The Division of Labor and Economies of Scale in Late Nineteenth Century American Manufacturing:

New Evidence

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Introduction

Over the nineteenth century the manufacturing sector in the United States grew substantially, such that on the eve of World War One, the US had become the leading industrial economy in the world (Bairoch 1982). Associated with American manufacturing ascendancy was a dramatic shift in the structure of production, from small "artisan shops" at the beginning of the period to much larger establishments at the end (Chandler 1977). The consensus view among economic historians is that this shift from small to large scale production reflected the capturing of economies of scale.. Fundamentally, these economies arose through the use of division of labor and the application of machinery driven by inanimate sources of power – initially, water power followed by steam and then, late in the century, electricity – in the production process.

Although the above describes what might be called the consensus view of America's first "industrial revolution"the view does not rest on widely agreed upon or unequivocal evidence of economies of scale. In particular, previous work has relied almost exclusively on establishment level data from the various nineteenth century enumerations of manufacturing, beginning with the 1820 and ending with the 1880 census (Atack 1976, 1977, 1985, 1986, 1987; Sokoloff 1984). There are, however, severe and arguably irresolvable problems in using the nineteenth century manufacturing census data to estimate economies of scale at least in the traditional (parametric) production function sense.[1] Much of the apparent evidence for the existence of economies of scale from the census data is highly sensitive to adjustments to the underlying data that have been proposed but which cannot be empirically justified (Margo 2014). Further, even if the parametric evidence were robust, there is, at best, limited information on the underlying sources

[1] Similar problems affect the use of twentieth century data; see Griliches and Ringstad (1971).

– data on machinery and power sources is extremely limited and, worse, there is no direct information whatsoever on the division of labor.

In this paper we provide a preliminary exploration of an extraordinarily detailed and rich data source for late nineteenth century manufacturing that has been little-used by economic historians. In the early 1890s the US Bureau of Labor Statistics commissioned an extensive survey of "hand" and "machine methods" of manufacturing that provides an extreme level of detail on each step in the production process, amounting to a "time and motion study" for paired establishments using these different methods . As we described further below, while not without problems, these data provide substantially better evidence on economies of scale than does the census and, in addition, permit us to document the division of labor directly and measure its effect on labor productivity. The previous use of these data by other economic historians has been very limited primarily because the quantity and complexity of the data far exceeded computational constraints until recently.

After discussing the shift towards large scale production in the nineteenth century and the previous work on economies of scale, we describe the BLS survey used in this paper in some detail because of their relative novelty and complexity. In brief, the BLS collected detailed data on the production of a set of (very) specific goods. For each good, data were collected from two "production units", one using hand methods and the other machine methods. Specifically, each step in the production process was quantified, giving us information on the specific capital goods used; the number of workers employed in the step, their age and gender and rate of pay; the total number of steps or tasks; and the total number of different workers employed. Most importantly, we know the length of time it took for each step to be completed and, thus, the total amount of time. Moreover, the labor inputs were scaled to yield a specific quantity of the finished product, whatever it might have been. The data were tabulated, summarized and published in two lengthy volumes, several thousand pages in total. These have been digitized and organized in a way that makes them amenable to standard econometric analysis.

Our analysis of these BLS data focuses on two aspects of the production process. The first is the division of labor. We show that there is sufficient information to generate a specific indicator of the division of labor – the proportion of production tasks undertaken by the average worker. By definition there can be no division of labor in one-person shops, because the single worker performs all tasks of production from start to finish. However, there is no "iron law" of economics that implies a shop with, say ten workers would necessarily practice division of labor: Each worker could still performs every task acting as his or her own production line, but all of the workers are gathered under a single roof. Indeed, much previous work on nineteenth century manufacturing presumes that a certain size threshold had to be reached before a "factory" scale was reached. Yet we find that division of labor set in extremely early in the transition from small to large establishments – indeed, as early as the transition from one to two workers, and very substantially comparing one worker establishments with units of six or more workers. Certainly these transitions opened up the possibility of specialization. This is true when we look over all establishments, or within power type (hand versus machine). Overall, establishments using machine methods practiced a greater degree of division of labor than hand establishments, largely because the former were much larger than the latter and because the nature of machine design mandated the simplification and reduction of tasks to a specific subset of operations or actions. Consequently, the use of machine methods was associated with an increase in the number of tasks in production, providing more scope for division of labor.

Our second analysis focuses on the consequences of that division of labor for labor productivity. Our measure of productivity is the amount of time necessary to complete a standard (whatever the BLS considered this to be) quantity of output. Because the BLS collected data from pairs of production units – one hand, the other machine – we can include "matched pair" fixed effects in our output regressions, giving our analysis a first difference flavor.

