Automation of Manufacturing in the Late 19th Century: The Hand and Machine Labor Study

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Abstract: Recent advances in artificial intelligence and robotics have generated a robust debate about the future of work. An analogous debate occurred in the late nineteenth century when mechanization first transformed manufacturing. We analyze an extraordinary data set from the late nineteenth century, the Hand and Machine Labor" study carried out by the US Department of Labor in the mid-1890s. 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 sheds light on the ability of modern task-based models to account for the effects of historical mechanization.

Over the course of the nineteenth century the United States experienced its first "industrial revolution". A central feature of this revolution was mechanization of production, first through water power and later, steam power. By the late nineteenth century, the process was well advanced, fostering serious concerns about its effects on labor (S. Giedion, 1948, David A. Hounshell, 1984). For example, David A. Wells (1889, p. 68), a prominent US economist of the time, wrote 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 he opined "the depression of industry in recent years has been experienced with greatest severity in those countries where machinery has been most extensively adopted." Indeed, the historical process was so disruptive that it inspired Edward Bellamy's *Looking Backward, 2000-1887* (1888), a utopian science fiction novel, which quickly became the era's third-largest bestseller and provoked extensive political and social discussion.

In the first annual report to Congress, Commissioner of Labor Carroll D. Wright (US Bureau of Labor 1886) drew attention to the problem of the "temporary displacement of labor and to conditions of industry and of society which would exist without the presence of power machinery," illustrating with several examples. In small arms production, for example, one worker 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 workers could turn and fit between 125 and 150 musket stocks per day, a 40- to 50-fold gain in labor productivity. 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).[1]

[1] The US Bureau of Labor was established in the Department of the Interior by the Bureau of Labor Act (23 Stat. 60) on June 27, 1884. The Bureau's mission was to collect information about employment and labor. The Act also

In 1894, Congress requested 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 are fast passing away, and the difficulty increases each year of securing the information sought…" (United States. Congress. House of Representatives., 1894). To this end, it directed the Commissioner of Labor to "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."

The resulting "Hand and Machine Labor" (HML) study took five years to complete, finally appearing as the thirteenth annual report of the Commissioner of Labor (United States. Department of Labor., 1899. Hereafter, BLS). The HML study presents its information at a level of detail that was highly unusual not only for its time but even ours, by analyzing the production of highly specific goods (for example, production of circular saw blades with a given number of teeth) at the task level 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

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created the post of US Commissioner of Labor to direct the Bureau. Carroll Wright served as the first US Commissioner of Labor. The Bureau of Labor became an independent (sub-Cabinet) department through the Department of Labor Act (25 Stat. 182) on June 13, 1888. As indicated by the title of the legislation, the Bureau of Labor was renamed the "US Department of Labor" in 1888. The cabinet-level Department of Commerce and Labor was created in 1903 by the Department of Commerce Act (32 Stat. 827) on February 14, 1903. The Act authorized a new "Bureau of Labor" within the Department of Commerce and Labor, which took over the activities of the preceding "Department of Labor". Finally, in 1913, Congress created a separate cabinet-level Department of Labor, within which the "Bureau of Labor" was renamed the Bureau of Labor Statistics (BLS). As is clear from this timeline, the 1890s "Department of Labor" is a direct predecessor of the modern BLS, which is why the National Archives stores the extant records of the 1890s department in its Record Group 257 ("Records of the Bureau of Labor Statistics"). The discussion in Rockoff (2019, pp.147-51) gives the impression that the "Bureau of Labor" created in 1884 functioned under this name until it was changed to the "Bureau of Labor Statistics" in 1913 but, as the above timeline makes clear, this impression is incorrect.

other data, the report specifies the amount of time each task took, 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, including steam power, which was the key "general-purpose technology" of that historical period. Brynjolfsson and McAfee (2014, p. 6), 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."

