on workers by skill level. Some data were collected, however, on gender and age and these have been used frequently as a proxy for skill; see Goldin and Sokoloff, “Women, Children, and Early Industrialization” and Sokoloff, “Was the Transition”; and Section III of this paper. See also Field, “Industrialization and Skill Intensity”.

[3] Atack, Bateman, and Margo, “Skill Intensity.” The establishment wage is the average wage of workers in an establishment (= total wages/number of workers).

[4] The difference in log of the establishment wage at the 10th and 50th percentiles rose by 0.28 log points between 1850 and 1880. Sixty-eight percent of this increase, or 0.19 log points, can be accounted for by the shift in employment towards large establishments; see Atack, Bateman, and Margo, “Skill Intensity,” p. 187.

[5] To see this, note that the standard Solow growth model can be written as follows:

$$\overset{0}{K} - \overset{0}{Y} = (1-\alpha)\overset{0}{k} - \overset{0}{A}$$

Where Y is output, K is capital, k is the capital-labor ratio, A is the index of total factor productivity, and a “^{0}” indicates the growth rate. Unless offset by increases in A, capital deepening (increases in k) will cause K/Y (the capital-output ratio) to rise.

[6] For a detailed discussion of this example, see U.S. Department of Labor, “Hand and Machine Labor,” pp. 1094-97.

[7] It would be desirable to extend our analysis to 1890 and 1900 but establishment-level data for both census years are no longer extant.

[8] Goldin and Katz, “The Origins”.

[9] The Leontief assumption is made for simplicity; see Goldin and Katz, “The Origins”.

[10] Since $K_O = \alpha S$ and $U = \varphi K_O$, $s = 1/(1 + \alpha\varphi)$.

[11] For evidence on the efficiency gains from the factor see Atack, “Economies of Scale” and Sokoloff, “Was the Transition”.

[12] On steam as a general purpose technology, see, Rosenberg and Trajtenberg, “A General Purpose Technology”; and Crafts, “Steam as a General Purpose Technology.”

[13] On the diffusion of steam power, see Fenichel, “Growth and Diffusion”; and Atack, Bateman, and Weiss, “The Regional Diffusion.” In the data analyzed in this paper, the proportion of workers employed in established using powered machinery increased from 45.7 percent in 1850 to 62.3 percent in 1880. The proportion of value added produced using powered machinery also increased, from 50.6 percent in 1850 to 71.2 percent in 1880.

[14] Atack and Bateman, “Nineteenth Century U.S. Industrial Development”

[15] Some information was reported on horsepower in the pre-1880 but the information is very scattered and of little use.

[16] Francis A. Walker, the superintendent of both the Ninth Census in 1870 and the Tenth Census in 1880, for example, complained: “No man in business knows what he is worth -- far less can say what portion of his estate is to be treated as capital”; see U.S. Census, Ninth Census, p. 381.

[17] The question itself was nothing more than ‘Capital invested in real and personal estate in the business, the aggregate amount of the capital, real and personal is to be inserted’ (see U.S. Census, Eighth Census, p. 25). While concerns about data quality are important, they should not be over-emphasized. If the data on capital were mostly noise, it would be highly unlikely that we would find systematic and plausible relationships between capital-labor ratios and various establishment characteristics, as we report in section III.

[18] See Gallman, “The United States Capital Stock,” p. 174, and “Investment Flows,” pp. 220-22.

[19]Certain interpretations of our model – for example, the inclusion of inventories of partially completed goods in operating capital – require the working capital be measured. It was the belief that working capital was under-reported that prompted the inclusion of a separate inquiry on working capital in the 1890 census. However, the reports on the special agent industries (see the text) in the 1880 census make it clear that, at least some of the time, enumerators in 1880 did enquire about working capital. Sokoloff, "Productivity Growth," p. 713 argues that "a major component" of working capital was included in the pre-Civil War censuses.

[20] The internal evidence is that some establishments reported positive amounts of output but no workers. The fraction of establishments with this characteristic is considerably higher in 1880 than the other census years.

[21] See Sokoloff, "Was the Transition." The adjustment may be too large in which case the regressions overstate the extent to which capital use was more intensive in large establishments. In this regard, it is worth noting that our proxy for the effective labor input may understate the extent to which skill intensity was decreasing in size (see the text and footnote 26), in which case the Sokoloff adjustment, even if too large, may counteract some of the bias built into our proxy for effective labor.