We show first that larger establishments, as measured by the number of workers, took much less time to produce a given quantity of output, that is, were more productive. A portion of this productivity advantage evaporates when we include a dummy variable for machine production, nevertheless the coefficient on the number of workers is still negative and statistically significant. But, when we include two measures of the division of labor – the proportion of tasks performed by the average worker, as mentioned above, and the number of tasks – we are then able to fully explain the scale effect. In other words, large establishments were more productive because they practiced division of labor and because they used powered machinery – the consensus view of the sources of productivity gain in the American industrial revolution of the nineteenth century.

Establishment Size and Economies of Scale in Nineteenth Century American Manufacturing: A Review of the Evidence

Over the course of the nineteenth century the share of the labor force engaged in agriculture declined from 76 percent in 1800 to 36 percent in 1900 (Weiss 1986, 1993). A significant fraction of the labor moving out of agriculture found its way into manufacturing. Early in the century most manufacturing was conducted in small widely distributed establishments, commonly referred to as "artisan shops". As the manufacturing sector grew, labor (and capital) shifted from artisan shops into larger establishments – factories – and these larger shops produced ever greater shares of industrial output and became geographically more concentrated.

Table 1, which is taken from Margo (2014), documents this process for the period 1850-1880 using data from the Atack-Bateman samples from the manufacturing census manuscript schedules.[2] The figures in the table show the distribution of workers by establishment size, weighting each establishment by the gross value of its output. In what follows we refer loosely to establishments with 16 or more workers as "factories" following the previous literature (Sokoloff 1984); however, as we discuss later in the paper, a crucial characteristic of factories – division of labor – appears to more continuous with respect to size than this sharp cutoff suggests.

Although not shown explicitly in the table, factories emerged in the early nineteenth century and were increasing their share of total output during the first half of the century (Sokoloff 1984). By 1850 almost half of the gross value of manufacturing output was produced

[2]Observations in Table 1 are at the establishment level. To be represented in the table, the establishment must be (1) in one of the "national" Atack-Bateman samples (2) have reported value of output exceeding $500 nominal dollars (this was the cutoff used by the census) Margo (2014) also excludes a small number (4) of establishments whose reported number of workers seems to be in error (too large to be credible); re-weights the 1880 data in an attempt to correct for the under-representation of establishments in so-called "special agent" industries (see, for example, Atack, Bateman, and Margo 2004); and, lastly, adjusts the 1850 and 1860 figures for under-representation of very small establishments (see the Data Appendix in Margo (2014)).

in establishments with 16 or more workers. The share of output produced in large establishments rose to approximately 71 percent in 1880 or by 22 points over the intervening three decades. Weighted by its output, the median establishment had 15 workers – almost a factory – in 1850; its counterpart in 1880 had 42 workers, or nearly 3 times as large.

As Margo (2014) shows, some of the shift towards large scale production reflected the pure "displacement" of smaller establishments in the sense that the relative number of large firms increased over time.[3] But this increase in relative numbers was fairly slow so that much of the trend evident in Table 1 is due to shifts in output, conditional on the size distribution of establishments.

The shift towards large scale production had several causes. Recent work by Hilt (2014) shows that a changing legal and institutional environment made the corporate organization form more broadly accessible, which facilitated the financing associated with larger establishments (see also Rousseau and Sylla 2005; and Atack 2014). The "transportation revolution" (Taylor 1951) – canals, inland waterways and, especially, railroads – played a role; a recent econometric analysis (Atack, Haines, and Margo 2012) shows that factories became more prevalent when an area gained rail access. Technological advances in inanimate power sources – steam power, first, and after 1880, electrical power – are important. These advances raised labor productivity and associated levels of capital intensity in large relative to small establishments (Goldin and Katz 1998; Atack, Bateman, and Margo 2008) and, as we discuss later in the paper, arguably facilitated a more intricate division of labor.

[3] The shift could also be due to changes in industrial or geographic composition; however, Margo (2014) presents a regression analysis which shows that most of the increase remains even if location or industry is held fixed.

The consensus view interprets the shift towards larger scale production as *prima facie* evidence that economies of scale were present in nineteenth century manufacturing and has sought to measure their size and contribution to productivity growth using conventional parametric estimation of cost or production functions based on the census manufacturing data.[4] However. because the census data provided only limited information on costs, most economic historians who have worked on this issue have chosen to estimate the cost dual, the production function. The first such studies were by Atack (1976, 1977) who reported estimates of production functions in 1850-70 by industry-region cells. Using a variable scale parameter specification popular in econometrics at the time, Atack (1977) concluded that there were economies of scale present in 1850 but these were exhausted at relatively low levels of output and, consequently, in just 5 of the 14 industry regions cells was the typical establishment operating in the range of increasing returns.[5] By 1860, however, the corresponding figure was 9 of 14 cells, suggesting that the optimal plant size was increasing before the Civil War.

