# Automation in the Historical Mirror: The Bureau of Labor Statistics *Hand and Machine Labor* Study

By

Jeremy Atack
Robert A. Margo
Paul Rhode
October 2018

Abstract: Recent advances in artificial intelligence and robotics have generated a robust debate about the future of work. A similar debate occurred in the late nineteenth century when mechanization first transformed manufacturing. We analyze an extraordinary data set from the late nineteenth century, the BLS "Hand and Machine Labor" study. We focus on transitions at the task level from hand to machine production, and on the impact of inanimate power, especially of steam power, on labor productivity. Our analysis reveals several ways in which current task-based models of automation might be modified to take account of historically relevant effects of mechanization.

Prepared for the Journal of Economic Perspectives. Jeremy Atack is Professor of Economics Emeritus, Vanderbilt University, and Research Associate, National Bureau of Economic Research; Robert Margo is Professor of Economics, Boston University, and Research Associate, NBER; and Paul Rhode is Professor of Economics, University of Michigan, and Research Associate, NBER.

## 1.0 Introduction

Recent advances in artificial intelligence (AI) and robotics have generated a robust debate over automation and the future of work (Daron Acemoglu and Pascual Restrepo, 2017a, b, Erik Brynjolfsson and Andrew McAfee, 2012, 2014). A similar debate occurred in the late nineteenth century when mechanization first transformed manufacturing.[1] Based on this historical precedent, some have argued that the likely effects today of AI-cum-robotics today will be qualitatively similar (Philippe Aghion et al., 2017, David H. Autor et al., 2003). Others (Erik Brynjolfsson and Andrew McAfee, 2014) assert that this time is different. Either way, the earlier example is worth a much closer look.

We will focus on the time, place, and sector—late-nineteenth-century U.S. manufacturing—most closely associated with rapid mechanization (S. Giedion, 1948, David A. Hounshell, 1984). Our analysis is underpinned by an extraordinarily detailed data source whose very existence attests to the era's agonizing concerns about mechanization and its effects on labor. David A. Wells, a leading U.S. economist, wrote in 1889 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..." (David Ames Wells, 1889, p. 68). In response to such worries, the U.S. 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

[1]The historical process was so disruptive that it inspired Edward Bellamy's *Looking Backward, 2000-1887* (1888). This utopian science fiction novel, quickly became the era's third-largest bestseller and provoked extensive political and social discussion.

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). The investigation took years to complete, finally appearing as the thirteenth annual report of the Commissioner of Labor where the enormously complex data were indexed, tabulated, and summarized in two large, very dense volumes (United States. Department of Labor, 1899. Hereafter, BLS). We have digitized these data, coding and restructuring them to be tractable to modern econometric techniques. The final product creates an historical lens through which changes in today's economy can be viewed.

Highly unusual for its time or for ours, the BLS report presents information at the task level of the production of highly specific goods (for example, circular saw blades with a given number of teeth) for a matched pair of establishments, one of which produced the product by "hand" (or traditional artisanal) methods and the other using "machine" methods. Among other information, the report specifies the amount of time required to complete each task, the sequence in which these were performed, the characteristics of the workers employed, the tool(s) used, and notably, the source of inanimate power, if any. In particular, this includes steam power, the historical general-purpose technology (GPT) that is universally invoked in today's debate. Brynjolfsson and McAfee (hereafter, BM), for example, describe steam power as the first machine age's "most important" technological development, "overcoming the limitations of muscle power, human and animal" and propelling a "sudden, sharp, and sustained jump in human progress" (Erik Brynjolfsson and Andrew McAfee, 2014, p. 6).

Our analysis focuses on transitions at the task level from hand to machine production, and on the impact of inanimate power on labor productivity in machine production. By "transitions at the task level" we mean whether particular tasks in hand production were no longer present under machine production (we call these 1:0 transitions); whether the task content remained the same, even if inanimate power was used under machine production (we call these 1:1 transitions); whether task reorganization occurred, of which there are several types (for example, 1:M, or a single hand task is subdivided in multiple tasks under machine labor); and entirely new tasks present under machine labor (0:1). Importantly, the transitions did not seem to have occurred randomly, but rather were systematically associated with the amount of time a particular task took under hand labor, and by the worker's hourly earnings. For example, the likelihood that a single hand task would be subdivided under machine production was increasing in the amount of time the task took under hand production, and in the wage paid. Lengthy expensive hand tasks were prime targets for task subdivision, which invariably went hand-in-hand with increased division of labor. Our analysis of steam power focuses on 1:1 transitions, as these were the most common. Steam power was more likely to be used in machine production if that hand tasks consumed a large share of the total time in hand production; if steam was used, labor productivity was greatly increased, considerably more than if water power was used.

To bring our findings to bear on the current literature, we consider them in light of Daron Acemoglu and Pascual Restrepo's (hereafter, AR) recent model of automation.[2] For example, the AR model predicts that, in response to technical progress, some tasks are abandoned, others automated, and new, non-automated tasks created. Substituting "mechanized" for "automated" in their framework we find a similar pattern in the BLS data. AR argue that automation is more

---

[2] The Acemoglu-Restrepo framework is part of a larger literature advancing a "task-based approach." This literature (Daron Acemoglu and David H. Autor, 2011, David H. Autor, 2013, Joseph Zeira, 1998) develops models allowing technological change to reduce returns to specific factors, which is not possible in standard models of factor-augmenting technological change.

likely to occur in tasks at which labor is at a comparative disadvantage. Again, we see a similar pattern in the BLS data.

Where the history clearly parts company with AR is the overwhelming importance of division of labor, which AR abstract from consideration.[3] Historically, one cannot divorce mechanization from division of labor; indeed, there is considerable evidence that the diffusion of steam power enhanced division of labor (Jeremy Atack et al., 2008). As we discuss in section 4, the issue here is the degree to which workers are specialized or not in the tasks they perform, and how this may feed back into human capital investment.

## 2.0 The BLS Hand and Machine Labor Study

In his first annual report, the Commissioner of Labor, Carroll D. Wright, had drawn attention to the "temporary displacement of labor and to conditions of industry and of society which would exist without the presence of power machinery" (United States. Bureau of Labor, 1886) which he illustrated with several examples.[4] Wright's examples intrigued Congress sufficiently to request a fuller investigation, noting "there are works now in existence where the very best and highest grade of machinery is used that formerly employed cruder methods, and the men in charge have knowledge of the old methods as compared with the new; but these men

[3] For a fuller analysis of the transformation of U.S. boot and shoe production, see Thomson (1989)

[4] In small arms production, for example, one man using conventional hand tools, turned and fitted one musket stock per ten-hour day whereas using specialized machines and dividing the tasks between them, three men could turn and fit between 125 and 150 musket stocks per day, a 40 to 50-fold productivity gain. Similarly, data from boot and shoe manufacturers suggested an 80 percent savings in labor for machine over handicraft production (United States. Bureau of Labor, 1886, p. 81).

are fast passing away, and the difficulty increases each year of securing the information sought…" (United States. Congress. House of Representatives, 1894).

Although the study was billed as "Hand and Machine Labor," when it was published five years later, Wright cautioned in his introductory remarks that the words were not used in their strictest sense but rather to characterize two different methods of production. "Machines" were used in "hand" production although these were usually simple hand tools—saws, hammers, chisels, files, knitting needles, screwdrivers and the like—what he called "the primitive method of production which was in vogue before the general use of automatic or power machines" (United States. Department of Labor, 1899, v1, p. 11). Similarly, a substantial portion of tasks in machine production continued to be performed by hand using simple tools.[5] For Wright, however, a crucial distinction was that, in machine production, "every workman has his particular work to perform, generally but a very small portion of that which goes to the completion of the article" – that is, division of labor (United States. Department of Labor, 1899, p. 11).

The data were reported in two parts by the BLS. In Part one, for each producing unit, the following information was published: 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 producing unit, the following information was published: a brief description of the task, in the order in which it was performed; a list of capital goods or machines used in the task;

[5] In the sample of tasks analyzed in this paper (see Table 1), approximately 83 percent of hand tasks used simple tools as described in the text; the corresponding percentage was 31.2 percent in machine production.

the type of motive power if used; the number of workers assigned to that task; the number, age, gender, and 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 comments.

