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Steam Power and Labor Productivity Growth in Nineteenth Century American Manufacturing

By

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I. Introduction

In the early nineteenth century United States most manufacturing took place in artisan shops. These typically were very small, usually consisting of a single worker and perhaps an assistant or two. Artisans fashioned the product from start to finish typically in response to a custom order, generally using only hand power, a few tools and little else. Consequently, capital requirements in artisan shops were very modest.

Larger establishments that still relied on hand tools and no inanimate sources of power were called "manufactories". Compared with the artisan shop, labor in the manufactory was less skilled, but through judicious use of division of labor productivity in the manufactory might be increased over that in the artisan shop. However, the productivity gains that could be achieved through the pure division of labor were exhausted at a relatively low level of scale and were confined to a relatively narrow range of industries (Sokoloff, 1984, 1986).

Another way to raise labor productivity was through the use of powered machinery. These machines replaced the hand tools previously used by the artisan and embodied instead the skills of the machine maker as a substitute for the skills of the artisan. Although water-driven machinery had long been used in manufacturing (for example, grist mills), it was the diffusion of steam power that caught the attention of contemporaries, particularly the diffusion of light, simple, and cheap steam engines along the lines developed by Oliver Evans. These engines were a plausible example of a "general purpose technology" (GPT). Generically such technologies are those that can be adapted for use in a wide range of industries and whose productivity effects are believed to be ubiquitous and, indeed, for which there may be external economies.[1] Today computers are perhaps the best known – and certainly the most studied – example of a GPT but as steam and later, electricity, demonstrate, there are many historical antecedents (David 1990; Crafts 2004; van Ark and Smits 2004).

Manufacturing establishments using water power obviously had to locate close to a feasible site. Such sites were in limited supply and, from an engineering standpoint, offered little or no potential for expansion. By contrast, establishments using steam power could be much more "footloose." While a steam-driven plant could not locate just anywhere but range of locations was far wider than for water power.

Economic historians have written extensively about the factors contributing to the diffusion of steam but less attention has been paid to measuring its productivity effects (Temin 1966; Atack 1979; Hunter, 1979; Atack, Bateman, and Weiss 1980). In this paper we report on a preliminary examination of the impact of steam on labor productivity in manufacturing between 1850 and 1880. Our analysis relies on nationally representative samples of establishment data drawn from the manuscript censuses of manufacturing (Atack and Bateman 1999).

There are four principal findings reported in this paper. First, the likelihood of adopting steam was increasing in establishment size, as measured by employment or output, controlling for location, industry, and other factors. Second, establishments using powered machinery had higher labor productivity than non-powered establishments, and the magnitude of the productivity effect was increasing in establishment size, again controlling for location, industry, and other factors. However, labor in steam powered

[1] For example, Rosenberg and Trajtenberg (2004) suggest that diffusion of steam may have promoted urbanization in the United States, which is assumed to have promoted external economies. See, however, Kim (2004) who argues that any such effect of the diffusion of steam was small in magnitude.

establishments was more productive than in water-powered establishments, regardless of establishment size. Third, some of the productivity advantages enjoyed by establishments using powered machinery can be attributed to higher capital intensity. However, even after controlling for capital intensity steam powered "factories" – establishments with 16 or more employees – had significantly higher total factor productivity than smaller establishments using steam. Fourth, the diffusion of steam was an economically significant factor behind the growth of labor productivity in manufacturing, accounting for 45 percent of growth between 1850 and 1880.