Laurie and Schmitz (1981, pp. 74-75) estimate Cobb-Douglas production functions using manuscript census data for Philadelphia in 1850 and 1880 and also some supplemental data for textiles in 1870. In 11 of 17 industries in 1850 and 13 of 17 industries in 1880 Laurie and

[4] See Atack (1985). Atack applies the so-called "survivor method" in which the central concept is the "minimum efficient scale of production (MES)" – the smallest size establishment such that establishments larger than this were increasing (or non-decreasing) their share of aggregate production over time. If the MES is increasing over time, the presumption is that economies of scale are present. Atack frames his paper in terms of the debate over the "origins of the modern corporation" as told by Chandler (1977). According to Chandler, truly large scale production emerged late in the nineteenth century in response to fundamental changes in technology that were not in place until well after the Civil War. However, Atack (1985, p. 47) shows the typical plant at the end of the century was "little different from the scale required of an efficient plant in 1870" and that, with the exception of a few industries, the long run growth in establishment size can be interpreted as a historical drift towards an equilibrium structure whose fundamental causes were put in play much earlier in the century.

[5] A variable scale production function permits the econometrician to estimate the share of establishment operating in the region of decreasing returns. The most substantial evidence of decreasing returns is found for cotton textiles in 1850 in which 28 percent of establishments in the North and 19 percent in the South are deemed to be subject to (local) decreasing returns; see Atack (1977, p. 348).

Schmitz reject the hypothesis of increasing or even constant returns to scale. Based on their regressions Laurie and Schmitz argue that American manufacturing in the nineteenth century was not characterized by scale economies, but rather the opposite.

For many economic historians Sokoloff (1984) is the iconic paper in this literature. Sokoloff focuses his attention on the first half of the nineteenth century. A key element of his analysis is the assumption that the census enumerators did not take proper account of the labor input of entrepreneurs. Sokoloff devised corrections for this alleged deficiency in the data and, once the corrections were applied, there was strong evidence of economies of scale as early as 1820. Very importantly, the evidence for scale economies is present in establishments that made no use whatsoever of inanimate power. Similar to Atack, however, Sokoloff showed that scale economies in non-mechanized establishments were exhausted at relatively low levels of output.

Atack (1987) is a comprehensive attempt to assess the extent of economies of scale using the census samples for 1820-1870 as they existed in their mid-1980s form.[6] For the majority of industries in every census year that he examined, Atack found efficiency advantages to large scale production – economies of scale – relative to small-scale production – artisan shops. Atack accounted for the persistence of small establishments by noting that many served markets that were protected from competition from more distant competitors by high shipping costs. Improvements in internal transportation and the diffusion of new technologies, such as steam, however, caused the market share of small establishments to erode over time.

In a recent paper, Margo (2014) re-assesses the evidence for economies of scale using the Atack-Bateman samples. Margo shows that, for the 1850-80 census years, the adjustment for

[6] Subsequently a census sample for 1880 was added and additional refinements made to the 1850-70 samples; see Atack and Bateman (1999a). These later changes also led to self-weighting, nationally representative samples of manufacturing establishments from the census manuscripts. Currently the 1850-80 samples and associated documentation are available to the public on Atack's Vanderbilt website: https://my.vanderbilt.edu/jeremyatack/data-downloads/.

non-reporting of entrepreneurial labor proposed by Sokoloff is absolutely critical to the finding; without such an adjustment, the evidence for scale economies largely disappears. Margo also assesses the evidence for Sokoloff's claim that the census under-reported the entrepreneurial labor input and concludes, contrary to Sokoloff, that there is no basis for his specific adjustment. To say that these results leave the consensus view out on the proverbial limb would be an understatement.

One interpretation of Margo's findings is that very small establishments were just as productive as larger establishments but that a variety of forces led to their displacement over time in favor of factories. A complementary point is that because there are no extant manuscript data from the 1890 or 1900 manufacturing censuses, it is possible that substantial scale economies did not appear until late in the century.

However, even if it were the case that the census data yielded unambiguous evidence of scale economies, this would still leave unresolved the issue of their source. Fundamentally, the underlying sources of any economies of scale were division of labor or the use of indivisible inputs. In the current context, the relevant indivisibility involves machinery driven by inanimate power sources. While the census did provide evidence on the use of inanimate sources of power, there is no direct information whatsoever on the machinery being driven or on division of labor. Instead, economic historians have argued by default that division of labor was important to productivity gains (as in Sokoloff 1984) or used various proxies for it reported in the census – among these are the percent of workers who were women or children, or the average wage in the establishment (Goldin and Sokoloff 1982; Atack, Bateman, and Margo 2004; Katz and Margo 2014) – that suggest its presence in large relative to small establishments. This, however, is very different from documenting division of labor directly and connecting it to productivity gains.

To summarize, economic historians have extensively mined the extant census of manufacturing data in attempts to measure the extent of economies of scale in nineteenth century American manufacturing. Despite these efforts, the evidence is fragile because of underlying data problems and the role of different mechanisms, division of labor in particular, remains obscure. In the remainder of the paper we discuss a different source of nineteenth century manufacturing data that provides direct and much sharper information on the extent of productivity differences by establishment size and their proximate causes, including division of labor.