The basic unit of observation in the BLS study was a matched pair of production units, one using hand methods, the other using machine methods to make a specified quantity of product. The products chosen were highly specific – for example, Unit 71 details the production of 100 pairs of "men's medium grade, calf, welt, lace shoes, with single soles and soft box toes" (United States. Department of Labor, 1899). Where necessary, production was scaled to industry norms by adjusting the time (and thus the cost) spent on tasks by the appropriate factor, keeping the number of workers unchanged.

The raw data were collected by trained BLS agents through direct observation or from written records, following up (sometimes repeatedly) where necessary to resolve inconsistencies and ambiguities. For machine production, the vast majority of the observations pertain to activities occurring in the mid-to-late 1890s (1894-98). For a few products, the BLS was unable to find matching hand production from the same year that occurred nearby, presumably because the relevant establishments were no longer in existence. In such cases, the BLS agents assiduously sought out historical records or, more rarely, found establishments overseas that they deemed similar to those that no longer survived in the United States.[6] In the majority of cases, two reports were secured for each unit from different, widely separated, localities to help spot

[6] All machine production data, however, was taken from U.S. establishments. All regressions reported in this paper include unit fixed effects and thus implicitly control for any variable that varied at the unit level, such as the year of production (hand or machine).

errors and omissions with “the better and more complete one then selected for presentation.” (United States. Department of Labor, 1899, v1, p. 13)

An example illustrates the exceptional (indeed, stupefying) detail in the published report (See Figure 1). In making men’s medium grade, laced shoes (Unit 71), the BLS compared production by a bespoke shoemaker producing a single pair of shoes with that of a factory producing 1,500 pairs, scaling the time (and cost) as if each in fact produced 100 pairs of shoes. The shoe size is not specified but is (implicitly) assumed to be different for each pair. The data were tabulated, verso and recto, across several pages, with task identifiers aligning the rows across the left- and right-hand pages and with the numbering sequenced according to the order in which the tasks were performed in machine production (part of which is shown here in Panel A of Figure 1).

In hand production, the individual shoemaker traced each foot to create a cutting pattern and carved a last (a wooden form around which each shoe was molded). These steps were crucial for the fit of the shoe and would be repeated for each customer served by the shoemaker. Producing these lasts was time consuming, taking 54 minutes 24 seconds per pair—almost 92 hours for the production run of 100 different pairs of shoes (see Panel 1B of Figure 1, line 1). The BLS assigned this task an uppercase letter in hand production because the factory bought pattern for the soles and lathe-turned lasts for left and right feet in standard sizes from outside specialist suppliers and so there were no corresponding tasks in machine production (at least in that particular establishment).[7] These patterns would be used in the fabrication of thousands of pairs of shoes.

[7] Remarkably, whenever there were intermediate inputs produced within the establishment, the BLS collected task data on these as well, and incorporated them into the tabulation.

In machine production, the BLS identified 173 separate tasks (we are able to show only the first 54 tasks in Figure 1). These include not only tasks directly related to the manufacture of shoes, like sorting leather, cutting out the vamps (the main part of the shoe between the toe and the laces), quarters (the heel portions), toes, soles, insoles, and heels and sewing these together around the last to form the shoe and punching holes for the laces, but also finishing the shoe like smoothing the welts, waxing and polishing, matching pairs, stamping with the maker's name and size and boxing for shipment. The study included the tasks to keep the shoe-making machinery in good order, and maintaining and firing the steam engine that powered the various machines. Some of the tasks, like sorting, required nothing more than a good eye. Others, like cutting out the parts, still used basic hand tools (scissors and knives) rather than steam-powered die presses. Eighty of the tasks, including trimming, making eyelets, nailing heels, polishing and buffing, made use of steam power driving specialized machines (United States. Department of Labor, 1899, v2, pp. 544-51).

Hand production involved fewer separate tasks—72 operations (including making the patterns and lasts)—than machine production. Selecting and sorting the leather were one task in hand production—presumably so that the uppers for one pair of shoes could come from the same hide—compared with eight separate operations (for uppers, vamps, quarters, outsoles, insoles, lifts and counters—which are machine-molded heel reinforcements that had to be both sorted and matched). This is shown in the second row in Panel 1B (United States. Department of Labor, 1899, v2, pp. 540-45). The BLS investigators carefully linked each operation in hand production to the corresponding operation in machine production via the machine task number. Machine tasks that were a part of several hand tasks had lowercase letters appended to the machine task number.

These data can also be displayed as a slope chart (Figure 2), relating each of the various hand tasks on the left to the (far more numerous) machine tasks on the right.[8] Some hand tasks link to multiple machine tasks. Some are performed in quite different sequences between hand and machine production—these lines cross over. A few hand tasks vanish in machine production (we have connected these to "Task 0" in Machine Production on the righthand side)—like line 1 in Panel B of Figure 1. Moreover, the white space on the righthand axis to which no hand production tasks connects represent new tasks created by mechanization for which there was no hand production analog. In the next section, we discuss these task "transitions" in more detail and more generally using the full sample of tasks from our digitized version of the BLS study.

Compared with the 1880 Census of Manufacturing (which Wright, as Superintendent of the Tenth Federal Census for Massachusetts, also helped oversee), the data collected by the BLS were vastly more detailed and complex. Indeed, the complexity totally overwhelmed statisticians at the time, as Carroll Wright himself noted (Carroll D. Wright, 1900a). This complexity has also largely prevented analysis by modern economic historians until very recently.[9]

Before turning to our findings, we highlight four limitations of the BLS study. First and foremost, the establishments included were, in no sense, a random sample either within or across

---

[8] See Tufte, 1983 p. 143, and https://www.edwardtufte.com/bboard/q-and-a-fetch-msg?msg_id=0003nk.

[9] "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" (Carroll D. Wright, 1900b). Stanley Engerman has informed us (personal communication) that he and Robert Fogel included the BLS study on a list of key data sources to be analyzed by cliometricians. However, in their view the data were far too complex to digitize and analyze – that is until recent advances in information technologies.

industries. That said, a wide range of goods and industries are covered. Second, no information was collected on output prices, revenues, or costs, except those pertaining to the labor involved directly in the production of the product (and its supervision). As a result, any analysis of productivity, including ours, must rely on the measure provided by the study – the amount of time that it took to complete a task – rather than a more conventional measure for economists (for example, value added per worker). Third, the BLS agents recorded additional information on the survey form that would have been useful for have for some analyses – for example, the names of the individual workers, or the address of the establishment. For privacy reasons this information was not included in the published study or kept in the agency records for privacy reasons.[10] Finally, as previously noted, the BLS reported the labor requirements for a standardized scale of production, which enhances comparability. But the number of workers employed and the organization of work may not reflect how producers, especially hand producers, would have operated at that scale under realistic time cost considerations.

## 3.0 Analysis of BLS Data: Task Transitions and the Role of Steam Power

The digitized version of the BLS study can be analyzed at the unit level (as in Atack, Margo, and Rhode (2017) or at the task level within units, as in this paper. The analysis here focuses on two broad features of the data – transitions of tasks from hand to machine labor; and

---

[10] We tracked down copies of the original survey instrument in Record Group (RG) 257 in the US National Archives (United States. Bureau of Labor Statistics, 1890-1905). The forms asked for additional information that was not published, such as the name and location of the establishment, and the names of the workers employed in the production of the various articles. So far as we can determine, the actual returns have not survived and so this additional information has been lost.

the adoption and effects of steam power in machine production for the subset of tasks that were common to both hand and machine labor (1:1 transitions, see below). All told, the full data set contains information on 626 units and 20,245 hand or machine labor tasks.[11]

Task Transitions: From Hand to Machine Production

The replacement of hand by machine labor involved massive changes in production. The BLS data allow us to "see" these changes in detail at the task level. The BLS agents listed machine tasks in their production order – that is, from start to finish. The same was done for hand tasks, with the addition of a column containing, in effect, a cross-walk linking hand to machine tasks. We can distinguish six different transitions:

a) 1:0, hand tasks that were no longer performed under machine labor ("old" tasks);
b) 1:1, tasks whose content the BLS deemed to be essentially the same in hand and machine production, except that the machine task might be mechanized;
c) 1:M, a single hand task that was subdivided into M machine tasks;
d) N:1, N hand tasks that were combined into a single machine tasks;
e) N:M, N hand tasks were mapped into M machine tasks, with both N and M greater than one; and, lastly,
f) 0:1, which corresponded to tasks present under machine production but not hand production ("new" tasks).