II. The Diffusion of Steam Power in American Manufacturing, 1850-1880

The empirical analysis in this paper draws upon recently available samples from the manuscript censuses of manufacturing for the census years 1850 through 1880. With one exception (see below), these samples are self-weighting and nationally representative. As it happens, these census years coincide with the substantial bulk of the diffusion of steam power in U.S. manufacturing during the nineteenth century (Fenichel 1966; Temin 1966; Atack, Bateman, and Weiss 1980).[2]

The censuses reported the value of "real and personal" capital invested along with information about outputs and inputs. The specifics of what was reported varied from census to census. All 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; in 1870 and 1880, the number of

[2] While it would be desirable to extend the analysis to the end of the nineteenth century, no establishment level data survive for 1890 or 1900.

adult males, adult females, and children were given. Most importantly for this paper, information was also reported on whether steam or water power was used in production. For 1850 and 1860, only the presence of such usage was indicated, whereas in 1870 and 1880, total horsepower was also reported (Atack and Bateman 1999).[3]

Although the manuscript census schedules are a fundamental data source, there is no question that some of the information collected was problematic. For example, census enumerators were given no guidance, as far as we can tell, as to whether "value" of capital meant book value or market value.[4] The leading authority on the subject, Robert Gallman (1986, p. 174; 1987, pp. 220-222), has argued, however, that book value was uncommon in the nineteenth century and that the capital figures refer typically to market value.

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. However, with one exception—1880—we can presume that such failures were random and, hence, do not bias the results. In

[3] Occasionally, information was reported on horsepower in steam or water powered establishments prior to 1880 but this information is too scattered to be of much use. In addition, some establishments reported that they used a "combination" of power sources but, unfortunately, the records do not precisely distinguish the type of sources used. For the purposes of this paper we assume that any such establishment employed hand (or animal) power, exclusively, not inanimately powered machinery. The number of such establishments, however, was small and, more importantly, we do not believe that our assumption biases the trend over time in power usage or our other analyses in significant ways.

[4] 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' (U.S. Census, 1860, 25). Census officials at the time routinely questioned the quality of the information on capital. Francis A. Walker, onetime Superintendent of the Census, for example, opined 'it is a pity ... that statistical information ... of high authority and accuracy should be discredited by association with statements so flagrantly false' (U.S. Census, 1872: 381-2). While these concerns about data quality are important, they should not be over-emphasized; if the data on capital were mostly noise, we would not find systematic and plausible relationships between capital-labor ratios and various establishment characteristics (see the text).

that year, certain industries were assigned to special agents who were more knowledgeable about the industry than the average census enumerator. 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 (Delle Donne 1973). Comparing the sample industry proportions with those of the population reported in the 1880 census volume, it is clear that establishments in the expert industries are under-represented in the sample. A few, however, appear in the sample—collected perhaps by overly-eager enumerators—and these have used these to re-weight the 1880 sample.[5]

Table 1 shows basic statistics on the incidence of steam or water powered machinery in manufacturing as derived from the establishment-level data used in this paper and described in the next section. Panel A reports the incidence statistics using establishments as the unit of observation. Measured at the establishment level steam power was barely in use in 1850 – slightly less than 7 percent of establishments reported using steam power. Water power was much more frequent employed – slightly more than a quarter of the establishments in the 1850 sample reported having water power.

Over time steam power gradually began to displace water power as fuel became cheaper and as efficiency and capacity of steam engines rose (Atack 1979). On the eve of the Civil War, about 15 percent of establishments reported using steam, while the fraction using water power fell slightly over the 1850s. The proportion using steam jumped another five percentage points between 1860 and 1870 but, according to the data in Panel A, increased only slightly in the 1870s. Use of water power slid during the Civil

[5]Details of the re-weighting are available from the authors on request. The 1880 figures in this paper correct the weighting used in Atack, Bateman, and Weiss (1980).

War decade but, as with steam power, further change appears to have been muted in the 1870s. As of 1880, the last year for which data are analyzed in this paper, steam power was used in about 22 percent of establishments, while water power use had declined to half the frequency in 1850. However, total use of powered machinery at the establishment level in 1880 (approximately 35 percent) – was barely higher than in 1850 (33 percent).

