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Capital deepening and the rise of the factory: the American experience during the nineteenth century[1]

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Over the course of the nineteenth century, manufacturing establishments in the United States used increasing amounts of capital per worker, a process that we refer to as 'capital deepening'. For example, we estimate that, after taking account of changes in the prices of capital goods, capital–labour ratios in manufacturing increased by at least 75 per cent between 1850 and 1880. This capital deepening occurred in tandem with a dramatic shift in the mode and locus of production. Early on, most manufacturing took place in artisan shops. These typically employed the owner-operator and possibly a small number of assistants, producing goods that were designed and made to order. Workers in artisan shops were, on average, highly skilled, but used relatively modest and non-specific capital goods such as a few general-purpose hand tools and a generic workshop that could be employed in many different lines of work.

As the manufacturing sector grew over the course of the century, production shifted from artisan shops to factories. There, tasks were subdivided and performed by less skilled workers using more specialized and expensive machinery. This machinery often required more power than human muscle and thus was driven by steam or waterpower.[2] The lumpiness in the capital goods, the regularity and ceaseless energy of inanimate power, and the opportunities afforded by the division of labour meant that production was conducted on a much larger scale than before. From a theoretical standpoint, it is uncertain whether or not these changes increase capital per unit of output. Our estimates, however, indicate that larger establishments used significantly more capital per unit of output than smaller ones.

In this note we use data from the decennial censuses of manufacturing establishments in the United States from 1850 to 1880 to examine the

[1] A longer version of this paper is available upon request from the authors. We are grateful to three referees, Alex Field, Lee Craig, Jan DeVries, and workshop participants at the National Bureau of Economic Research, the University of California at Berkeley, and the Economic History Association for helpful comments.

[2] For general discussion of the development of United States manufacturing in the nineteenth century and the specific points made in this paragraph, see Engerman and Sokoloff, 'Technology and industrialization'; Field, 'Industrialization'; Sokoloff, 'Industrialization and growth'; Atack, Bateman, and Margo, 'Skill intensity'; and Wright, 'Origins'.

extent to which the dramatic transition from the artisan shop to the factory can account for the observed increase in capital per worker.[3] Earlier censuses of manufacturing in the United States were irregular and incomplete.[4] Later censuses of manufacturing have been lost or destroyed.[5] The data used here are nationally representative random samples from the surviving records, and we rely particularly heavily upon the 1880 sample, which provides more detailed data regarding each firm's labour force.[6] Several adjustments to the data have been made, including accounting for working capital and for the probable omission of the labour of the entrepreneur in 1880.[7] The censuses reported dollar amounts in nominal terms. Since prices were also changing, nominal values have been deflated into real terms using the price indices shown in Panel A of table 1.[8] Panels B and C report sample

[3] The manufacturing census data underlying this paper are available on-line from http://www.vanderbilt.edu/Econ/faculty/Atack/atackj.htm

[4] The first effort to collect data on manufacturing as part of the 1810 census was made belatedly and without providing schedules or detailed guidance to the enumerators. The 1820 census is regarded as geographically incomplete and no census of manufacturing was attempted in 1830. Fishbein, 'Census of manufactures'.

[5] The records for 1890 were destroyed by a fire in the Commerce Department in 1921. Subsequent economic censuses were destroyed by Congressional authorization to protect privacy. Fishbein, 'Census of manufactures'; U.S. Congress 'A list of useless Papers', 1912, 1930, 1931.

[6] Atack and Bateman, 'U.S. industrial development'. The 1880 enumeration, however, suffers from one particularly important defect: some establishments in certain industries were enumerated by so-called 'special agents' and the forms collected by these agents have not survived (Delle Donne, 'Federal Census schedules'). Consequently, it is necessary to re-weight the 1880 sample to correct for this under-enumeration prior to estimation. The sample is re-weighted such that the special agent share of total reported employment or value-added matches the aggregate shares reported in the published 1880 census and the distribution of employment or valued by establishment type in special agent industries matches those in the 1870 Atack-Bateman sample.

[7] The census directed enumerators to report the aggregate 'Capital invested in real and personal estate in the business' (see U.S. Census, *Eighth Census*, p. 25). The leading modern authority on the question, Robert Gallman, argued that book value was uncommon at the time and that the capital figures refer typically to market value. See Gallman, 'US capital stock,' p. 174, and 'Investment flows,' pp. 220–2. There is considerable uncertainty as to whether the 1850–80 capital values include working capital. Working capital, however, was reported in 1890. To impute working capital values for 1850–80 we assume 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 cells, but not across years. With regard to entrepreneurial labour, the internal evidence suggests that the entrepreneurial labour input may not have been counted in 1880 but this is less certain for other years. To allow for this possibility, we follow Sokoloff ('Transition') and add one to the count of workers in 1880 prior to estimating the regressions in Table 2, and we also present capital–labour ratios in Panel B with this imputation for the other census years.