[11] There are 672 paired units in the BLS volume, 27 of them in agriculture, 10 in mining and quarrying, and 9 in transportation, leaving 626 paired units producing manufactures on which we focus. In 13 cases, the hand operation data were from establishments outside of the United States.

Panel A of Table 1 shows the transitions from the standpoint of hand production, and Panel B from the standpoint of machine production. Both panels also show the proportion of tasks that were mechanized, whether by steam or water.

Although some hand tasks became archaic and were abandoned in the transition to machine labor, these comprised a very small share – 6 percent – of hand tasks. The largest category of transitions in hand production is 1:1 – that is, the BLS was able to match a singleton hand task with a singleton machine task whose content was deemed to be the same, except that the machine task was far more likely than the hand task to be mechanized. As can be seen in Panel B, slightly more than half (51.2 percent) of these 1:1 tasks used inanimate power under machine production; of these, 94 percent (48.3/51.2) were steam powered.

Task reorganization was nearly as common as the 1:1 transitions. Approximately similar proportions of singleton hand tasks were subdivided (1:M transitions) versus multiple hand tasks that were combined into a singleton machine task (N:1 transitions). Somewhat less common were more complex changes, which could involve either subdivision or consolidation or both (N:M transitions). Note, however, that as a group and especially the consolidations (N:1) were far more likely to be steam powered than the average machine task.

Turning to Panel B, we see an overall expansion in the number of tasks of approximately 74 percent (12,878/7,367). Roughly half of the expansion is attributable to the emergence of tasks that the BLS considered to be entirely novel (0:1), that is, not present under hand production. Compared with the other tasks performed by machine labor, the new tasks were considerably less likely to use steam power, although the overall rate of steam use in new tasks, about 37 percent, was still substantial in an absolute sense. Many of these tasks were themselves directly related to that power source: engineers and firemen, for example, represented 15% of these new tasks. However, the more important group of new non-powered tasks in machine production were those related to monitoring of the workplace activities (e.g. foreman/supervisor) and inspection of the finished product (inspector, examiner, packer and finisher, for example). These activities made up about 20% of the 0:1 tasks and were essential to the smooth flow of the production line and the quality of the final product given that no other worker or group of workers assumed responsibility for the outcome of the production process. The remaining expansion in the number of tasks is accounted for by the 1:N transitions; and by the N:M transitions, which on net involved more subdivision of tasks than consolidation.

The increase in the total number of tasks from hand to machine labor is not simply an artefact of arbitrary delineation by the BLS in describing what workers did. We know this because mechanization invariably went hand-in-hand with an increase in the division of labor. As Atack, Margo, and Rhode (2017) describes in detail, it is possible to use the information in the BLS study to compute a summary statistic of the division of labor, the proportion of tasks performed by the average worker. Scaling by the number of tasks transforms the statistic into the average number of tasks per worker. In hand production, the average was 4.3, but in machine production it was just 1.2. The division of labor in machine production was virtually complete – if the BLS described a task, one or more workers were assigned to it and, on average, that was pretty much all they did, as far as the production of the specific good was concerned.

Can anything be said about the factors behind the different transitions identified in Panels A and B in Table 1? As detailed as the BLS data are, they are limited in terms of plausible covariates at the task level; any regressions reported here should be viewed as descriptive, rather than causal, because there are no instrumental variables (or any other identification strategy, for that matter). With this limitation in mind, Table 2 reports linear probability regressions of the various transitions using the hand labor portion of the sample. We focus on two variables, the log of the amount of time that it took to complete the task and the average hourly earnings of the worker performing the task. All regressions have unit fixed effects, so that any variable measured at the unit level – for example, the year of the hand observation, or the number of workers in the establishment, among others – is implicitly controlled for; the coefficients are identified off the variation across tasks within units.

The regressions demonstrate that the task transitions were far from random. Tasks that took up a large amount of time relative to the total amount of time that it took to fashion the complete good were more likely to be subdivided under machine production (1:M) or subject to more complex reorganization (N:M). Relatively expensive tasks (high average hourly earnings) were more likely to be subdivided (1:M) while hand tasks performed by cheaper than average labor were more often abandoned (1:0) or consolidated (N:1).

## Adoption and Effects of Steam Power in Machine Production

Economic historians have long had a keen interest in the diffusion of the steam engine and its attendant microeconomic and aggregate effects, such as the geography of steam adoption, changes in relative power costs in face of technological innovation, externalities such as its role in fostering urbanization, and its impact on aggregate total factor productivity growth (Jeremy Atack, 1979, Jeremy Atack et al., 1980, Sukkoo Kim, 2005, Peter Temin, 1966). More recently, there have been studies of how mechanization, whether steam power or electrification, affected the relative demand for different occupations which captures, albeit indirectly, the effects on tasks (Alexandra de Pleijt et al., 2018, Raphaël Franck and Oded Galor, 2017, Rowena Gray, 2013, Jari Ojala et al., 2016). By comparison, the BLS study allows us to narrow the focus much further, down to the task level for highly specific goods, comparing hand to machine production. This is straightforward to accomplish for the 1:1 overlap tasks; for these, we can simply difference the data at task level across the matched pair of establishments with products. As previously we caution that our analysis is not causal; we can only measure correlates of steam power or of labor productivity, not true treatment effects. The regressions, which are reported in Table 3, all include unit fixed effects.

In column 1 of Table 3 we report the results of a linear probability regression of the adoption of steam power at the task level in machine production. The key independent variables in the regression are the log of the amount of time that the task took in hand production and the average hourly earnings of the worker performing the task. We also control for whether the task was mechanized in hand production (that is, used water or steam power). The coefficient of this variable is positive, indicating that some use of inanimate power carried over in the transition from hand to machine labor. Controlling for whether the task was mechanized previously, the likelihood that it would use steam power in machine production increased if the task took considerable time, but decreased if the worker was highly paid.

In columns 2 and 3, we report regressions of the change in labor productivity in the task between machine and hand production. Productivity is measured in terms of the amount of time (measured in hours) that it took to complete the task. Note that the sample mean of this variable is negative, indicating that machine production took less time – much less, in fact – than hand production on average. Column 3 differs from column 2 in that we include the log of the amount of time the task took in hand production, in effect, allowing for regression to the mean. Regardless of the specification, use of steam power dramatically reduced the amount of time needed to complete the given task. In column 2 for example, the value of the steam power coefficient, -1.11, is a large fraction of the dependent variable, indicating that diffusion of steam accounted for a significant fraction of the higher level of productivity of machine production. Although relative few tasks in machine production used water power, those that did enjoyed a productivity boost compared with hand production, but the size the productivity gain was much smaller than for use of steam.

## 4. Discussion

In a conventional production function, gross output of a final good is a function of capital, labor of various types (for example, skilled, unskilled), and intermediate inputs (raw materials). Automation is as a type of factor-augmenting technical change. Recent scholarship shows, however, that this framework can be very misleading in terms of predictions of the effects of automation, for example, on wages or employment.

By contrast, a task-based model of production posits that output of the final good is a function of completion of a set of tasks. One prominent example is the AR (Daron Acemoglu and Pascual Restrepo, 2018) model. In this model, tasks form a continuum along the unit interval from K– 1 to K. Tasks are arrayed in terms of the relative productivity of labor, from those as which labor is at a comparative advantage (close to the K– 1) endpoint to those at which labor has a comparative advantage (close to the K endpoint). For a threshold value in labor productivity, those for which labor productivity falls below the threshold can be performed either by labor or capital (perfect substitutes), but for those above the threshold, only labor can be used. Whether capital will be used for tasks below the threshold depends on economic feasibility, that is, if capital is sufficiently cheap. Over time, however, some tasks below the threshold substitute capital for labor ("automate") which, in equilibrium, affects labor demand and wages. The AR model also allows for new tasks to be created that are more productive versions of old tasks, which then are abandoned. AR's assumptions ensure that new tasks will appear at K, the right endpoint of the unit interval. The entire interval then moves to the right, as tasks at K-1, where labor is at its worst comparative disadvantage initially, are abandoned.