The statistics in Panel A suggest that powered machinery, in general, and steam in particular, diffused at a relatively slow pace in mid- nineteenth century American manufacturing. The slow pace of diffusion has caused some scholars to question the characterization of steam as a GPT (van Ark and Smits 2004). However, the pace of diffusion is cast in a rather different light in Panel B. Here, rather than treating each establishment as the unit of observation we weight establishments by total reported employment.

The picture that emerges from weighting by employment is one of earlier and more rapid diffusion of powered machinery; and, with respect to steam, steadier pace of diffusion across decades. In 1850 approximately 17 percent of manufacturing workers were employed in establishments using steam power compared with 27 percent of workers in establishments using water power. The proportion of workers in establishments using steam power increased steadily after 1850 while the proportion of workers using water power declined. Although the 1860s were still the decade of most rapid change, change was also quite rapid in the 1870s compared with the 1850s, unlike the story told by Panel A when establishments are equally weighted. By 1880, over half of all manufacturing workers were employed in establishments using steam power whereas the share employed in establishments using water power had declined to 9 percent. The increase in steam power usage, weighted by employment, was substantial enough such that, by 1880, about 62 percent of all manufacturing workers labored in establishments with powered machinery, an increase of approximately twenty percentage points compared with 1850.

Weighting by employment matters because size was correlated with the use of powered machinery. Panels A and B of Table 2 reports coefficients of establishment size dummies from linear probability regressions of the use of powered machinery (steam or water power = 1), and separately by use of steam and water. The regressions also include dummy variables for location (the state in which the establishment was located and an urban dummy) and for industry, measured at the three-digit SIC code level. Panel A reports the results for 1850 and panel B for 1880.

In both years the probability of using water power was essentially unrelated to establishment size. However as columns 1 and 2 demonstrate, this was not because of a general aversion to powered machinery on the part of larger establishments, but a relative preference for steam over water power. Further, the size gradient with respect to steam power became steeper between 1850 and 1880.

Panel C of Table 2 shows the percentage of total manufacturing employment in "factories" – establishments with 16 or more workers – and the shares of factory employment in establishments powered by steam or water. Between 1850 and 1880 the percentage of total manufacturing employment in factories rose from 57 to 74 percent The share of factory employment in steam-powered establishments rose sharply (from 23 percent in 1850 to 63 percent in 1880) whereas the share in water-powered establishments fell sharply. That is, the growth of employment in factories between 1850 and 1880 was concentrated disproportionately in establishments using steam power.

The Economics of the Diffusion of Steam Power

In this section we sketch a simple framework for understanding the economics of the diffusion of steam power in the context of the growth of the factory system. This framework combines elements of Goldin and Katz's (1998) model of manufacturing with Atack's (1979; see also Temin 1966) analysis of the relative costs and benefits of steam versus water power.

To fix ideas, we assume that, for any given good, there are two production processes available: the "artisan shop" and the "factory". Within each process production is divided into two stages. In the first stage, skilled labor is combined with "raw" capital to produce an intermediate input called "operating capital". Following Goldin and Katz, the production of operating capital K_O follows a Leontief function

$$K_O = \min (L_s/\alpha, K_r)$$

In stage two, operating capital is combined with unskilled labor to produce the finished good, q. Continuous substitution – for example, as in a Cobb-Douglas technology – is permitted in the second stage. In selecting the factor ratio in the second stage, firms are assumed to minimize costs. Let $\varphi = L_u/K_O$ be the optimal ratio of unskilled labor to operating capital. It is straightforward to show that S, the share of skilled labor in total labor ($L = L_s + L_u$), is given by the expression