The BLS Hand and Machine Labor Data

Our analysis makes use of the original data collected and published by the Bureau of Labor Statistics in the so-called "Hand and Machine Labor Study" (United States. Department of Labor. 1899). Congress directed that the Commissioner of Labor "investigate and report upon the effect of the use of machinery upon labor and the cost of production, the relative productive power of hand and machine labor … and whether changes in the creative cost of products are due to a lack or surplus of labor or to the introduction of power machinery." (United States. Congress. 1894). Among the factors that may have motivated this Congressional interest were claims by the influential economist and adviser to James Garfield and Grover Cleveland, David Ames Wells, that "the increasing frequency of strikes and industrial revolts...have been largely prompted by changes in the conditions of production resulting from prior labor-saving inventions and discoveries" and that "the depression of industry in recent years has been experienced with greatest severity in those countries where machinery has been most extensively adopted..." (Wells 1889).

The basic unit of observation in the BLS study was a matched pair of producing units, one using hand methods of production and the other using machine (inanimate power) methods. Each matched pair is linked to a specific product and quantity. The products chosen were very specific – for example, a pair of men's "medium grade, calf, welt, lace shoes, with single soles and soft box toes" (United States. Department of Labor. 1899).

The data were reported in two parts by the BLS. In Part one, for each producing unit the following information was reported: an industry classification, the product, quantity, the year in which the production under each method took place, the number of separate tasks of production, the number of different workers employed, and the total number of hours of work to produce the given quantity, the total labor costs, and the average daily hours of operation of the unit. In Part two, for each separate task in the production of each good, there is a written description of the task, in the order in which it was performed; the list of capital goods or machines used in the task; the type of motive power, if used; the number of workers assigned to each machine, if used in the task; the number, age, and gender of the workers employed in the task; the occupational titles of the workers employed in the task; the hours of work by each employee engaged in the task; the labor cost of each employee engaged in the task; and miscellaneous information.

The raw data were collected by trained BLS agents, compiling the information from observation or current and historical written records. For the machine production units, the vast majority of the observations pertain to production activities occurring in the mid-to-late 1890s (1894-98). However, in many cases, the BLS was unable to find matching hand units from the same year, presumably because these were no longer in existence (itself a clue to their relative productivity). In such cases, the agents (very assiduously) sought out historical records or found establishments overseas that they deemed similar to those which no longer survived in the U.S., taking pains to record the year to which the data refer. Because we know the year of production, we are able to include it in our empirical analyses (see below). [7]

As an illustration of the kind of exceptional detail contained in the BLS report consider the manufacture of a plow, one of the final products included in the survey. In hand manufacturing of the plow, two men cut the iron to size using a hammer, anvil and chisel. They then welded points using a hammer, sledge and anvil. One of the men then fit the blade to wooden standards using a hatchet, mallet and chisel and beams, handles and moldboard were fashioned by ax, chisel and shave. The moldboard then had a steel edge attached using a hammer, an auger was used to bore holes in the handles and beams and the handles were rounded using a spoke shave. Colter bolts were forged using the anvil and a hammer, the frame was riveted to the moldboard and the plow was finished using a hammer and sledge. Making the plow by hand required 11 different operations performed by two men who worked a thirteen-hour day and one of whom served primarily as assistant and helper (United States. Department of Labor. 1899).

By contrast the manufacture of a similar plow in a factory engaged the work of 52 different workers performing 97 different tasks. Fifty-one of the workers worked a ten-hour day on producing the plows. The remaining worker served as watchman at the factory and worked a

[7] The BLS survey was not the first or only such data collected. Earlier, the Wisconsin Bureau of Industrial and Labor Statistics had reported on hand and machine production separately, giving the "product per day of hand and machine labor" for 49 trades, but made no effort to pair observations and match products (Wisconsin. Bureau of Labor and Industrial Statistics. 1888). Consequently, comparisons within the same trade are difficult to make because both methods were rarely covered nor can these be linked to the later BLS study.

twelve-hour day. Seventy-two of the operations were assisted by steam power, among them "smoothing surface of points," "grinding moldboards and pointing landsides," "cutting beams to size," "shaping beams," "cutting out handles," "turning necks of handles," "bending frames," "punching holes for wheels and wheel frame bolts," "welding rings into eyes," "cutting off back clevises," "flattening ends of clevises," "bending clevises" and "tapping nuts." Among the hand activities were "putting on nuts," "painting and blacking moldboards, points and landsides," "nailing boxes together," "packing plows," shipping plows" and "firing boiler." (U.S. Department of Labor 1899, pp. 476-9).