The AR model is far too stylized to apply literally to actual data, whether the BLS study or modern. For example, in the AR model individual tasks, being on a continuum, take an infinitesimal amount of time to complete. In the BLS data, however, tasks are discrete and take a finite time to complete. For AR, new tasks appear at K, where labor is at its highest relative productivity; this displaces old tasks at K-1 where labor is at its lowest relative productivity. In the BLS study new tasks are simply those that the agents gave sequential numbers to that could not be matched to any existing hand task, or combination thereof; old tasks are hand activities that could not be matched to any machine task or combination thereof. The BLS definition is closer to the everyday meaning of "new" whereas AR's definition is model-based.

Although it cannot be applied literally we believe that the AR model is a useful framing device. Consider the prediction in the AR model that automation increases as capital costs fall. In the nineteenth century there is no question that (real) capital costs fell absolutely and relative to wages (or the price of output), and that manufacturing technology improved, rendering widespread mechanization economically feasible. As the BLS data show, when the transition from hand to machine labor occurred, some hand tasks disappeared; others were mechanized; and wholly new tasks emerged. This pattern is broadly consistent with the AR model.

The AR model also predicts that among the tasks that could be automated, those at which labor is at a comparative disadvantage are automated first. We do not have exogenous (i.e.

experimental) measures of relative labor productivity in hand production in the BLS study, so a direct test of the AR prediction is not possible. However, the regression of adoption of steam power for 1:1 transitions (column 1, Table 3) comes close. This regression shows that, controlling for the worker's wage, if the worker took a relatively long time to complete the hand task, the corresponding machine task was more likely to use steam power. Conversely, controlling for the amount of time it took to complete the hand task, the higher the worker's wage – which presumably, was positively correlated with the worker's underlying skill or ability – the greater the likelihood the task would not be mechanized in machine production. Again, both patterns are broadly consistent with the AR model. Lastly, in the AR model, overall productivity growth occurs through automation of existing tasks and the net impact of creation of new tasks. The regressions on the productivity effects of inanimate power (columns 2 and 3, Table 3) show that steam power – and, to a lesser extent, water power – dramatically reduced the amount of time that it took to complete production tasks – again, broadly consistent with the AR model.

The AR ceases to be useful, however, as an historical frame when we try to use it to confront what Carroll Wright considered to be an essential feature of machine production – its virtually complete division of labor. In the simple AR model there is a single type of labor; automation and new tasks engage in a race of sorts which, on net, raises or lowers labor demand. AR extend the model to include two types of labor, skilled and unskilled, to address issues of inequality. Neither version of the model, however, incorporates division of labor directly.

In the tiniest artisan shops that are iconic depictions of hand production in early manufacturing, workers were highly skilled in the sense of performing most or all of the production tasks from start to finish, as well as "non-production" tasks associated with managing their business affairs and marketing their products. In the transition to machine labor, the artisan shop was displaced by the factory, a process that labor historians often refer to as “de-skilling”.

Examples of deskilling are everywhere to be found in the BLS data. We have already cited one, shoemaking; another, is blacksmithing. Blacksmiths were the quintessential “jack of all trades”, fashioning metal objects like pots, pans, plows, and numerous other objects from iron; the “village smithy” could be found in small towns and in the countryside all over the United States, as late as 1850. Atack and Margo (2019) use census data to study the relative decline of blacksmithing as a “hand trade” over the second half of the nineteenth century. Machine production led to establishments specializing in, for example, agricultural implements. These establishments were much larger in terms of employment than blacksmith shops, and far more productive making plows, rakes, and hoes and related tools. Faced with such competition, blacksmith shops shifted away from making objects to fixing them (i.e. repair services) or simply disappeared. Once considered sufficiently numerous to warrant its own industry classification, blacksmithing was dropped from the manufacturing census at the very end of the nineteenth century no longer the worth the trouble to enumerate.

The point we are making, however, is not about deskilling per se but rather that the AR model is silent about the implications of the extent to which individual workers might be specialized in allocating their labor across tasks. The massive division of labor that coincided with the diffusion of steam power, and documented front and center in the BLS study, dramatically affected the nature of the human capital investment decision facing successive cohorts of American workers contemplating whether to not to enter the manufacturing sector. Early in the century the human capital investment problem such workers faced was mastering the diverse set of skills associated with most or all of the tasks involved in making a product, along with managing the affairs of a (very) small business, an artisan shop. The investment problem facing the prospective manufacturing worker in the 1890s was quite different from his counterpart earlier in the century. There was little or no need to learn how to fashion a product from start to finish; mastery of one or two tasks would do, which might be accomplished quickly on the job. The more able or ambitious might gravitate to learning new skills, such as designing, maintaining, or repairing steam engines, or clerical/managerial tasks, the demand for which had grown sharply as average establishment size increased over the century (Lawrence F. Katz and Robert A Margo, 2014).

For many decades in the twentieth century specialization was economically beneficial to workers – the costs of learning skills were relatively modest and the return on the investment – a relatively secure, highly paid job in manufacturing – made that investment worthwhile. The prospect of widespread automation has arguably changed the calculus. No single "job" is safe and the optimal investment strategy may be very different – a suite of diverse, relatively uncorrelated skills as insurance against displacement by robotics and AI. This is perhaps the sense in which history is not repeating itself, and "this time" really is different.

## 5. Concluding Remarks

The modern debate over automation and labor frequently invokes historical antecedents, most notably the steam engine during the early industrialization. Typically, historical evidence serves as anecdote to provide a context against which qualitative predictions can be made. Revolutionary in its time, the steam engine "destroyed" some jobs but created many others. But perhaps AI and robotics are truly "different" and the past is no prologue to the future.

To understand the effects of automation, labor economists have turned away from traditional “black box” models of production and their assumptions of relative complementarity or substitutability between capital and different types of labor. Instead, production is modeled as a collection of tasks, some of which might be performed by labor or capital (automated). Empirical assessments of these models have generally been indirect, in part because the data demands are so formidable. Even in today’s world awash in “big data” information on production is rarely recorded at the task level. In the absence of such data, analysts must infer the task content of jobs indirectly through the use of, for example, the Dictionary of Occupational Titles (United States Employment Service., 1991).

This paper has reported on some preliminary analyses of a data set long known by economic historians the 1899 BLS Hand and Machine Labor (United States. Department of Labor, 1899) study but almost never used because it was, until recent advances in information technologies, too complex to analyze. Itself a product of the machine age, the BLS study collected astonishingly detailed data on the tasks of producing very specific goods by archaic “hand” methods versus modern (for the time) machine methods. Focusing on the use of steam power in machine production, our analysis of the BLS data confirms the modern view that the “machine age” was transformative. Our analysis also reveals, however, several ways in which current task-based models of automation might be modified to take account of certain effects of mechanization on labor that were historically relevant. It remains an open question whether similar disruptive effects will appear if and when AI diffuses throughout the economy, but we will not know what to look for if the models do not guide us properly.[12]

[12] One could imagine, for example, that AI would reduce the cost of reassigning and reorganizing tasks, allowing for more efficient dynamic optimization of production in response

to changing conditions.  As our analysis shows, task reorganization was common in the transition from hand to machine labor, and strongly correlated with mechanization (see Table 1).

Table 1
The Transition from Hand to Machine Labor: Production Tasks

Panel A: Hand Labor

| Transition | Number of Tasks | Percent of Total Hand Labor Tasks | Percent using Steam Power | Percent Using Water Power | Average Real Hourly Labor Cost |
|---|---|---|---|---|---|
| 1:0 | 445 | 6.0 | 0.7% | 0.7% | 0.144 |
| 1:1 | 4,390 | 59.6 | 1.4 | 3.4 | 0.162 |
| 1:M | 923 | 12.5 | 2.8 | 1.1 | 0.173 |
| N: M, N>1, M>1 | 610 | 8.3 | 0.7 | 1.7 | 0.197 |
| N:1 | 999 | 13.6 | 1.2 | 9.1 | 0.143 |
| Total | 7,367 | 100.0 | 1.4 | 4.1 | 0.162 |

Notes to Panel A: computed from digitized version of BLS Hand and Machine Labor Study, see text and (United States. Department of Labor, 1899). Old: hand labor tasks that disappeared in the transition to machine labor. 1:1: hand labor tasks that a unique counterpart in machine production. 1:M: a single hand labor task subdivides into M machine tasks. N:M: N hand labor tasks transition into M machine labor tasks, N> 1, M>1. N:1: N hand tasks combine to a single machine task.