$$S = \alpha K_O/(\alpha K_O + \varphi K_O) = \alpha/(\alpha + \varphi)$$

And $k = K_O/L$, capital intensity, is given by the expression

$$k = K_O/(\alpha K_O + \varphi K_O) = 1/(\alpha+\varphi)$$

In the typical artisan shop α is presumed to be large and φ is presumed to be small. When α is large, large amounts of skilled labor are needed to produce operating capital from raw capital. In such shops, a large proportion of the operating capital was fashioned by highly skilled craftsmen using hand tools, with the finishing touches applied by less skilled apprentices, implying a small value of φ. In the typical factory, on the other hand, α is presumed be small and φ is large – that is, more raw capital per skilled worker and more unskilled labor per unit of operating capital. These differences work towards making the factory less skill intensive than the artisan shop (see Atack, Bateman and Margo 2003 for evidence in favor of this proposition). If, in addition, in the shift from shop to factory, the decrease in α is large relative to the increase in φ, the factory will be more capital intensive as well (see Atack, Bateman, and Margo, 2005).

Powered machinery can be introduced in this model in terms of the values of α and φ. Such machinery was more complex than hand tools and required costly installation and periodic maintenance. Thus, firms utilizing powered machinery, ceteris paribus, would have higher values of α – that is, relatively more skilled labor per unit of raw capital. In addition, powered machinery typically required modifications to the physical structure of the plant that would result in more capital per unit of unskilled labor; that is, a lower value of φ. The implications are that, conditional on the choice of "scale" (shop versus factory), firms using powered machinery would be more skill and more capital intensive (see Atack, Bateman, and Margo, 2003, 2005).

Atack (1979; see also Temin 1966) provides a comprehensive analysis of the economics of the choice of steam versus waterpower. In Atack's analysis, the crucial issue for the firm is the amount of horsepower, H, required by the machines, and to be generated either by steam or by water. In the context of the model presented here, we can rewrite the second stage of production as $q = F(L_U, H(S + W))$ where $H' > 0$, and $H'' < 0$ (diminishing returns). In this setup, firms choose the method of power purely on the basis of user costs. If the user cost of steam power is less than that of water power, the firm opts for steam; whereas, if the cost is lower for water, the firm opts for water. Based on the available information, Atack (1979) argues that, on an average cost (per horsepower) basis, it is likely that the user cost of steam fell below that of water sometime in the 1850s on average, although in certain locations (for example New England) water power remained the cheaper alternative well into the later half of the nineteenth century. Atack shows that, at the national level, the diffusion of steam power is consistent with a model in which the choice of steam versus water was driven by relative costs. However, his analysis does not directly speak to why steam power was preferred to water in large establishments.

There are several reasons why large establishments may have preferred steam over water (Hunter 1979). Steam was "scalable" from an engineering standpoint whereas water was not. A water power site had a maximum horsepower; marginal user costs, in other words, could never be constant beyond a certain level of output. At some point the marginal costs of steam would also increase but, over a larger range of output, these costs were (approximately) constant than was true for water. Therefore, even if costs and other factors favored water for smaller establishments, larger establishments would prefer steam. Second, larger steam engines were more efficient than smaller engines. As long as factor proportions were (approximately) fixed, an establishment adopting a large steam engine would also employ more labor.

Third, despite substantial improvements in technology, water power was inherently less reliable than steam power. In the early years of the American industrial revolution, many establishments were "part-year" – they did not operate for the entire year, often shutting down for months at time. Over time, however, a growing share of establishments operated on a full-year basis (Atack, Bateman, and Margo 2002). Although such establishments did shut down production regularly – for example, at night and on Sundays – unexpected shutdowns due to power interruptions could be very costly. Steam power, of course, was far from fully reliable, requiring constant care from specialized workers – but it was more reliable than water power. Because larger establishments were more likely to operate on a full-year basis, it is plausible that such establishments would have a stronger preference for a reliable power supply, and hence prefer steam.

Fourth, over time an increasing share of establishments located in urban areas, and the probability of an urban location was increasing in establishment size. As Hunter (1979) points out repeatedly, establishments considering the adoption of powered machinery in many urban areas had to choose steam because water was not a feasible alternative.