[8] The notes to Table 1 also outline the various data selection criteria that are applied throughout. The capital price deflator is a weighted average of price index numbers for equipment, structures, and working capital (see Sokoloff, 'Productivity gains'). The weights, which are computed from the 1890 Census of Manufactures, are equipment, 0.412; structures, 0.275; working capital, 0.313. Working capital is assumed to be divided equally between finished output and raw materials. The equipment capital price index is from Brady ('Price deflators', pp. 110–11, 'Machine-shop products'). Structures capital price is from Brady, 'Price deflators' (pp. 110–11, 'Factors, office-buildings') with an imputation for 1859 based on change in construction costs for 'Houses, churches, schools' (pp. 110–11) between 1854 and 1859, and an 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, *Historical statistics*, series N138, p. 629). The price index for finished products component of working capital is set equal to Warren-Pearson wholesale price index. The output price deflator is computed by taking the ratio of Gallman's ('Gross national product', tab. A.13) estimates of aggregate nominal and real value added in manufacturing, 1850–80, and re-scaling so that 1850 = 100.

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–labour ratios (1850 = 100)

			Real Capital-Labour Ratios			
		Imputation for Working Capital?	*No*	*Yes*	*No*	*Yes*
	Number of Establishments	*Imputation for Entrepreneurial Labour 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, 'US Industrial Development'. 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/labour). 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 and those for which the data were deemed unreliable. Indices are based on weighted averages of establishment estimates; weights equal to the establishment's share of aggregate sample employment or value added. 1880 sample is re-weighted; see note 4 in the text.

sizes, real capital–labour, and capital–output ratios, expressed in index number form (1850 = 100). Capital–output ratios, measured here by value added, increased between 1850 and 1880. The real capital-to-value-added ratios grew most slowly during the 1850s and most rapidly during the 1870s. More importantly for our analysis here, the census data imply increases in average real capital–labour ratios of between 75 and 94 per cent from 1850 to 1880, depending on the imputations made regarding entrepreneurs and working capital. Capital–labour ratios rose particularly rapidly during the 1870s, and most slowly during the Civil War decade. However, as we will show, the shifts in employment and output toward large establishments explain only a modest portion of this capital deepening over the period.

The pronounced shift from hand to machine production methods during the nineteenth century was the subject of a special survey by the U.S. Commissioner of Labor. This documents the kinds of changes taking place within our data. For example, with regard to the manufacture of boots and shoes, the Commissioner observed:

> There is probably none of the older industries . . . in which the introduction of machinery has been more rapid. . . . Following the primitive shoemaker, who worked on the bench in his own home making shoes to measure . . . the first change introduced the old-fashioned shoe shops which were large enough to accommodate but 3 or 4 workmen. . . . [I]n time this system gradually gave way to the modern factory system . . . in which, with the exception of the upper-cutting department, machinery has almost entirely displaced hand methods. . . .
>
> In 1880, when the subdivision of labor had about reached its limit . . . efforts were next directed to the production of subordinate parts of the product . . .
>
> Aside from those operations which are peculiar to the factory method of production, such as the work performed by bunchers, engineers, firemen, foremen, machinists, markers, monogramers, packers, stampers, sweepers, watchmen, etc., there are a number of other operations . . . that . . . are the result of the exhaustive subdivision of labor.[9]

In the hand production of men's boots and shoes, one or two workers performed between 45 and 83 different operations. In machine production, boot and shoe manufacturers employed between 98 and 371 workers, who performed between 84 and 173 different operations, about a half of which were powered or assisted by steam. Depending upon the quality, a pair of handmade boots or shoes took between 2 hours and 50 minutes and 22 hours 15 minutes to complete. The same quality boots and shoes produced with the help of machines took between 38 minutes and 2 hours 58 minutes to produce.[10]

Similarly, the factory production of men's shirts engaged 230 workers performing 39 distinct operations using cutting presses, stamping machines, sewing machines, awls and press irons, shears, pleating machines, brushes, knives, and buttonhole cutters as well as needles and thread, whereas in the artisan shop a single worker performed 25 operations, all by hand, with shears, patterns, needle, thimble, and a press iron.[11]

Our empirical analysis of the census data is guided by a theoretical framework that captures the salient features of production in artisan shops and factories.[12] Both modes use raw capital and a mix of skilled and unskilled labour to produce output but the manner in which they do so

[9] U.S. Department of Labor, 'Hand and machine labor,' volume 1, pp. 113 and 121.