Panel B: Machine Labor

| Transition | Number of Tasks | Percent of Total Machine Labor Tasks | Percent using Steam Power | Percent Using Water Power | Average Real Hourly Labor Cost |
|---|---|---|---|---|---|
| 1:1 | 4,378 | 34.0 | 48.3 | 2.9 | 0.205 |
| 1:M | 2,859 | 22.1 | 62.6 | 3.2 | 0.184 |
| N: M, N>1, M>1 | 813 | 3.1 | 69.2 | 3.1 | 0.184 |
| N:1 | 398 | 6.3 | 73.1 | 4.0 | 0.201 |
| 0:1 | 4,442 | 34.4 | 36.8 | 1.3 | 0.200 |
| Total | 12,878 | 100.0 | 49.6 | 2.4 | 0.197 |

Notes to Panel B: see Panel A for source information and definition of row headings. 0:1: new tasks under machine labor.

Table 2: The Transition from Hand to Machine Labor Tasks: Regression Analysis

| | 1: 0 | 1:1 | 1:M | N:1 | N:M |
|---|---|---|---|---|---|
| Ln (Time spent in task) | -0.010 (4.33) | -0.032 (7.34) | 0.031 (9.83) | -0.001 (0.46) | 0.012 (4.85) |
| Ln (Average hourly earnings) | -0.026 (2.17) | 0.010 (0.46) | 0.036 (2.18) | -0.033 (2.10) | 0.013 (0.99) |
| Sample mean of dependent variable | 0.060 | 0.598 | 0.127 | 0.133 | 0.080 |
| Adjusted R2 | 0.092 | 0.249 | 0.133 | 0.237 | 0.185 |

Unit of observation is the task. Sample restricted to hand labor tasks with complete data on dependent and independent variables (N = 6,752). All regressions include unit fixed effects, worker age, and gender dummy (=1 if female). 1:0: dependent variable = 1 if hand task is abandoned under machine labor; 1:1: = 1 if hand task is the same as a single machine task; 1:M = 1 if a single hand task is subdivided into M machine tasks; N:1 = 1 if N hand tasks are combined into one machine task; N:M = 1 if N hand tasks are mapped into M machine tasks, N >1 and M > 1.

Table 3: The Adoption and Productivity Effects of Steam Power in Machine Tasks: 1:1 transitions in the BLS Study

| Dependent Variable | = 1 if Machine Task Uses Steam Power | Ln (time spent in machine task) – Ln (time spent in hand task | Ln (time spent in machine task)- Ln (time spent in hand task) |
|---|---|---|---|
| Ln (Time spent in hand task) | 0.088<br>(16.64) | | -0.361<br>(29.43) |
| Ln (Average hourly earnings, hand task worker) | -0.052<br>(2.60) | | |
| Machine task uses steam – Hand task uses steam | | -1.109<br>(28.58) | -0.821<br>(22.57) |
| Machine task uses water – Hand task uses water | | -0.404<br>(4.19) | -0.306<br>(3.51) |
| Hand task is mechanized? | 0.589<br>(15.36) | | |
| Mean value of dependent variable | 0.482 | -1.737 | -1.737 |
| N | 4,365 | 4,366 | 4,366 |
| Adjusted R2 | 0.554 | 0.515 | 0.605 |

Note: regressions in the table pertain to 1:1 transitions with complete information on the relevant variables (see Table 2). See Table 1 for source information.

Figure 1A

Partial Recomposed Image for Unit 71 for the Production of "100 pairs men's medium grade, calf, welt, lace shoes, single soles, soft box toes" by Machine Method