Because our model implies that establishments using powered machinery would likely be more capital intensive, it is also likely that such establishments would have higher labor productivity. If, in addition, the use of powered machinery facilitated a greater division of labor, total factor productivity might be higher as well. Several of the explanations just offered also suggest that the impact of steam on labor productivity may have exceeded that of water power, particularly in large establishments. Although the evidence presented in the next section is not as precise or detailed as one might like, it is consistent with the hypothesis that labor was more productive using powered machinery. At the margin, the productivity effect was approximately equal in smaller establishments whether the power was generated by steam or water, but in larger establishments – factories -- steam had an advantage over water.

III. The Productivity Effects of Steam: Evidence for 1870 and 1880

In this section we present regressions estimates of the effects of power use on labor productivity. We use the 1870 and 1880 samples for this purpose, for three reasons. First, both censuses reported more detailed information on the demographic characteristics of workers, enabling a better adjustment for the effective labor input (see below). Second, both censuses reported months of full-time equivalent operation. Information on months of operation is useful because many establishments in nineteenth century manufacturing operated for only part of the year (see Atack, Bateman, and Margo 2003). Third, and most important, both censuses reported total horsepower generated by powered machinery (steam or water), as opposed to the mere usage as in 1850 and 1860, enabling a more precise characterization of the productivity effects (see below).

In the estimations that follow 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. In addition, 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 those outside this range had data that were suspect.[6] We also exclude establishments in three industries, one of which was production of steam engines (SIC 351).[7]

The dependent variable in the regressions is the log of (nominal) value added per effective worker, where "effective" means in adult male-equivalent terms. Following Sokoloff (1984, 1986) we also add one to the count of effective workers, in order to correct for the possible under-reporting of the entrepreneurial labor input. All regressions include dummy variables for industry measured at the three-digit (SIC) level; the state in

[6] The accounting procedure is discussed in the appendix of Atack, Bateman, and Margo (2003). We exclude observations with very high or low rates of return on the grounds that capital in such establishments is likely to have been (severely) mis-measured.
[7] The reason for excluding SIC 351 is to ensure that we are examining the impact of steam usage, rather production of steam engines. The other excluded industries are SIC 999 (miscellaneous) and SIC 492 (gas works, not a manufacturing industry per se).

which the establishment was located; an urban dummy indicating if the establishment was located in a town or city of population 2,500 or more; the size of establishment; months of full-time equivalent operation; and a dummy variable for 1880.[8]

Column of Panel A of Table 3 reports coefficients of dummy variables for steam and water power use. Compared with establishments using hand power (the left-out category), steam-powered establishments had 38 percent (= [exp(0.32) – 1] x 100 percent) higher labor productivity. Use of water was also associated with a gain in productivity, but smaller in magnitude (23 percent = [exp(0.211) – 1] x 100 percent) than with steam; the difference between the two estimates is statistically significant at the 5 percent level. Column 2 adds interactions between the power dummies and a dummy variable for factory status (16 or more employees). In smaller establishments, use of steam added considerably to labor productivity raising it by nearly 27 percent, whereas use of water was associated with five percent higher labor productivity compared to non-mechanized establishment. Use of powered machinery generated additional gains in labor productivity in factories relative to smaller establishments; in this regard, however, the gains in productivity from moving from a small establishment using powered machinery to a powered factory were larger for water than for steam. Even so, labor productivity in water-powered factories fell below that of steam-powered factories by about 5 percent [exp(0.287-0.341) x 100 percent].

The productivity advantages of steam evident in Panels A and B may have been due to higher efficiency per se or to higher amounts of capital per worker. In columns 3

[8] The dummies for industry and location are included to control for variation in output price (recall that the value added is the measure of output) along with idiosyncratic factors (for example, access to transportation or variations in the skill level of workers) that may have affected productivity. We could deflate nominal value added by the price index described in section x, but as this index is sector-wide (that is, not industry specific) there would be no advantage to doing so.

and 4 we report coefficients of the power dummies from regressions in which the dependent variable is the log of capital per effective worker. Use of powered machinery was associated with higher amounts of capital per effective worker; consequently, when we control for capital intensity, the coefficients of the steam and water power dummies are smaller in magnitude (column 5) than when we do not (column 1). However, because use of water was associated with a somewhat larger increase in capital intensity than use of steam, steam's advantage in productivity compared with that of water is increased slightly when capital intensity is controlled for (compare column 5 with column 1). In this regard, controlling for capital intensity has little effect on the relative (to water) productivity advantage of steam in smaller establishments, but enhances it in the case of factories (compare column 6 with column 2).