[10] U.S. Department of Labor, 'Hand and machine labor,' volume 2, pp. 524–47.

[11] U.S. Department of Labor, 'Hand and machine labor,' volume 2, pp. 1094–7. On the diffusion of powered machinery in manufacturing, see Fenichel, 'Growth and diffusion'; Atack, Bateman, and Weiss, 'Regional diffusion'.

[12] See Atack, Bateman, and Margo, 'Skill intensity'; and Goldin and Katz, 'Origins' for detailed discussions of this framework.

differs. In artisan shops, skilled labour produces operating capital in the form of semi-finished manufactures from any given amount of raw capital. These semi-manufactures are subsequently assembled and finished by a less-skilled assistant or two. In the factory, on the other hand, a small number of skilled workers produce, install, and maintain highly specialized machines that complement the work of a much larger group of unskilled labourers who operate the machines, possibly with the aid of an inanimate power source. The pattern of wages between artisan shops and factories is consistent with this.[13]

Under these circumstances, we can show that, for any amount of operating capital produced, the factory uses less skilled labour per unit of raw capital than does the artisan shop. In this sense, the factory substitutes (raw) capital for skilled labour. This tends to make capital per worker (that is skilled and unskilled weighted equally without regard to gender or age) and especially per 'effective' worker—that is, adjusted for skill composition—higher in the factory than in the artisan shop, although this is by no means assured. Capital per unit of output may also be higher provided that labour productivity in the factory is not too much higher than in the artisan shop.[14]

Table 2 reports the coefficients on establishment type from cross-sectional regressions for 1880. We experimented with a variety of ways of categorizing establishment type but, for simplicity, settled on four dummy variables created by interacting a 'factory' dummy (16 or more workers) with a 'power' dummy (use of an inanimate power source).[15] Dummy variables for industry and location are also included.[16]

[13] See U.S. Department of Labor, 'Hand and machine labor,' especially volume 2 for evidence in support of this. For example, in the production of cheap shoes (Unit 69), the male artisan shoemakers were paid 30 cents an hour, while the females were paid 20 cents an hour. In machine production, the men who were paid hourly were paid between 12.5 cents and 30 cents an hour, while the women were paid 12.5 cents an hour. Several jobs were paid by the piece while others, such as the job of engineer, were paid by the day or the week. The engineer was paid $21/week. See U.S. Department of Labor, 'Hand and machine labor,' volume 2, pp. 524–33; and Atack, Bateman, and Margo, 'Skill intensity'.

[14] The capital substitution effect makes the share of skilled labour lower in factories. Whether capital per worker (the sum of skilled and unskilled labour) is higher or lower in factories depends on how large the capital substitution effect is versus the increase in the total number of workers through division of labour. However, the increase in the total number of workers overstates the increase in the effective labour input because the share of skilled workers is lower in factories. For evidence on the productivity effects of the factory system see Atack, 'Economies of scale' and Sokoloff, 'Transition'.

[15] Although the 15-worker cut-off for the 'artisan shop' is arbitrary, productivity effects do appear to be discontinuous at this size; see Sokoloff, 'Transition'. The substantive conclusions, however, are not affected if a finer classification of size is used (for example, 6–15 workers, 16–50, 50–100, and so on).

[16] The industry dummies are measured at Standard Industrial Classification (SIC) 3-digit level—the finest detail available in the sample. 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 Executive Office of the President, Office of Management and Budget, *Standard Industrial Classification Manual.* Despite the absence of internal tariff barriers, the United States in 1880 was far from a 'common market'. If firms were choosing factor ratios optimally, then geographic variations in wages relative to rental rates of capital should have affected capital intensity. Geography may also have affected the size distribution of establishments because the division of labour was limited by the extent of the market. To control for the effects of location, we include dummy variables for urban status (= 1 if the establishment was located in a town or city of population 2,500 or more) and state.