| Operation number. | Work done. | Machine, implement, or tool used. | Motive power. | Persons necessary on one machine. | Employees at work on the unit. Number and sex. | Occupation. | Age. | Time worked. h. m. | Pay of labor. Rate. | Pay of labor. Per— | Labor cost. | Operation number. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Selecting and sorting upper stock | None used | ...... | ...... | 1 M | Upper-stock selector | 37 | 10.0 | (a) | Year | $0.0692 | 1 |
| 2 | Cutting out vamps | Knives, cutting boards, and patterns. | Hand | 1 | 5 M | Vamp cutters | 28–40 | 3–16.7 | $0.27½ | Hour | .9015 | 2 |
| 3 | Cutting out quarters | Knives, cutting boards, and patterns. | Hand | 1 | 7 M | Quarter cutters | 27–45 | 4–35.3 | .22½ | Hour | 1.0324 | 3 |
| 4 | Cutting out tips | Knives, cutting boards, and patterns. | Hand | 1 | 2 M | Tip cutters | 29, 33 | 1–18.7 | .25 | Hour | .3279 | 4 |
| 5 | Cutting out linings | Knives, cutting boards, and patterns. | Hand | 1 | 2 M | Lining cutters | 24, 26 | 53.6 | .25 | Hour | .2233 | 5 |
| 6 | Cutting out sock linings | Mallets, dies, and blocks | Hand | 1 | 3 M | Sock-lining cutters | 17–22 | 32.0 | .12½ | Hour | .0667 | 6 |
| 7 | Cutting out trimmings | Mallets, dies, and blocks | Hand | 1 | 3 M | Trimming cutters | 17–22 | 1–26.0 | .12½ | Hour | .1792 | 7 |
| 8 | Perforating toe tips | Mallets, punches, and blocks | Hand | 1 | 2 M | Tip punchers and scallopers. | 26, 30 | 1–18.7 | .25 | Hour | .3279 | 8 |
| 9 | Cutting out doublers to quarters | Knives, cutting boards, and patterns. | Hand | 1 | 2 M | Quarter-lining cutters | 22, 25 | 1–18.7 | .12½ | Hour | .1640 | 9 |
| 10 | Overseeing upper-cutting department | None used | ...... | ...... | 1 M | Foreman | 37 | 30.0 | (a) | Year | .2076 | 10 |
| 11 | Sorting vamps | None used | ...... | ...... | 2 M | Vamp sorters | 31, 36 | 49.2 | .30 | Hour | .2460 | 11 |
| 12 | Sorting quarters | None used | ...... | ...... | 1 M | Quarter sorter | 38 | 39.3 | .25 | Hour | .1638 | 12 |
| 13 | Throating vamps | Knives, cutting boards, and patterns. | Hand | 1 | 2 M | Vamp throaters | 25, 40 | 1–18.7 | .25 | Hour | .3279 | 13 |
| 14 | Tying parts in bunches | None used | ...... | ...... | 2 M | Upper bunchers | 30, 35 | 1–18.7 | .30 | Hour | .3935 | 14 |
| 15 | Marking vamps for tips | Tip marker | Hand | 1 | 1 M | Tip marker | 27 | 20.0 | .22½ | Hour | .0750 | 15 |
| 16 | Selecting doublers for quarters | None used | ...... | ...... | 1 M | Matcher | 30 | 20.0 | .22½ | Hour | .0750 | 16 |
| 17 | Skiving vamps | Skiving machines | Steam | 1 | 2 M | Vamp skivers | 19, 27 | 49.2 | .20 | Hour | .1640 | 17 |
| 18 | Skiving tips | Skiving machines | Steam | 1 | 2 M | Tip skivers | 20, 25 | 49.2 | .17½ | Hour | .1435 | 18 |
| 19 | Skiving doublers | Skiving machine | Steam | 1 | 1 M | Doubler skiver | 29 | 39.3 | .17½ | Hour | .1146 | 19 |
| 20 | Skiving trimmings | Skiving machines | Steam | 1 | 2 M | Trimming skivers | 22, 30 | 49.2 | .22½ | Hour | .1845 | 20 |
| 21 | Skiving quarters | Skiving machines | Steam | 1 | 2 M | Quarter skivers | 26, 32 | 49.2 | .25 | Hour | .2050 | 21 |
| 22 | Matching and marking parts for stitching room | Pencil | Hand | 1 | 1 M | Distributer | 31 | 39.3 | .25 | Hour | .1638 | 22 |
| 23 | Marking linings | Stamps | Hand | 1 | 3 F | Lining stampers | 17–20 | 1–36.7 | .15 | Hour | .2418 | 23 |
| 24 | Pasting facings to lining pieces | Brushes | Hand | 1 | 3 F | Facing pasters | 20–25 | 1–36.7 | .15 | Hour | .2418 | 24 |
| 25 | Sewing facings to linings | Sewing machines | Steam | 1 | 3 F | Facing stitchers | 21–26 | 1–56.0 | .12½ | Hour | .2417 | 25 |
| 26 | Marking places for second-row stitching | Markers | Hand | 1 | 3 F | Second-row markers | 18–20 | 58.0 | .12½ | Hour | .1208 | 26 |
| 27 | Folding top of quarters | Folding sticks | Hand | 1 | 3 F | Folders | 18–20 | 1–36.7 | .12½ | Hour | .2015 | 27 |
| 28 | Sewing second rows | Sewing machines | Steam | 1 | 3 F | Second-row stitchers | 20–25 | 1–36.7 | .15 | Hour | .2418 | 28 |
| 29 | Sewing back seam of quarters | Sewing machines | Steam | 1 | 2 F | Top closers | 20, 25 | 1– .4 | .15 | Hour | .1510 | 29 |
| 30 | Making linings and sewing on back stays | Sewing machines | Steam | 1 | 6 F | Lining makers | 18–25 | 3–52.0 | .15 | Hour | .5800 | 30 |
| 31 | Sewing linings to quarters | Sewing machines | Steam | 1 | 3 F | Closers-on | 18–25 | 1–56.0 | .16 | Hour | .3093 | 31 |
| 32 | Cementing linings and turning tops | Brushes and turning irons | Hand | 1 | 6 F | Cementers and turners | 20–25 | 3–52.0 | .15 | Hour | .5800 | 32 |
| 33 | Trimming edges of uppers | Under-trimming sewing machines | Steam | 1 | 6 F | Upper edge trimmers | 20–34 | 17.4 | .16 | Hour | .0464 | 33 |
| 34 | Sewing around tops | Under trimming sewing machines | Steam | 1 | 6 F | Top stitchers | 20–34 | 3–34.6 | .16 | Hour | .5723 | 34 |
| 35 | Fastening eyelets | Gang punches and eyelet machines | Steam | 1 | 4 M | Eyeleters | 18–25 | 2–37.3 | .17½ | Hour | .4588 | 35 |
| 36 | Sewing stays on back seam of quarters | Sewing machines | Steam | 1 | 6 F | Stayers | 25–30 | 3–52.0 | $0.17 | Hour | $0.6573 | 36 |
| 37 | Blacking edge of vamps | Brushes | Hand | 1 | 2 M | Vamp blackers | 22, 25 | 49.2 | .15 | Hour | .1230 | 37 |
| 38 | Cementing doublers to vamps | Brushes | Hand | 1 | 3 F | Vamp cementers | 18–22 | 1–36.7 | .12½ | Hour | .2015 | 38 |
| 39 | Sewing tips to vamps | Sewing machines | Steam | 1 | 3 F | Tip stitchers | 20–30 | 1–36.7 | .16 | Hour | .2579 | 39 |
| 40 | Sewing back seam of vamps | Sewing machines | Steam | 1 | 2 F | Vamp closers | 20, 25 | 1– 1.5 | .25 | Hour | .2563 | 40 |
| 41 | Rubbing down back seams | Seam-rubbing machines | Steam | 1 | 2 M | Seam rubbers | 20, 25 | 1– 1.5 | .15 | Hour | .1538 | 41 |
| 42 | Cementing vamps to quarters and putting on stays | Hammers and brushes | Hand | 1 | 2 F | Vamp cementers | 20, 25 | 1– .4 | .12½ | Hour | .1258 | 42 |
| 43 | Sewing vamps to quarters | Double-needle sewing machines | Steam | 1 | 12 F | Vampers | 25–40 | 7–44.0 | .25 | Hour | 1.9333 | 43 |
| 44 | Lacing uppers for lasting | None used | ...... | ...... | 3 F | Last lacers | 18–20 | 1–56.0 | .10 | Hour | .1933 | 44 |
| 45 | Rubbing down top seams | Rubbing irons | Hand | 1 | 2 M | Seam rubbers | 18, 20 | 59.0 | .15 | Hour | .1475 | 45 |
| 46 | Barring toe linings | Sewing machines | Steam | 1 | 2 F | Lining barrers | 18, 20 | 1– 1.5 | .12½ | Hour | .1281 | 46 |
| 47 | Overseeing fitting and stitching department | None used | ...... | ...... | 1 M | Foreman | 37 | 40.0 | (a) | Year | .2662 | 47 |
| 48 | Cutting leather into strips for outsoles | Stripping machine | Steam | 1 | 1 M | Outsole-stock stripper | 60 | 23.6 | .20 | Hour | .0787 | 48 |
| 49 | Rolling outsole strips | Rolling machine | Steam | 1 | 1 M | Outsole-strip roller | 55 | 15.9 | .20 | Hour | .0530 | 49 |
| 50 | Cutting out outsoles | Sole-cutting machine | Steam | 1 | 1 M | Outsole cutter | 25 | 39.3 | .25 | Hour | .1638 | 50 |
| 51 | Sorting outsoles | Sorting table | Hand | 1 | 1 M | Outsole sorter | 30 | 26.2 | .25 | Hour | .1092 | 51 |
| 52 | Tying up outsoles | None used | ...... | ...... | 1 M | Outsole buncher | 30 | 11.8 | .25 | Hour | .0492 | 52 |
| 53 | Overseeing sole-leather cutting department | None used | ...... | ...... | 1 M | Foreman | 60 | 40.0 | (b) | Year | .3195 | 53 |
| 54 | Skiving outsoles | Skiving machine | Steam | 1 | 1 M | Outsole skiver | 40 | 13.9 | .25 | Hour | .0579 | 54 |

Source: (United States. Department of Labor, 1899, v2, pp. 544-47)