The regressions reported in Panel A include all establishments regardless of the type of power employed. In Panel we report labor productivity regressions conditional on the use of steam (columns 1-4) or water (5-8). In these regressions, the impact of power usage is measured by a continuous variable, the log of horsepower per effective labor, so the coefficients are elasticities. In the regressions without the factory interaction terms, the elasticity of output with respect to horsepower was higher for steam (e = 0.152) than for water (e = 0.111) if capital intensity is not controlled for; when capital intensity is controlled for, there are no (marginal) efficiency gains in water-powered establishments from using more horsepower per worker (column 5) whereas such gains remain in steam powered establishments (column 2). In the regressions with the factory interactions, the elasticity of output with respect to horsepower per effective worker was greater for water than for steam in small establishments, whether or not capital intensity is controlled for. However, in larger steam-powered establishments, there were labor productivity and pure efficiency advantages at the margin from increasing the amount of horsepower per worker, but this was not true in the case of water (compare columns 7 and 8 with columns 3 and 4).

In sum, the regressions suggest that labor productivity was enhanced by the diffusion of steam power, partly through the use of more capital per worker (compared with non-mechanized establishments) and partly because there appear to have been pure gains in efficiency, relative to non-mechanized establishments and to water-powered establishments. Conditional on the use of steam, productivity and efficiency were increasing in firm size.

We have shown that the share of manufacturing labor employed in steam-powered establishments increased sharply between 1850 and 1880 and that labor productivity was higher in steam powered establishments than in non-mechanized establishments or establishments using water power. These two findings suggest that the diffusion of steam power might be an important factor accounting for the growth of labor productivity in manufacturing over the same period.

We compute how much of the change in labor productivity in manufacturing from 1850 to 1880 can be attributed to the diffusion of steam power. By “attribute” we mean the following: if the distribution of employment with respect to the use of steam in 1880 been unchanged from the distribution in 1850, how much lower on average would labor productivity in 1880 have been?

The first step is to compute an index of labor productivity from the sample evidence.   We calculate productivity for each establishment in the sample, and then weight by establishment employment to produce the overall average. Because the data are reported in nominal dollars, it is necessary to deflate by an index of manufacturing output prices (see Atack, Bateman, and Margo 2003 for a discussion of the price index). The nominal productivity index, price deflator, and real index are shown in columns 1-3 of Table 4 in 1850. In real terms, output per worker in manufacturing rose by about 18 percent between 1850 and 1880.

Next, we compute what the real productivity index would be if the distribution of employment between steam, water, and non-mechanized establishments were held constant at the 1850 distribution. We accomplish this by first calculating the percentage change in the mean value of labor productivity by holding everything else constant but changing the mean values of the distribution of employment across establishments by power source (from Table 1), using the regression coefficients in column 1 of Table 3. This calculation yields the index of real labor productivity shown in column 4 of Table 4. Had steam and water not diffused after 1850 according to the actual pattern observed, productivity would have continued to increase but at a slower pace. By 1880 labor productivity would have been 9.9 percent higher than in 1850, representing an increase of about 55 percent of the actual increase (18 percent). Consequently the diffusion of steam accounts for 45 percent of the real growth in labor productivity in American manufacturing from 1850 to 1880.