Compared with the census of manufacturing, the data collected by the BLS was vastly more detailed and complex. Indeed, the complexity totally overwhelmed statisticians at the time, as Carroll Wright himself noted (Wright 1900), and we believe that this has largely inhibited use of the data by modern economic historians.[8] That said, there are a number of (very) important limitations to the BLS data.

First, while the data cover products in many industries, they are in no sense a random sample or even a representative sample of the manufactured goods of the time. Any inferences that we draw about the importance of economies of scale or division of labor and so forth are limited to the production units covered in the data.[9]

Second, we have no information about output prices or revenue. This means that our analyses must include "matched pair" fixed effects to make sense. When we include these

[8] "This report answers in a measure the many demands for information … but no aggregation can be made because it is impossible to carry out calculations through the innumerable ramifications of production under hand and machine methods … although such a summary would be of the greatest possible value in the study of the question of machinery." (Wright 1900)

[9] In particular, the data contain no evidence on machine production early in the century – for all practical purposes, only the 1890s. While we know when hand production occurred, we cannot say whether these data are representative for the year in question.

effects, our analysis has the flavor, as we reiterate later in the paper, of a first-difference or within-estimator – controlling for the good in question, we are asking if the difference in, say, the number of workers between the hand and production unit can account for the difference in labor productivity. But this is not the same as having panel data in which we observe a transition from one method to another – fundamentally, our analysis is cross-sectional. Moreover, we lack certain information that has been shown to be important to productivity and which is known in the census data but not in the BLS survey.[10]

Third, while we have extraordinary detail on the capital equipment used in production the capital data are, in an important sense, too disaggregated – the capital goods are too specialized (and too numerous) to control for in a regression analysis. Consequently, we have, in effect, only one control for capital intensity – a dummy variable for the hand method. There is no doubt that mechanized production was (much) more capital intensive than hand production so we expect that, even with controls for the division of labor (see the final section of the paper) there may be – and, indeed, are -- large remaining differences in productivity between hand and machine production. But we cannot say how much of the remaining difference is due to differences in capital intensity.

The basic unit of observation in the BLS survey is the production task, aspects of which (for example, the amount of time the task took) can be aggregated to the "production unit". For each good survey there are two production units, one using hand methods and the other using machine methods. We use the phrase "production unit" rather than firm or establishment,

[10] The specific location of production is a good example. The BLS chose the units from what it considered to be the main geographic area of production for each type of product, but it did not indicate, for example, the state in which the unit was located or even if it was located in an urban or rural area.

because it is for the workers engaged in producing the specific good that we have information.[11]. Table 2 displays some of the sample averages in the regression analyses reported later in the paper, grouped by production method (hand versus machine). Across final products the sample is balanced (two production units per final good) so that the difference in sample means between the machine and hand methods is equivalent to the coefficient on a dummy variable for the machine method in a regression with final good fixed effects.

On average, machine production units used four times as many workers as hand production units. On average the machine method subdivided production into more tasks than the hand method. Some of this difference, which was apparent to the BLS at the time, can be attributed to greater preparation at the beginning and, especially, packaging at the end of production. Perhaps most importantly, the machine method produced the good, on average, in about 20 percent of the time that it took for the good to be produced by hand methods. Over a specific "operating time" – a standard ten--hour day, for example – the machine method would yield a greater quantity of finished goods – exactly how much, we cannot say, because this is not reported in the survey (and there could have been greater periods of "downtime" within the day for the machine method involving, for example, machine maintenance). Gender and age differences between the machine and hand methods were small.

Our goal in the remainder of the paper is to explain the difference in productivity between the two methods. As noted above, there is no question that the machine method was more capital intensive than the hand method, by definition, and this surely is a key reason for the productivity difference. But the machine units were also larger than hand units, in the sense of employing more workers. This, along with the difference between the methods in the number of

[11] For some machine units we have information on certain non-production workers but this is not the norm.

tasks, suggests differences in the degree of division of labor, which we consider in the next section.

The Division of Labor: Hand versus Machine

A unique feature of the BLS data is that they provide direct evidence on the division of labor. This is because the data report each step, or task, in the production process, along with the number of workers assigned to each task. Separately, the data report the number of different workers employed in producing the good. With this information, it becomes possible to quantify two features of production – the proportion of production tasks performed by the average worker, and the number of individual tasks to produce the finished product– which are completely obscured in the standard census data.

Our preliminary analysis of the division of labor is in the spirit of recent work by Acemoglu and Autor (2010) who model the final good in a production process as the outcome of a series of steps, or tasks. The output of each task is a function of labor and capital and other inputs, one of which is the partially finished product from previous tasks.

To fix ideas, let X be the quantity of the final good to be produced, $S = \{s_1, \ldots, s_N\}$ be the set of tasks involved in producing X, and S* the (much) larger collection of all proper subsets of S. Imagine an initial scenario in which all of the s's might be performed by a single individual. We say that "division of labor" has occurred when a set Z consisting of elements of S* is selected such that (1) the elements of Z covers all tasks in S -- so that X, in fact, can be produced -- and (2) each element of Z is assigned to a different worker.