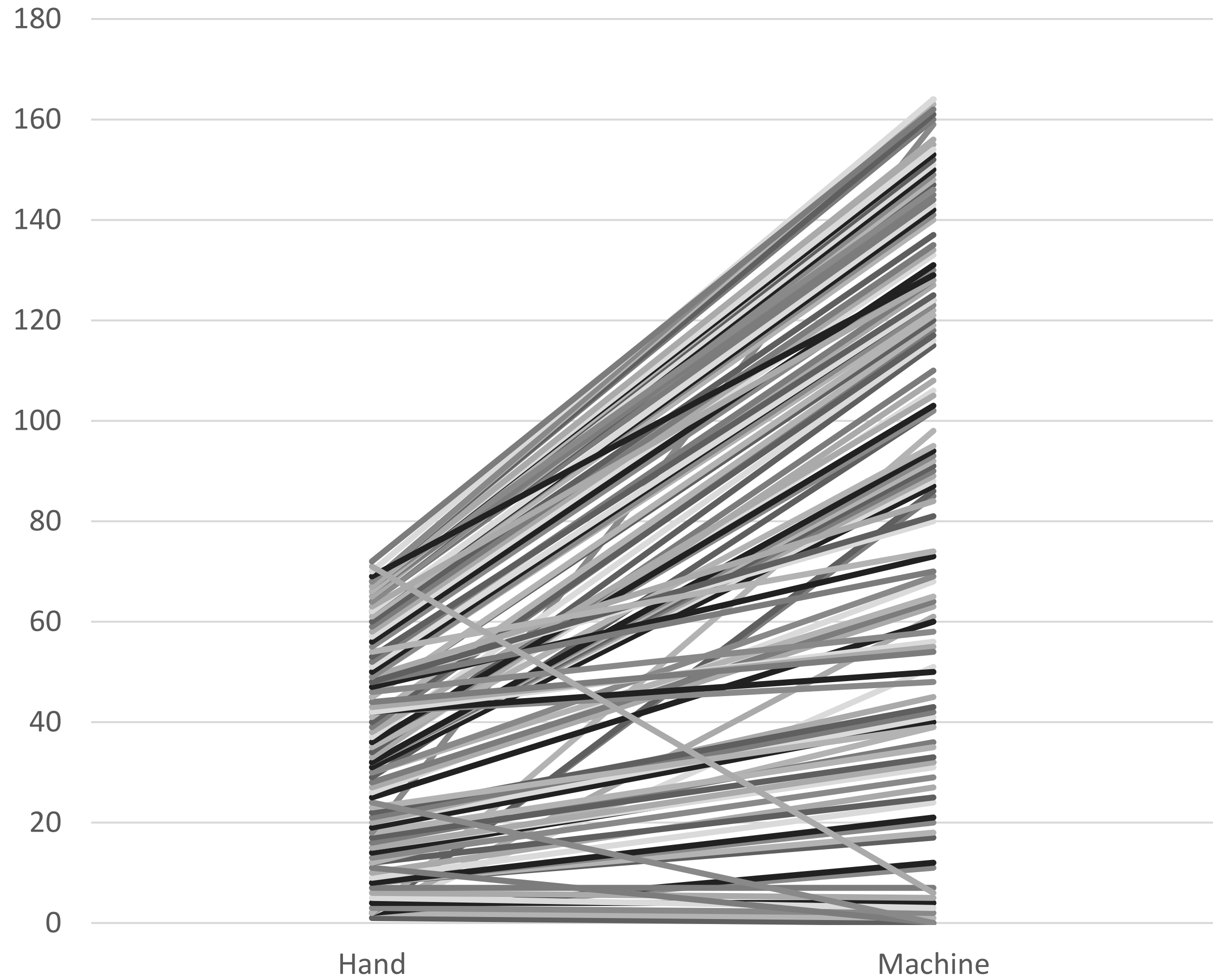
Figure 1B

Partial Recomposed Image for Unit 71 for the Production of "100 pairs men's medium grade, calf, welt, lace shoes, single soles, soft box toes" by Hand Method

| Operation number. | Work done. | Machine, implement, or tool used. | Motive power. | Persons necessary on one machine. | Employees at work on the unit. Number and sex. | Occupation. | Age. | Time worked. h. m. | Pay of labor. Rate. | Pay of labor. Per— | Labor cost. | Operation number. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | Measuring feet, cutting patterns, and fitting lasts to measure. | Tape measure, size stick, lasts, knife, etc. | Hand | 1 | 1 M | Shoemaker | 36 | 91-40.0 | $2.50 | Day | $22.9167 | A |
| 1, 11, 12, 51, 61, 85, 86, 98 | Selecting and sorting stock | None used | ...... | ...... | 1 M | Shoemaker | 36 | 33-20.0 | 2.50 | Day | 8.3333 | 1, 11, 12, 51, 61, 85, 86, 98 |
| 2 | Cutting out vamps | Knife, cutting board, and pattern. | Hand | 1 | 1 M | Shoemaker | 36 | 8-20.0 | 2.50 | Day | 2.0833 | 2 |
| 4 | Cutting out tips | Knife, cutting board, and pattern. | Hand | 1 | 1 M | Shoemaker | 36 | 5 | 2.50 | Day | 1.2500 | 4 |
| 3 | Cutting out quarters | Knife, cutting board, and pattern. | Hand | 1 | 1 M | Shoemaker | 36 | 16-40.0 | 2.50 | Day | 4.1667 | 3 |
| 5 | Cutting out linings | Knife, cutting board, and pattern. | Hand | 1 | 1 M | Shoemaker | 36 | 8-20.0 | 2.50 | Day | 2.0833 | 5 |
| 7 | Cutting out facings and stays | Knife, cutting board, and pattern. | Hand | 1 | 1 M | Shoemaker | 36 | 8-20.0 | 2.50 | Day | 2.0833 | 7 |
| 17, 18, 20, 21 | Skiving upper stock | Knife and skiving table | Hand | 1 | 1 M | Shoemaker | 36 | 16-40.0 | 2.50 | Day | 4.1667 | 17, 18, 20, 21 |
| 24 | Pasting facings to linings | Brush | Hand | 1 | 1 M | Shoemaker | 36 | 8-20.0 | 2.50 | Day | 2.0833 | 24 |
| 27 | Folding top of quarters | Folding stick | Hand | 1 | 1 M | Shoemaker | 36 | 16-40.0 | 2.50 | Day | 4.1667 | 27 |
| B | Making wax ends | Awl and knife | Hand | 1 | 1 M | Shoemaker | 36 | 33-20.0 | 2.50 | Day | 8.3333 | B |
| 25, 30 | Making linings and sewing on facings and stays | Awl, needle, thimble, etc | Hand | 1 | 1 M | Shoemaker | 36 | 50 | 2.50 | Day | 12.5000 | 25, 30 |
| 29 | Sewing back seam of quarters | Awl, needle, thimble, etc | Hand | 1 | 1 M | Shoemaker | 36 | 25 | 2.50 | Day | 6.2500 | 29 |
| 32a | Pasting linings to quarters | Brush | Hand | 1 | 1 M | Shoemaker | 36 | 5 | 2.50 | Day | 1.2500 | 32a |
| 31, 32b | Sewing linings to quarters and turning tops | Awl, needle, thimble, etc. | Hand | 1 | 1 M | Shoemaker | 36 | 100 | 2.50 | Day | 25.0000 | 31, 32b |
| 36 | Sewing stays on back seam of quarters | Awl, needle, and thimble | Hand | 1 | 1 M | Shoemaker | 36 | 50 | 2.50 | Day | 12.5000 | 36 |
| 33 | Trimming edges of uppers | Welt awl | Hand | 1 | 1 M | Shoemaker | 36 | 16-40.0 | 2.50 | Day | 4.1667 | 33 |
| 35, 159 | Fastening eyelets | Punch and hammer | Hand | 1 | 1 M | Shoemaker | 36 | 25 | 2.50 | Day | 6.2500 | 35, 159 |
| 40 | Sewing back seam of vamps | Awl, clamp, and knife | Hand | 1 | 1 M | Shoemaker | 36 | 25 | 2.50 | Day | 6.2500 | 40 |
| 41, 45 | Rubbing down seams | Hammer and rubbing stick | Hand | 1 | 1 M | Shoemaker | 36 | 8-20.0 | 2.50 | Day | 2.0833 | 41, 45 |
| 42 | Pasting quarters to vamps | Brush | Hand | 1 | 1 M | Shoemaker | 36 | 8-20.0 | 2.50 | Day | 2.0833 | 42 |
| 43 | Sewing vamps to quarters | Awl, clamp, and knife | Hand | 1 | 1 M | Shoemaker | 36 | 133-20.0 | $2.50 | Day | $33.3333 | 43 |
| 39 | Sewing tips to vamps | Awl, clamp, and knife | Hand | 1 | 1 M | Shoemaker | 36 | 50 | 2.50 | Day | 12.5000 | 39 |
| C | Fitting lasts to measure | Last, knife, and hammer | Hand | 1 | 1 M | Shoemaker | 36 | 50 | 2.50 | Day | 12.5000 | C |
| 60 | Cutting out insoles | Knife and pattern | Hand | 1 | 1 M | Shoemaker | 36 | 16-40.0 | 2.50 | Day | 4.1667 | 60 |
| 68 | Tempering insoles | Water basin and sponge | Hand | 1 | 1 M | Shoemaker | 36 | 3-20.0 | 2.50 | Day | .8333 | 68 |
| 63 | Skiving insoles | Knife and skiving board | Hand | 1 | 1 M | Shoemaker | 36 | 1-40.0 | 2.50 | Day | .4167 | 63 |
| 64 | Rounding and fitting insoles | Knife and pattern | Hand | 1 | 1 M | Shoemaker | 36 | 5 | 2.50 | Day | 1.2500 | 64 |
| 102a | Tacking insoles to lasts | Hammer and last | Hand | 1 | 1 M | Shoemaker | 36 | 6-40.0 | 2.50 | Day | 1.6667 | 102a |
| 65, 69 | Cutting and turning insole channel | Knife and channel iron | Hand | 1 | 1 M | Shoemaker | 36 | 8-20.0 | 2.50 | Day | 2.0833 | 65, 69 |
| 87 | Cutting out counters | Knife and pattern | Hand | 1 | 1 M | Shoemaker | 36 | 8-20.0 | 2.50 | Day | 2.0833 | 87 |
| 88-94 | Skiving counters | Knife and skiving board | Hand | 1 | 1 M | Shoemaker | 36 | 25 | 2.50 | Day | 6.2500 | 88-94 |
| 106, 108 | Cutting out welts | Knife and board | Hand | 1 | 1 M | Shoemaker | 36 | 3-20.0 | 2.50 | Day | .8333 | 106, 108 |
| 110, 115 | Skiving and fitting welts | Knife and skiving board | Hand | 1 | 1 M | Shoemaker | 36 | 16-40.0 | 2.50 | Day | 4.1667 | 110, 115 |
| 95 | Hammering counters | Hammer and lapstone | Hand | 1 | 1 M | Shoemaker | 36 | 3-20.0 | 2.50 | Day | .8333 | 95 |
| 102b, 103 | Inserting counters and shank and drawing uppers over lasts and tacking them to insoles. | Hammer, pincers, knife, etc | Hand | 1 | 1 M | Shoemaker | 36 | 116-40.0 | 2.50 | Day | 29.1667 | 102b, 103 |
| 116 | Sewing welts to uppers and insoles | Awl, knife, clamp, pincers, and hammer. | Hand | 1 | 1 M | Shoemaker | 36 | 98 | 2.50 | Day | 24.5000 | 116 |
| 105 | Pulling out tacks | Pincers | Hand | 1 | 1 M | Shoemaker | 36 | 2 | 2.50 | Day | .5000 | 105 |
| 118 | Beating up welts | Hammer, peaning iron, and knife | Hand | 1 | 1 M | Shoemaker | 36 | 8-20.0 | 2.50 | Day | 2.0833 | 118 |
| 117 | Trimming welts | Welt knife | Hand | 1 | 1 M | Shoemaker | 36 | 8-20.0 | 2.50 | Day | 2.0833 | 117 |
| 119 | Filling bottoms | Hammer and knife | Hand | 1 | 1 M | Shoemaker | 36 | 25 | 2.50 | Day | 6.2500 | 119 |
| 48, 50, 56 | Cutting out outsoles | Knife and pattern | Hand | 1 | 1 M | Shoemaker | 36 | 8-20.0 | 2.50 | Day | 2.0833 | 48, 50, 56 |
| 55 | Tempering outsoles | Water basin and sponge | Hand | 1 | 1 M | Shoemaker | 36 | 6-40.0 | 2.50 | Day | 1.6667 | 55 |
| 54 | Skiving outsoles | Knife and skiving board | Hand | 1 | 1 M | Shoemaker | 36 | 16-40.0 | 2.50 | Day | 4.1667 | 54 |