These calculations suggest that the diffusion of steam contributed significantly to the growth of labor productivity in nineteenth century American manufacturing, as manufacturers knew at the time and as economic historians have long contended. But they also demonstrate that it would be a mistake to conclude that labor productivity growth was entirely dependent on the spread of steam power. As Sokoloff's (1984) analysis of labor productivity in early manufacturing shows, it was possible to generate efficiency gains through division of labor alone; mechanical power was not necessary per se. Moreover, as our calculations clearly demonstrate, a significant portion of the labor productivity growth that occurred in manufacturing between 1850 and 1880 must have been due to factors other than the diffusion of steam – factors such as a general increase in capital intensity, increases in establishment size, and presumably many others. Still, it is likely that among the specific technological changes occurring in manufacturing after 1850, none was probably more important overall, or more pervasive in the sense of affecting large number of workers, than the shift to steam power.

V. Conclusion

This paper has used establishment level data to estimate the effects of steam on productivity in United States manufacturing over the period 1850-80. Controlling for location, industry, firm size, and other factors, we have shown that steam powered establishments had higher labor productivity than establishments using hand or water power. Moreover, use of steam appears to have generated efficiency gains, and these gains were greater in large – factories -- than in small establishments, consistent with the pattern of diffusion with respect to establishment size. Overall, diffusion of steam alone can explain close to a fifth of labor productivity growth in manufacturing over the period 1850-80.

It is important to understand, however, the limitations of the findings presented here. Recent research by economic historians has, as the introduction pointed out, suggested that steam is a good historical example of a "general purpose technology". However, when economic historians have seriously attempted to trace the effects of GPT's on aggregate productivity growth, the results have generally been disappointing. This has certainly been the case with steam, as demonstrated by Craft's (2004) careful analysis of the English case (see also van Ark and Smits 2004). The results presented here do not suggest that the diffusion of steam somehow changed the course of aggregate productivity growth in the nineteenth century American economy. But the results do show that the diffusion of steam raised labor productivity in manufacturing; had the diffusion not occurred, real wages and the standard of living would have been lower and, quite probably, the pace of industrialization would have been slower.

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Table 1: Steam Power in American Manufacturing, 1850 – 1880

Panel A: Percent Using Steam or Water Power, Establishment Weighted

	1850	1860	1870	1880
Percent Using Steam	6.8 %	14.6 %	20.1 %	21.8 %
Percent Using Water	26.4	24.1	14.8	13.5
Percent Using Steam or Water	33.2	38.7	34.9	35.3
Number of Establishments	4,855	4,940	3,779	7,062

Panel B: Percent Using Steam or Water Power, Employment Weighted

	1850	1860	1870	1880
Percent Steam	16.5 %	23.3 %	39.2 %	52.5 %
Percent Water	26.5	25.7	16.9	8.8
Percent Using Steam or Water	43.0	49.0	56.1	61.3

Table 2: Steam Power and Establishment Size

Panel A: Coefficients of Establishment Size Dummies: Linear Probability Regressions of Use of Powered Machinery, 1850

Establishment Size	Steam or Water = 1	Steam = 1	Water = 1
6<=workers<=15	0.106 (0.012)	0.148 (0.014)	-0.017 (0.012)
16<=workers<=100	0.155 (0.017)	0.266 (0.014)	-0.042 (0.018)
100+ workers	0.224 (0.041)	0.337 (0.017)	-0.037 (0.043)
Adjusted R^2	0.693	0.387	0.608

Panel B: Coefficients of Establishment Size Dummies: Linear Probability Regressions of Use of Powered Machinery, 1880

Establishment Size	Steam or Water = 1	Steam = 1	Water = 1
6<=workers<=15	0.114 (0.009)	0.153 (0.017)	-0.035 (0.009)
16<=workers<=100	0.321 (0.012)	0.395 (0.016)	-0.027 (0.011)
100+ workers	0.584 (0.027)	0.648 (0.017)	-0.007 (0.025)