Table 2. *Coefficients of size dummies, regressions of log (capital/labour), log (capital/effective labour), and log (capital/value added) ratios: 1880 sample*

	Capital–labour	*Capital–labour*	*Capital–effective labour*	*Capital–effective labour*	*Capital–value added*	*Capital–value added*
Working Capital Imputation?	No	Yes	No	Yes	No	Yes
Factory = 0 and Power = 1	0.699	0.498	0.701	0.500	0.562	0.359
	(0.044)	(0.036)	(0.044)	(0.035)	(0.046)	(0.031)
Factory = 1 and Power = 0	0.175	0.147	0.254	0.226	0.163	0.135
	(0.060)	(0.047)	(0.059)	(0.044)	(0.055)	(0.034)
Factory = 1 and Power = 1	0.846	0.718	0.898	0.770	0.500	0.373
	(0.051)	(0.039)	(0.050)	(0.038)	(0.047)	(0.030)
Adjusted R^2	0.358	0.443	0.361	0.452	0.300	0.388

Source: see tab. 1. Standard errors are in parentheses. The sample size is 7,178 establishments. All regressions include dummy variables for urban status, state, and 3-digit SIC code. Unit of observation is the establishment. Firm classification is based on reported count of workers adjusted for entrepreneurial labour input. Factory = 1 if workers > 15. Power = 1 if steam or water-driven machinery were used. The sample is re-weighted; see tab. 1. Labour = 1 + adult males + adult females + children. Effective labour = 1 + adult males + 0.5*adult females + 0.33*children; see text

The dummy variables imply that non-powered factories used between 16 and 29 per cent more capital per worker (depending upon the adjustment made) than smaller, non-powered establishments, while powered factories were more than twice as capital intensive.[17] Smaller powered establishments, many of them flour and lumber mills, also were more capital intensive than the non-powered factories but less so than the powered factories, suggesting that use of inanimate power not only added to a firm's capital investment but also changed the way that goods were produced.

None of the samples directly report the number of workers by skill level. Instead, we have used information on gender and age as a proxy for their skill level. Specifically, we define the effective amount of labour to be $L^* = 1 + \text{Men} + \lambda_1\text{Women} + \lambda_2\text{Children}$, where λ_1 and λ_2 are both less than one.[18] The logic is that, on average, woman and (especially) children were less skilled than men.[19] With this definition of effective labour the factory coefficients remain positive and, as required by our theoretical framework, are larger in magnitude than the coefficients in columns 1 and 2. Non-

[17] For non-powered factories, the increase in capital intensity ranges from $e^{0.147} = 1.158$ or 16% higher to $e^{0.254} = 1.289$, that is to say 29 per cent higher, whereas for powered factories, the range is 105 per cent ($= e^{0.718}$) to 145 per cent ($= e^{0.898}$) higher.

[18] 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 gains'. Plausible variation in the values of λ_1 and λ_2 do not affect our substantive findings.

[19] See Goldin and Sokoloff, 'Women, children, and industrialization'. It is likely that our proxy for effective labour 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 factories. Evidence that workers in factories were less skilled on average, even controlling for gender composition, is presented in Atack, Bateman, and Margo, 'Skill intensity'.

powered factories used more capital per unit of output than smaller non-powered establishments, but powered factories used about the same capital per unit of output as smaller powered establishments.[20]

The regression coefficients imply that changes in the distribution of employment and output across establishment size categories in principle have a big effect upon capital deepening. If all production in 1880 were shifted between smaller, non-powered establishments and large powered factories, the predicted change in the mean value of the log of the capital–labour ratio would be between 0.72 and 0.85 log points, depending on the adjustment for working capital, or 101–134 percentage points—that is, by more than double.[21]

However, the actual impact of the transition to the factory over the period 1850–80 was more modest than this hypothetical example suggests. Table 3 shows the distribution of establishments, employment, and value-added by size and use of power in 1850 and 1880. Although powered and non-powered factories made up only 9.8 per cent of establishments in 1850, they already accounted for 59 per cent of employment and 57 per cent of value added. By 1880 the employment and value-added shares of factories had increased to 74 and 75 per cent respectively. Detailed calculations (not shown) demonstrate that the shift toward powered factories from 1850 to 1880 occurred in a wide variety of industries; and that in virtually all industries, the effect of the factory on capital use was positive.[22]

According to Table 1, the average real capital–labour ratio increased from 75 to 94 per cent from 1850 to 1880, depending on the adjustments for the entrepreneurial labour input and working capital. If, for example, we simulate the 1880 index value using the regression coefficients from columns 1 and 2 from table 2 and the 1850 size distribution by workers in table 3, the simulated value would be 176.0 compared with an actual value of 194 (working capital imputed), or 165.2 compared with an actual value of 184.5 (no imputation for working capital).[23] Thus shifts in the distribu-

[20] Because powered factories used much more capital per worker than smaller non-powered establishments but not more capital per unit of output, our framework implies that labour productivity must have been higher in powered factories. The 1880 sample includes information sufficient to compute the average annual hours of operation and, consequently, average annual hours of labor; see Atack, Bateman, and Margo, 'Productivity in manufacturing'. If the capital–labour ratios are adjusted for annual hours, the size gradient is somewhat flatter (larger establishments operated more hours per year) but remain large and statistically significant.