For example, suppose n = 10 (tasks). The ten tasks could be performed by a single person, or the first five tasks performed by one person, and the remaining five by another person. Division of labor has occurred because the work formerly performed by a single person is divided up between two workers. In comparing establishments with different numbers of workers, it is theoretically possible that no division of labor has occurred. That is, an establishment with, say, 25 workers could simply be 25 people replicating each other, performing each task in order until the final good emerges. However, as long as some workers are performing only a subset of tasks, division of labor is present.

It is important to note that a task as we have defined it may be "primitive", in the sense, that it cannot itself be further sub-divided into additional steps, or it may be a collection of distinct, but related activities that are grouped together under a single heading, or description. In other words, exactly what defines one task versus another is a margin for economic decisions; moreover, the availability of new technology embodied in capital goods may generate entirely new tasks. As we show below, the number of tasks differed between hand and machine production and, generally, machine production involved more tasks than hand production for a given quantity of the finished product.

In any given division of labor, the degree of specialization across workers may be incomplete or complete. It is incomplete if there is some overlap in the tasks performed by different workers. In the above example where n = 10, imagine that the penultimate task is "finishing" and the final task is "packaging". The first worker might perform tasks #1-4, while the second performs tasks #5-8, but both do finishing (task #9) and packaging (#10). By contrast, specialization is complete if there is no overlap of tasks – as in the original example above, where the first worker does tasks #1-5, and the second #6-10.

For any given S, there is a maximal degree of specialization in which each distinct worker performs one and only one task. A necessary (but not sufficient) condition for maximal specialization is that the number of distinct workers be at least as large as N, the number of tasks in S. However, there may be tasks which require more than one worker – for example, because a machine is used that requires two operators – or there may be tasks which are replicated to generate the requisite flow of production. To continue the above example, we could imagine that tasks #1-8 are each performed by a single, separate worker, but there are two finishers (task #9) and two packagers (task #10) because, for example, these tasks require more time than a single worker has to match the flow of production into that stage. In this example, specialization is at its maximum because the mapping between tasks and workers is one-to-one -- but there is an intensive margin on tasks #9 and #10. This intensive margin might reflect the nature of the machines used in tasks #9 and #10, which may require more than one worker to operate properly, or there may be replication across individual workers at the task level.

With the above discussion in mind, how might the division of labor be quantified? As a step towards answering this question imagine a matrix M whose elements m(j, k) index workers (j) and tasks (k). A variety of functions defined over the m(j, k) could serve as useful summary statistics of the division of labor. These could be refined in various ways, for example, by weighting by the amount of time a worker spends on a task, or by the amount of skill involved in performing it.

To construct such functions we must be able to measure the elements of M – that is, allocate specific workers to specific tasks. Although the BLS data are, by any standard, extremely detailed, this level of detail is not specifically present – that is, the data do not identify specific workers by name (or ID number). Nevertheless, for some production units we do have sufficient information to literally infer which worker is which – and therefore, allocate specific workers to specific tasks – but we cannot do this for all observations in the data.

Because of this limitation, we focus our preliminary analysis on a summary statistic that can be calculated for all observations. This statistic is the proportion, P(N), of total tasks performed by the average worker (the summation in the expression below is over j workers):

P(N) = Proportion of Total Tasks Performed by the Average Worker = ([∑ (number of workers assigned to task k)] /Total number of different workers)/N

To see this statistic in action, consider the above example where n = 10, there are two distinct worker first performing tasks #1-4 and the second performing tasks #5-8, and both performing tasks #9 and #10. In this example, the summand in the numerator will be 12; this is divided by 2 workers, and then further divided by 10 tasks. The result is 0.6 – the average worker performs 60 percent of the tasks.

Panel A of Table 3 reports the overall difference in the percent of tasks performed by the average worker between hand and machine units, along with the difference conditional on the number of workers. Panel A displays a central result of our preliminary analysis – according to the BLS data, division – and specialization of labor set in very early as the number of different workers – the size of the establishment – increased. Indeed, there is already considerable division of labor in going from one to four or five workers, regardless of whether hand or machine power was employed. In hand production the extent of division of labor seems to have bottomed out in the size category of 16-50 workers whereas in machine production, further division of labor continues to occur even in the largest establishments. Panel A suggests, therefore, that the proximate reasons why the overall degree of division of labor was higher in machine production are the larger size of establishments and a more extensive division of labor in the largest firms.

Finally, in Panel B we report regressions of the proportion of tasks performed by the average worker. We know from Panel A that there was a large difference overall in division of labor between hand and machine production. The first regression in Panel B demonstrates that much of this gap is explained by controlling for the number of individual workers involved in the production process which has a negative (and highly significant) coefficient. If we add the number of tasks to the regression it, too, has a negative (and highly significant) coefficient, and the magnitude of the coefficient of the hand dummy is further reduced in size. Including controls for the average age and percent male among the workers does not change the substantive patterns.