The enormously complex HML data were published in two large, very dense volumes. We have digitized these data, coding and restructuring them to be tractable to modern econometric techniques. Our analysis here 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; whether the task content remained the same, even if inanimate power was used under machine production; whether task reorganization occurred in the move from hand to machine labor; or whether entirely new tasks were present under machine labor. Transitions in which the task content remained the same except for the possibility of mechanization – we call these 1:1 transitions -- were the most common. However, highly complex task reorganization did occur, and new task creation substantially dominated the abandonment of obsolete hand tasks. Overall, the transition to machine labor brought very large gains in productivity. We show in a regression analysis of the 1:1 transitions that use of steam power explains a large fraction of the productivity gain. Economic historians have been studying the diffusion and impact of steam power for a very long time; as far as we know, our regressions are the first ever to show the productivity effects of steam power at the level of individual production tasks in an historical context.

We consider the HML data and our findings in the context of the modern "task-based approach" to production (Daron Acemoglu and David H. Autor, 2011, David H. Autor, 2013, Joseph Zeira, 1998). This literature develops models allowing technological change to reduce returns to specific factors, which is not possible in standard models of factor-augmenting technological change. We will focus on particular on Acemoglu and Restrepo's (2018) recent model of automation (also discussed in their paper for this symposium). Their model is quite useful in drawing out inferences as to how, 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 data from the HML study. However, we will also argue that our historical example clearly parts company with Acemoglu and Restrepo in that their model abstracts from the division of labor. Indeed, there is considerable evidence that the diffusion of steam power enhanced division of labor (Jeremy Atack et al., 2008) as Thomson (1989) also shows in the transformation of US boot and shoe production during this time. The underlying issue 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. Indeed, we will suggest that one of the meaningful differences between nineteenth-century mechanization and the current technological revolution based in robotics and artificial intelligence is that they seem to have quite different implications for the division of labor and thus for human capital investment.

The Hand and Machine Labor Study

Although the title of the 1899 study was "Hand and Machine Labor," Commissioner of Labor 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, some tasks in machine production continued to be performed by hand using these same simple tools, including adjusting the machinery. 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 was central (United States. Department of Labor., 1899, p. 11).

The basic unit of observation in the HML study was a matched pair of production units: one using hand methods, the other using machine methods to make a particular 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. We elaborate on this below. Overall, there are 672 paired units in the HML study: 27 in agriculture, 10 in mining and quarrying, and 9 in transportation, leaving 626 paired units producing manufactures. It is on these manufactures which we focus.

As mentioned, the data were reported in two parts (volumes). In Part One, the following was reported for each unit (matched pair of plants producing a highly specific product): an industry classification, an exact description of the product, the standardized quantity of that product, 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, the following information was reported for each mode of producing the product: 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; 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; and the labor cost of each employee engaged in the task along with any miscellaneous comments.

The raw data were collected by trained agents either through direct observation or from written records, following up (sometimes repeatedly) when necessary to resolve inconsistencies and ambiguities. For machine production, the vast majority of the observations pertain to activities conducted in the mid-to-late 1890s (1894-98). For a few products, the study 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 agents assiduously sought out historical records or, in 13 instances, located hand production establishments overseas that they deemed similar to those that no longer survived in the United States. All machine production data, however, was taken from US establishments. Moreover, in the majority of cases, two reports on hand and machine production were secured for establishments/manufacturers from different, widely separated, localities to help spot errors and omissions with "the better and more complete one then selected for presentation." (United States. Department of Labor., 1899, v1, p. 13).

A concrete example illustrates the exceptional (indeed, stupefying) detail in the published study. In making men's medium grade, laced shoes (Unit 71), the study 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. [2] 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.