Adjusted R^2	0.657	0.496	0.433

Panel C: Employment in Steam-Powered Factories

	1850	1860	1870	1880
Percent of Employment in Factories	57.4%	63.7%	70.0%	73.6%
Share of Factory Employment Using Steam	0.228	0.270	0.466	0.629
Share of Factory Employment Using Water	0.295	0.286	0.190	0.074

Notes to Panels A, B, C: figures are computed from samples of establishments from the 1850-1880 manuscript censuses of manufactures; see Atack and Bateman (1999). To be included in the samples, establishments had to report positive values of: value added (value of outputs – value of raw materials); raw materials; employment (= sum of male and female workers in 1850 and 1860 or sum of adult male, adult female, and children in 1870 and 1880); and capital. Establishments in SIC industries 351, 492, and 999 were excluded, as were a small number of observations judged to be outliers. 1880 sample is re-weighted to take account of under-reporting of “special agent” industries; see text.

Factory =1 if employment>=16.

Table 3: The Effects of Powered Machinery on Labor Productivity: Pooled 1870-80 Sample

A. Coefficients of Power Dummies

Dependent Variable	Log Value Added Per Effective Labor	Log Value Added Per Effective Labor	Log Capital Per Effective Labor	Log Capital Per Effective Labor	Log Value Added Per Effective Labor	Log Value Added Per Effective Labor
Steam = 1	0.320 (0.018)	0.241 (0.032)	0.462 (0.025)	0.572 (0.046)	0.183 (0.017)	0.070 (0.031)
Water = 1	0.211 (0.028)	0.050 (0.044)	0.519 (0.038)	0.609 (0.061)	0.057 (0.025)	-0.132 (0.041)
Steam x Factory = 1		0.101 (0.037)		-0.144 (0.051)		0.143 (0.034)
Water x Factory = 1		0.237 (0.052)		-0.123 (0.072)		0.274 (0.048)
Log (Capital/Effective Labor) Included?	No	No	NA	NA	Yes	Yes
Adjusted R^2	0.375	0.376	0.410	0.411	0.479	0.481

Source: pooled 1870-80 sample of manufacturing establishments (N=10,551).

Regressions also include dummy variables for state, size (6-15, 16-100, 100+

employees), 3-digit SIC industry code, urban location, months of full-time equivalent operation, and year (1880 = 1). Effective Labor = 1 + men + 0.5*women + 0.33*children. Observations weighted by total reported employment + 1. Factory =1 if total reported employment>15. NA: not applicable.

B. Elasticities of Horsepower per Effective Worker on Value Added Per Effective Worker: Steam =1 or Water = 1

Dependent Variable = Log of Value Added Per Effective Worker	Steam	Steam	Steam	Steam	Water	Water	Water	Water
Log (Horsepower/Effective Labor)	0.152 (0.018)	0.090 (0.018)	0.119 (0.047)	0.054 (0.039)	0.111 (0.027)	0.006 (0.027)	0.197 (0.038)	0.103 (0.057)
Log (Horsepower/Effective Labor) x Factory = 1			0.038 (0.040)	0.041 (0.041)			-0.159 (0.052)	-0.181 (0.049)
Log (Capital/Worker) Included?	No	Yes	No	Yes	No	Yes	No	Yes
Adjusted R-square	0.447	0.502	0.447	0.502	0.481	0.553	0.484	0.537

See notes to Panel A. Regressions estimated on observations reporting use of steam (columns 1-4) or water (columns 5-8).

Table 4: Steam and Labor Productivity Growth in Manufacturing, 1850-1880

	Nominal	Price Deflator	Real	Real, with 1850 distribution of steam and water
1850	100.0	100.0	100.0	100.0
1860	122.2	103.6	118.0	115.6
1870	185.4	165.2	112.1	107.0
1880	128.8	109.2	118.0	109.9

Figures in column 1 are index numbers based on weighted sample means; weight is establishment's share of total employment. Price Deflator is from Atack, Bateman, and Margo (2003). Column 3: Nominal/Price Deflator. Column 4: see text.