In sum, the BLS data reveal that larger establishments and production processes in which tasks were more narrowly defined (and possibly, therefore, closer to "primitive" as discussed above) were associated with higher average degrees of division of labor. In the next section we explore whether the measures of the division of labor affected labor productivity.

Regression Analysis of Labor Productivity

Unlike the census of manufactures, the BLS data set does not record a unit's aggregate output (or their values) over a specified period of time, which would be the conventional outcome measure in a production function. Instead, as previously noted, the data report the amount of time that a unit of production spent in each step of the production process, such that if these times are summed, we know the total amount of time, T, needed to produce a standard unit of the good X. Our outcome measure is the logarithm of T.

Our full estimating equation is:

$$\text{Ln } T_{ijt} = \alpha \ln L_{ijt} + X_{ijt}\beta + \delta_i \text{ (Product = i)} + \gamma_j \text{ (Machine method = 1)} + \lambda_t \text{ (Year t = 1)} + \varepsilon_{ijt}$$

Where L = total number of workers used in producing a single unit of the good, X = measures of the division of labor, δ is the coefficient of the product fixed effect, γ is the coefficient of a dummy variable taking the value 1 if the good is produced using the machine method, λ is the coefficient of the dummy variable taking the value 1 for the year to which the records pertain, and ε is the error term.

As in the analysis of the division of labor in Table 3 this equation has the flavor of a difference-in-difference specification as the coefficient α and γ are identified by within-product differences in the specific features of the production method. If production units using more labor overall achieve economies of scale, we should estimate a negative value for α in a regression with fixed product and time effects. If some of the productivity advantage of larger units is explained by the use of powered machinery, γ should be negative and α should be smaller in absolute value. By adding controls for the division of labor, we should be able to whittle away further at the value of α.

The regression results are reported in Table 4. In column 1 we include the hand dummy variable and the logarithm of the number of workers. The coefficient of the hand dummy is large and statistically significant but nevertheless considerably smaller in magnitude than the average difference in productivity shown in Table 2. Note, as well, that the coefficient on the number of workers is negative and significant. Units with more workers were more productive

– produced the good in less time – controlling for the type of production (hand). Thus some of the overall difference in productivity in Table 2 can be explained by the fact that the machine units had more workers, which is consistent with economies of scale.

In column 2 we add the controls for the percent of tasks performed by the average worker and the logarithm of the number of tasks. In units in which workers performed a large fraction of total tasks the amount of time needed to produce one unit of the good was significant higher whereas if the number of tasks were greater – a finer subdivision of the activities of production – productivity was higher. These are the patterns we would expect to see if division of labor functioned in the way that Adam Smith described. When we add these controls to the regression the coefficient on the number of workers switches sign. Controlling in an admittedly imperfect way for capital intensity, the reason why the larger units were more productive is not that they had more workers per se, but that there was more division of labor. Adding demographic controls further reduces the magnitude of the coefficient on the number of workers and renders it statistically insignificant.

In the remaining columns we add our measures of the division of labor. These enter with the expected sign and are separately significant. Aa finer division of labor – whether accomplished by increasing the number of tasks or by dividing up tasks among more workers -- is associated with higher productivity. Remarkably, when we include the measures of the division of labor, the coefficient on the number of workers switches sign but is no longer significant.

In column 2 of Table 4 the coefficient of the hand dummy is 1.1 or about 0.9 in log points less than the overall difference in productivity shown in Table 2. This implies that 45 percent, or slightly less than half, of the difference in productivity between hand and machine production can be attributed to division of labor. The remainder is due presumably to the difference in capital intensity although, for the reasons stated earlier, we cannot measure this precisely given the data.

Concluding Remarks

The consensus view of American industrialization in the nineteenth century holds that scale economies were central to increasing labor productivity. Previous work has shown that the evidentiary basis for the consensus view, which largely rests on census of manufacturing data, is weak and non-robust. The results of this paper, which are based on better data, strongly re-affirm the consensus view.

This paper has presented a first look at a neglected data source – the BLS Hand and Machine Labor Study from the late 1890s. This source provides unprecedented detail on the production process in manufacturing in the late nineteenth century and is arguably much more informative about the sources of productivity gains associated with scale than other source from the period, such as the census of manufacturing samples (Atack and Bateman 1999).

Using the BLS data, we examine differences in the division of labor between hand and machine production, as well as differences with respect to the number of workers. We find that firms with a large number of workers engaged in more extensive division of labor, as did firms whose production process was divided more finely into specific tasks. When we control for these directly, we still find a lower degree of division of labor in hand production, but the gap relative to machine production is much attenuated.