Hand production of medium grade, laced shoes involved 72 tasks. 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—all of which had to be both sorted and matched). In hand production, the individual shoemaker traced each foot to create a cutting pattern and subsequently hand-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 individual customer served by the shoemaker. Producing lasts by hand was time-consuming, taking 54 minutes 24 seconds per pair—almost 92

[2] Exhibits 1 and 2 in the online Appendix available with this paper at http://e-jep.org reproduce sections of the tables for Unit 71 detailing the tasks in the hand and machine production of men's medium grade, laced shoes from the HML report (United States. Department of Labor., 1899. Available from HathiTrust.org: http://hdl.handle.net/2027/nnc1.cu08593957)

hours for the production run of 100 different pairs of shoes By contrast, under machine production, the factory skipped these steps, instead purchasing lathe-turned lasts for left and right feet in standard sizes from outside specialist suppliers, which would be used in the fabrication of thousands of pairs of shoes—an example of the subsidiary industries predicted to emerge to meet special needs once a certain scale of operation was achieved (Alfred Marshall and Mary Marshall, 1881, p. 52).

In the machine production of these shoes, the HML study identified 173 separate tasks. 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. Tasks also included finishing the shoes for market by smoothing the welts, waxing and polishing, matching pairs, stamping with the maker's name and size and boxing for shipment. Moreover, other tasks involved keeping the shoe-making machinery in good order, and maintaining and firing the steam engine that powered the various machines—tasks not directly involved with production but vital to that production. 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, however, 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).

The study 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.

The data showing the connections from hand tasks to machine tasks can be as a "slope chart" shown in Figure 1 relating each of the various hand tasks for shoe-making on the left to the (far more numerous) machine tasks for shoe-making on the right (Edward R. Tufte, 1983, p. 143. https://www.edwardtufte.com/bboard/q-and-a-fetch-msg?msg_id=0003nk).

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 like "selecting and sorting stock" vanish in machine production (we have connected these to "Task 0" in Machine Production on the right hand side). Moreover, the white space on the right hand axis to which no hand production tasks connect represent new tasks created by mechanization for which there was no hand production analog. In the next section, we discuss these task "transitions."

The complexity of the HML data totally overwhelmed statisticians at the time. As Carroll Wright (1900) would later remark "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." Its complexity has also largely prevented analysis by modern economic historians until very recently.[3]

Before turning to our findings, we highlight four limitations of the HML data. First, although a wide range of goods and industries are covered, the establishments that were included are in no sense a random sample either within or across industries. Second, no information was

[3] Stanley Engerman has informed us (via personal communication) that he and Robert Fogel included the HML study on an unpublished list of key data sources in US economic history that the two prepared in the early 1970s. However, in their view the data were far too complex to digitize and analyze at that time, which was a reasonable judgement until recent advances in information technologies.

collected on output prices, revenues, or costs, except those pertaining to the labor involved directly in the production of the product (and its supervision). Consequently, 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 measure that would be more conventional for economists like value added per worker. Third, while the agents recorded additional information on the survey form that would have been very useful for have for some analyses – for example, the names of the individual workers, and the address of the establishment--this information was not included in the published study. Moreover, as far as we can determine, the completed survey forms have not survived and so this additional information has been lost.[4] Finally, as previously noted, the study 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.

Task Transitions and the Role of Steam Power

We focus on three broad features of the HML data – transitions of tasks from hand to machine labor; the overall productivity gains associated with machine labor; and the impact of steam power on productivity in machine production for the subset of tasks that were common to both hand and machine labor (tasks in the 1:1 transition category; see below).

[4] We tracked down copies of the original survey instrument which are now stored 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.

Task Transitions: From Hand to Machine Production

The data from the HML study allow us to see the transition from hand to machine labor at the task level. The agents collecting the data listed tasks in production order under both hand and machine manufacture, adding a column linking hand to machine tasks. This allows us to draw a slope chart as in Figure 1 and to distinguish six types of transitions from hand to machine tasks:

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

Table 1 presents summary statistics from the point of view of the origin – hand labor (Panel A)– and the destination – machine labor (Panel B). Instead of counts of transitions, we focus on task shares. We normalize within production units either by the total number of tasks (equal weights) or by weighting each task by its share of total production time (time weights); in either case, our estimates of average shares are equally weighted across units. Both panels also show the proportion of tasks that were mechanized, whether by steam or water, similarly weighted. The sample used to compute Table 1 covers 610of the original 626 manufacturing units.[5] For the most part, our discussion of Table 1 focuses on the equally weighted statistics in Table 1.