[22] Delle Donne, "Federal Census Schedules".

[23]The notes to Table 1 describe the weighting procedure.

[24] The accounting procedure is discussed in the appendix of Atack, Bateman, and Margo, "Capital Deepening". We exclude observations with very high or low rates of return on the grounds that capital is likely to have been severely mis-measured. In addition, we exclude a small number of other establishments on the grounds that certain variables (for example, the count of workers) are clearly erroneous, possibly because of errors in transcribing data from the handwritten manuscripts.

[25] This level is one step removed from the product—for example, "Leather Tanning and Finish" (= SIC 311) but not "Belting leather" versus, say, "Glove leather" (both of which fall into SIC 3111 but would have different 6-digit SIC codes) or "Women's Outerwear" (=SIC 233) but not "Women's Blouses and Shirts" (=SIC 2331) versus, say "Women's Dresses" (=SIC 2335). See, for example, Executive Office of the President, Office of Management and Budget, *Standard Industrial Classification Manual.*

[26] We set $\lambda_1 = 0.5$ and $\lambda_2 = 0.33$. These values are meant to approximate the relative marginal products of women and children and, as such, are reflected in (and measured by) relative wages; see, for example, Sokoloff, "Productivity Growth". Plausible variation in the values of λ_1 and λ_2 do not affect our substantive findings.

[27] See Goldin and Sokoloff, "Women, Children, and Industrialization." It is likely that our proxy for effective labor understates the extent to which skill intensity was decreasing in establishment size because it does not adjust for differences in average skill among men in different size establishments. Evidence on differences in establishment wages across size classes consistent with this argument is reported in Atack, Bateman, and Margo, "Skill Intensity", footnote 35, p. 181.

[28] Regressions from the sensitivity analysis are available from Robert A. Margo.

[29] We exclude establishments operating fewer than 7 hours per day on the grounds that these may have been part-time enterprises. Those over 13 hours are excluded because there may have been multiple shifts involved but these cannot be identified directly. Inclusion of establishments falling outside this range, however, does not affect our substantive findings. The 1880 census also reports information sufficient to calculate full-time equivalent months of operation. Annual hours of operation is equal to average daily hours times the number of "full-time equivalent" months of operation times 25.75 full-time days per month; see Atack, Bateman, and Margo, "Productivity in Manufacturing".

[30] The reason the gradient is slightly flatter is that larger establishments operated more hours per year and thus the labor input is greater when measured in terms of hours than in terms of number of workers.

[31] We have also estimated regressions of capital intensity and the capital output ratio pooling the 1850 and 1880 samples, including a dummy variable for 1880. The coefficient of the dummy variable is only slightly smaller when the regression includes the size, industry, and location dummies, consistent with the argument in the text that capital deepening was a widespread process. The pooled regression is available from Robert A. Margo.

[32] In 1880, 12 percent of the smallest establishments (<6 workers) used steam powered machinery.

[33] The point here is that while the diffusion of steam among the smallest of establishments may have been inherently limited, establishments of any size could benefit from electricity. On the effects of the diffusion of electricity on capital use see Goldin and Katz, "The Origins".
[34] Evidence of a secular rise in real wages in manufacturing during the nineteenth century may be found in Margo, "The Labor Force". Our capital price deflator refers to the price of capital goods which, in theory, could diverge from the rental price of capital if real interest rates moved in an opposite direction from that of capital goods prices. However, nominal interest rates were similar in value in 1850 and 1880 (see Homer, A History, ch. 16). and there is little reason to believe that the expected rate of change in the price level differed substantially between these two years.
[35] See Sokoloff, Industrialization and the Growth of the Manufacturing Sector, p. 32.
[36] Habakkuk, American and British Technology.
[37] The literature critiquing the Habakkuk hypothesis is extensive; see, in particular, Temin, "Labor Scarcity"; Summers and Clarke, "The Labour Scarcity Controversy"; James and Skinner, "The Resolution"; and, especially, Field, "Land Abundance". On the role of resource endowments and capital use in manufacturing, see Summers and Clarke, "The Labour Scarcity Controversy" and Wright, "The Origins".
[38] Sokoloff, "Inventive Activity ".
[39] Rousseau and Sylla, "Emerging Financial Markets".
[40] Bodenhorn, State Banking, pp. 60-61; Davis, "The New England Textile Mills"; Lamoreaux, Insider Trading.