The BLS data provide a unique measure of labor productivity, the amount of time needed to produce one unit of a (very) specific good. Comparing hand and machine production of the same good, we find that hand methods took much longer than machine methods. The gap between the two is smaller when we control for the number of production workers – the greater the number of workers, the shorter the time needed to produce one unit. When we control for the division of labor, the positive effect of scale on labor productivity evaporates, but about half of the gap in productivity in favor of machine production remains, a reflection of the much higher level of capital intensity.

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Table 1: Establishment Size Distributions in Manufacturing, 1850-1880:

Atack-Bateman Sample Evidence

	Median	1-2 workers	3-5workers	6-15 workers	16-100workers	>100workers	16 or more workers
1850	15	14.6%	15.7%	20.5%	31.1%	18.1%	49.2
1860	25	11.9	14.4	16.3	32.8	24.7	57.5
1870	44	7.6	8.1	15.7	35.9	32.6	68.5
1880	42	6.6	8.6	13.9	38.4	32.5	70.9

Note: Source is Atack and Bateman (1999a) national samples of manufacturing establishments from the 1850-80 manuscript censuses of manufacturing. See text for inclusion criterion. Each establishment is weighted by its gross value of output. Number of workers in 1850-60 is the sum of male and females; number in 1870 and 1880 is the sum of adult males, adult females, and children. 1880 data are reweighted to correct for under-sampling of establishments in special-agent industries (see text); sample size.

Table 2: Sample Means, BLS Hand and Machine Labor Study

	Hand	Machine	Difference, Machine - Hand	Hand	Machine	Difference
Level or Logs?	Level	Level	Level	Log	Log	Log
Number of Workers	8.9	34.6	24.7	1.29	2.73	1.44
Number of Tasks	10.3	17.6	7.3	1.86	2.45	0.59
Time (in hours) Needed to Complete One Unit of Output	30.03	5.62	-24.41	0.73	-1.25	-1.98
Percent Male	0.73	0.70	0.03			
Average Age of Workers in Years	31.9	31.2	-0.70			

Unit of observation is the product (or, equivalently, matched hand-machine production unit), N = 619 for number of workers, tasks, time to complete one unit, and fraction of tasks performed by average worker. Sample size is smaller for average age and percent male because of missing observations.

Table 3: The Division of Labor: BLS Hand and Machine Labor Study

Panel A: Percent of Tasks Performed by the Average Worker: By Size and Power Type

Number of Different Workers	Sample Size, Hand Production Units	Percent of Tasks Performed by the Average Worker, Hand	Sample Size, Machine Production Units	Percent of Tasks Performed by the Average Worker, Machine	Difference in Percent Performed, Machine – Hand
1	163 units	100.0%	11 units	100.0%	0
2	120	70.9	14	52.4	-18.5
3	58	42.9	23	34.0	- 8.9
4	50	27.6	36	27.0	- 0.6
5	33	23.0	31	23.1	0.1
1-5	424	69.2%	115	37.4%	-32.4 p.p
6-10	79	17.4	149	15.0	- 2.4
11-15	25	16.7	75	10.8	- 5.9
16-50	78	14.0	179	7.4	- 6.6
51-100	6	23.7	51	4.3	-19.4
100+	7	22.6	50	3.9	-18.7
All	619	52.7	619	14.6	-38.0

p.p.: percentage points

Source: See Table 2. Fraction of Tasks Performed by the Average Worker = ([∑ (#workers assigned to task i)] /Total number of different workers)/(Number of Tasks).

Panel B: Regressions of Percent of Tasks Performed by a Worker

	Coeff.	Coeff.	Coeff.	Coeff.
Hand Production = 1	0.138 (0.044)	0.081 (0.036)	0.086 (0.037)	0.067 (0.034)
Ln (# of Workers)	-0.176 (0.016)	-0.147 (0.016)	-0.146 (0.017)	-0.169 (0.016)
Ln (# of Tasks)		-0.163 (0.028)	-0.163 (0.029)	-0.133 (0.028)
Age and Gender?	No	No	No	Yes
Number of Matched Pair Units	613	613	587	587

Source: see Panel A. All regressions include year and matched-pair fixed effects. Standard errors clustered at the final product (matched pair) level are reported in parentheses.

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Table 4: Regressions of Ln (Time in Hours to Complete One Unit of Output)

Sample	All	All	All	All
Ln (# of workers)	-0.169 (0.068)	0.125 (0.049)	0.137 (0.174)	0.024 (0.107)
Hand = 1	1.447 (0.185)	1.100 (0.115)	1.137 (0.174)	1.123 (0.179)
Percent of Tasks Performed by Average Worker		1.103 (0.198)	1.061 (0.365)	0.862 (0.365)
Ln (# of Tasks)		-0.557 (0.092)	-0.563 (0.152)	-0.514 (0.145)
Age and Gender?		No	No	Yes
Number of Matched Pairs	613	613	587	587

Source: see Table 2. All regressions include year and matched pair fixed effects. Standard errors are clustered at the matched-pair level.