Although some hand tasks were abandoned in the transition to machine labor, these comprised a small share of hand tasks and of the time spent in hand labor. The largest category of transitions was 1:1 – that is, the agents were able to match a singleton hand task with a singleton machine task whose content was deemed to be the same, except that the machine production, the task was far more likely to be mechanized. As can be seen from Panel B, about 48 percent of 1:1 machine tasks used inanimate power; of these, 92 percent (0.44/0.48) were steam-powered.

As examples of mechanization in 1:1 transitions, consider the relatively large number of tasks involving trimming excess leather at various stages (e.g. operations 33, 117, 133 and 135) or "skiving" leather where it overlapped to reduced bulk (operations 17-21, 54, 63, 71, 82, 88-93 and 135) in the production of boots and shoes, such as in Unit 71. Many patents were issued for tools and machines to facilitate these activities (see, for example, patents issued for leather trimming and skiving prior to 1874: (United States. Patent Office, 1874). Under hand production, these activities were accomplished with a sharp (sometimes, specialized) knife, guided by hand and eye. Under machine production, however, the knives were built into powered machines (e.g. see, for example, US Patent 609868A granted 1898. Also

[5]We excluded units from foreign countries, those that used horses, and which were otherwise missing data necessary for our analyses.

https://www.youtube.com/watch?v=Jv-nE1ixiB0 for a more or less contemporaneous with the HML study of a belt-driven skiving machine). These operated at high speed, allowing little chance of recovery if the product were wrongly placed and with considerable risk to the operator. The operation of the trimming machine (and trimmer), for example, is described as follows: "[it] consists of a sharp knife edge, operating constantly against a sharp edged revolving top. The man who works the machine stands, holding upside down somewhat below the level of his eyes, the partly made, still unsoled shoe. He turns it skillfully and rapidly on the revolving top, against whose sharp edge the second knife-blade operates, cutting off all the surplus crimpled leather. The work is extremely rapid and absolutely uniform. But it takes skill and close attention. The machine could easily cut off too much, or could cut into the upper, if the swift handling of the shoe were not absolutely correct" (Josephine Goldmark and Louis Dembitz Brandeis, 1912, p. 65).

The more complex transitions that involved subdividing (1:M) or consolidating (N:1) tasks, or possibly both (N:M) were less common but by no means unusual. Keeping with the example of producing medium grade, laced shoes (unit 71), machine production consolidated all the tasks associated with creating a pattern and shoe last to custom fit the shoes to the customer by making the shoes in pre-determined "standard" sizes (i.e. a 1:M transition). However, a true uniform standard for shoe sizes was not adopted in the US until around the First World War, first with the "Ritz stick" (measuring foot length and patented 1916) and later in the 1920s with the Brannock measure (https://brannock.com/pages/about-us) which is the measure that you still find in most shoe-stores today and measures both length and width. Similarly, the development of a super heavy-duty sewing machine (such as patent US 502873, granted to J. E. Bertrand in 1893) which allowed the outsoles to be attached to the welts directly while locking the shoe shank in place. This reduced what had been two separate tasks in handicraft production to a single machine operation (that is, a N:1 transition, or consolidation). From the perspective of hand labor, about 28 percent of hand tasks, on average, fell into the 1:M, N:M, or N:1 transitions; the corresponding figure from the perspective of machine labor was smaller, about 21 percent. As Panel B shows, the more complex transitions were also more likely to be mechanized by steam, especially consolidations.

An important finding in Panel B is that new tasks were nearly a third of all tasks in machine labor, a much higher fraction than the share of hand labor tasks that were abandoned. Compared with the other tasks performed by machine labor, these new tasks were considerably less likely to use steam power, although the overall rate of steam use in new tasks, about 36 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 percent 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 (for example, the task of. foreman/supervisor) and inspection of the finished product (for example, inspector, examiner, packer and finisher). These activities made up about 20 percent 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 single worker or group thereof assumed responsibility for the outcome of the production process.