[21] In the case of no imputation for working capital, if all production were shifted to powered factories, the increase in the mean log capital–labour ratio would be 0.320 log points (= 0.846*(1 − 0.494) + 0.175*(0 − 0.245) + 0.699*(0 − 0.093)) see tab. 3 below for the distribution of labour among different types of establishment. If all production were shifted to smaller non-powered factories, the reduction in the mean log capital–labour ratio would be −0.526 log points. Consequently, the range is 0.85 log points (= 0.32 + 0.53) or 134 per cent (= (exp(0.85) − 1) × 100 per cent).

[22] These calculations are available in an appendix table from R. A. Margo on request.

[23] In the case of no imputation for working capital, the simulated index value is 0.895 (= exp(−[0.846*(0.494 − 0.332) + 0.175*(0.245 − 0.260) + 0.699*(0.093 − 0.127])) times the actual value of 185.4, which equals 165.2. The other calculations are similar in construction. The simulations of the capital–output ratio use the 1850 and 1880 distributions of establishment type by value-added and the size coefficients from the capital-output regressions.

Table 3. *Distribution of establishment type, 1850 and 1880: Atack-Bateman samples*

	1850	*1880*	*1850*	*1880*	*1850*	*1880*
Distribution By	*Establishments*	*Establishments*	*Workers*	*Workers*	*Value-added*	*Value-added*
Factory = 0 and Power = 0	0.610	0.596	0.282	0.168	0.210	0.113
Factory = 0 and Power = 1	0.292	0.264	0.127	0.093	0.224	0.142
Factory = 1 and Power = 0	0.053	0.057	0.260	0.245	0.327	0.359
Factory = 1 and Power = 1	0.045	0.083	0.332	0.494	0.239	0.386

Source: see tab. 1. Figures are proportions (0.61 = 61 per cent of establishments, 0.596 = 59.6 per cent of workers, and so on).

tion of establishments account for 19 (= 18/94) to 23 (= 19.3/84.5) per cent of the increase in real capital per worker from 1850 to 1880.[24]

If changes in the distribution of establishment types explain a relatively modest portion of capital deepening from 1850 to 1880, then deepening must have occurred primarily because of the increased use of capital *within* establishment types.[25] Precisely why this happened is a matter for further research, but a leading candidate, as suggested by the price index in Table 1, is a secular decline in the price of capital goods. The decline was not only absolute, but also relative to output and to labour.[26] Manufacturers, regardless of size, responded to this by substituting capital for labour and using more capital per unit of output.[27] The increased use of capital may also have been facilitated by the growing extension and sophistication of capital markets and financial intermediaries.[28]

[24] These calculations use the indices with the entrepreneurial labour input imputed. The percentage explained is slightly higher if the indices without this adjustment are used. An analogous calculation shows that shifts in the distribution explain somewhat less of the increase in the capital–output ratio from 1850 to 1880—7.8 per cent if working capital is imputed and 9.3 per cent if it is not.

[25] We have also estimated regressions of capital intensity and the capital output ratio pooling the 1850–80 samples, and including time dummies. The time dummies are smaller in magnitude when establishment type is controlled for but remain relatively large and statistically significant, consistent with the argument in the text that capital deepening was a widespread process.

[26] It is likely that the post-1850 decline in capital goods prices was the continuation of a longer-term trend; see Sokoloff, 'Industrialization and growth', pp. 32–3, 244. The post-1850 decline in the price of capital goods relative to output is evident in tab. 1. For evidence that real wages in manufacturing were increasing over the nineteenth century, see Margo, 'Labor force'. The relative decline in capital goods prices could have been offset by a relative increase in interest rates, but there is no evidence of such an increase over the period. On interest rates, see Homer and Sylla, *History of interest rates*.

[27] For evidence that manufacturers did respond in this manner, see Margo and Hutchinson, 'Impact of the Civil War'.

[28] See Davis, 'New England textile mills' and 'Investment market'; Sokoloff, 'Industrialization and growth', ch. 7; Lamoreaux, *Insider lending*; Bodenhorn, *State banking*; and Rousseau and Sylla, 'Emerging markets'.

This note has examined the role played by the transition from the artisan shop to the factory in accounting for the increased use of capital in nineteenth-century US manufacturing. Manuscript census data reveal that large establishments, particularly those using powered machinery, were far more capital intensive than small, non-powered establishments—artisan shops. But the shift of workers and production to larger establishments does not explain much of the increased use of capital in manufacturing from 1850 to 1880. Capital deepening during this period appears to have been a far more widespread process than a simple consequence of the switch to the factory system.

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