Source: (United States. Department of Labor, 1899, v2, pp. 544-47)

Figure 2
Slope Chart Linking Hand to Machine Tasks for Unit 71



Bibliography

**Acemoglu, Daron and David H. Autor.** 2011. "Skills, Tasks and Technologies: Implications for Employment and Earnings," In *Handbook of Labor Economics,* ed. O. Ashenfelter and D. Card, 1043-171. Amsterdam: Elsevier-North Holland.

Acemoglu, Daron and Pascual Restrepo. 2018. “Demographics and Automation.” NBER; 24421.

____. 2017a. “The Race between Machine and Man: Implications of Technology for Growth, Factor Shares and Employment.” NBER; 22252.

____. 2017b. “Robots and Jobs: Evidence from Us Labor Markets.” MIT and Boston University.

Aghion, Philippe; Benjamin F Jones and Charles I Jones. 2017. “Artificial Intelligence and Economic Growth.” NBER; 23928.

**Atack, Jeremy.** 1979. "Fact or Fiction? The Relative Costs of Steam and Water Power: A Simulation Approach." *Explorations in Economic History*, 16(4), pp. 409-37.

**Atack, Jeremy; Fred Bateman and Robert A. Margo.** 2008. "Steam Power, Establishment Size, and Labor Productivity in Nineteenth Century American Manufacturing." *Explorations in Economic History*, 45(April), pp. 185-98.

**Atack, Jeremy; Fred Bateman and Thomas Weiss.** 1980. "The Regional Diffusion and Adoption of the Steam Engine in American Manufacturing." *Journal of Economic History,* 40(2), pp. 281-308.

**Atack, Jeremy and Robert A Margo.** 2019. "Gallman Revisited: Blacksmithing and American Manufacturing, 1850–1870." *Cliometrica*, (forthcoming).

Atack, Jeremy; Robert A Margo and Paul W Rhode. 2017. “The Division of Labor and Economies of Scale in Late Nineteenth Century American Manufacturing.”

**Autor, David H.** 2013. "The ‘Task Approach’ to Labor Markets: An Overview." *Journal for Labour Market Research*, 46(3), pp. 185-99.

**Autor, David H.; Frank Levy and Richard J. Murnane.** 2003. "The Skill Content of Recent Technological Change: An Empirical Exploration." *The Quarterly Journal of Economics*, 118(4), pp. 1279-333.

**Bellamy, Edward.** 1888. *Looking Backward, 2000-1887*. Boston: Ticknor and Co.

**Brynjolfsson, Erik and Andrew McAfee.** 2012. "Race against the Machine : How the Digital Revolution Is Accelerating Innovation, Driving Productivity, and Irreversibly Transforming Employment and the Economy," In ed. M. S. S. o. Management.

**____.** 2014. *The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies*. W. W. Norton.

de Pleijt, Alexandra; Alessandro Nuvolari and Jacob Weisdorf. 2018. “Human Capital Formation During the First Industry Revolution: Evidence from the Use of Steam Engines.” Centre for Economic Policy Research; 12987.

Franck, Raphaël and Oded Galor. 2017. “Technology-Skill Complementarity in Early Phases of Industrialization.” NBER; 23197.

**Giedion, S.** 1948. *Mechanization Takes Command : A Contribution to Anonymous History*. New York: Oxford University Press.

**Gray, Rowena.** 2013. "Taking Technology to Task: The Skill Content of Technological Change in Early Twentieth Century United States." *Explorations in Economic History*, 50(3), pp. 351-67.

**Hounshell, David A.** 1984. *From the American System to Mass Production, 1800-1932 : The Development of Manufacturing Technology in the United States*. Baltimore: Johns Hopkins University Press.

**Katz, Lawrence F. and Robert A Margo.** 2014. "Technical Change and the Relative Demand for Skilled Labor: The United States in Historical Perspective," In *Human Capital in in History: The American Record*, ed. L. Boustan, C. Frydman and R. A. Margo, 15-57. Chicago: University of Chicago Press.

**Kim, Sukkoo.** 2005. "Industrialization and Urbanization: Did the Steam Engine Contribute to the Growth of Cities in the United States?" *Explorations in Economic History*, 42, pp. 586-98.

**Ojala, Jari; Jaakko Pehkonen and Jari Eloranta.** 2016. "Deskilling and Decline in Skill Premium During the Age of Sail: Swedish and Finnish Seamen, 1751–1913." *Explorations in Economic History*, 61, pp. 85-94.

**Temin, Peter.** 1966. "Steam and Waterpower in the Early Nineteenth Century." *Journal of Economic History.*, 26, pp. 187-205.

**Thomson, Ross.** 1989. *The Path to Mechanized Shoe Production in the United States*. Chapel Hill: University of North Carolina.

**United States Employment Service.** 1991. *Dictionary of Occupational Titles*. [Washington, D.C.]: : U.S. Department of Labor [Supt. of Docs., U.S. G.P.O., distributor].

1886.*First Annual Report of the Commissioner of Labor, March 1886: Industrial Depressions.*Washington DC: GPO.

**United States. Bureau of Labor Statistics.** 1890-1905. "Rg 257 Records of the Bureau of Labor Statistics, Records of the Department of Commerce and Labor, Reports of Bureau

Activities, 1890-1905 Box No. 1, Scrap Book: Memo and Compilations.," In ed. N. A. a. R. Administration. National Archives.

**United States. Congress.** 1894. "Joint Resolution Providing for an Investigation Relating to the Effects of Machinery on Labor," In *53 Cong.*, *Sess II*, *Res. 43*. Washington DC.

H. R. 526.1894.*Effects of Machinery on Labor.*

1899.*Thirteenth Annual Report of the Commissioner of Labor. 1898. Hand and Machine Labor.*Washington DC: GPO.

**Wells, David Ames.** 1889. *Recent Economic Changes, and Their Effect on the Production and Distribution of Wealth and the Well-Being of Society*. New York,: D. Appleton.

**Wright, Carroll D.** 1900a. "Hand and Machine Labor," In *Gunton's Magazine*, 209-17. New York: Political Science Publishing Co.

**____.** 1900b. *History and Growth of the United States Census*. Washington DC: GPO.

**Zeira, Joseph.** 1998. "Workers, Machines, and Economic Growth." *Quarterly Journal of Economics*, 113(4), pp. 1091-117.