The relative importance of new tasks declines when the data are weighted by time, indicating that many of the new tasks were relatively brief in duration. Even allowing for this, however, new tasks performed by machine labor accounted for a larger share of total production time than the share of time accounted for by old tasks in hand labor. We return to this point later in the paper when we consider our findings in light of Acemoglu and Restrepo's model of automation.

Although we have focused on task shares in Table 1 it is important to acknowledge that the absolute number of tasks increased from hand to machine labor. This increase is a direct manifestation of the increased division of labor that accompanied mechanization As Atack, Margo, and Rhode (2017) describe in detail, it is possible to use the information in the HML study to compute a summary statistic of the division of labor—specifically, the proportion of tasks performed by the average worker. Multiplying by the number of tasks transforms the statistic into the average number of tasks per worker. In hand production overall, the average number of tasks per worker was 4.3, but in machine production it was just 1.2. In other words, the division of labor in machine production was virtually complete – if the HML study delineated 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. As Marshall (Alfred Marshall and Mary Marshall, 1881, p. 49) would note, "when the division of [labor] is carried very far a man's whole attention is concentrated on one operation…[and] such operations are performed …with a rapidity and an unerring accuracy…" We return to the division of labor below.

The Productivity Effects of Machine Labor and the Role of Steam Power

The standard way to measure labor productivity is by the flow of output over some period of time (e.g. annual) divided by total labor hours over the same period. The HML study did not do this. Rather, for a standardized quantity of the specific good, the HML staff computed the amount of time each task took and then summed to get the total amount of time. Because the specific good is held constant (insofar as this is ever possible) as is the standardized quantity, the overall productivity gain is simply the difference in total time between machine and hand labor. Given that the products in question were so very different, we do not compute the productivity gain in absolute units of time (e.g. hours) but rather calculate the logarithm of the ratio of machine to labor time, which is then averaged (equally weighted) across units. This average is -1.96. If we take the exponent, it is 0.14 [= exp (-1.96)] -- that is, on average, machine labor reduced total production time by a factor of seven (H1/0.14).

What accounts for these remarkable gains in productivity? In our earlier paper (Jeremy Atack, Robert A Margo and Paul W Rhode, 2017) we concentrated on the role of division of labor (see also the discussion below). In this paper we shift our attention to mechanization – that is, the use of an inanimate power source, in particular, steam power.

Economic historians have long had a keen interest in the diffusion of the steam engine and its attendant microeconomic and aggregate effects. These include 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 also been studies of how mechanization, whether steam power or electrification, affected the relative demand for different occupations (Alexandra de Pleijt et al., 2018, Raphaël Franck and Oded Galor, 2017, Rowena Gray, 2013, Jari Ojala et al., 2016). By comparison, the HML study allows us to narrow the focus 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 difference the data at the task level within production units..

Table 2 reports OLS regressions in which the dependent variable is the difference in the logarithm of the amount of time that the task took in machine versus hand production and the independent variables of interest are the differences between machine and hand production in use of steam or water power. We cannot claim this to be a causal analysis because inanimate power use was not randomly assigned – however, the regressions include a full set of unit fixed effects which should help with omitted variable bias. Note that the sample mean of this variable, -1.74, is somewhat less than the overall difference in productivity (-1.96), implying that the more complex transitions in Table 2 accounted for more of the overall productivity gain than did the 1:1 transitions.

Use of steam power is associated with a substantial reduction in time needed to complete the given task, accounting for a relatively large share of the overall productivity gain from hand to machine production. In column 1 of Table 2, for example, the value of the steam power coefficient, -1.13, is equal to 65 percent of the mean value of the dependent variable. Column 2 differs from column 1 in that we include the log of the amount of time the task took in hand production, allowing for regression to the mean. This reduces the explanatory power of steam power use, but it is still quantitatively significant (the coefficient, -0.84, accounts for 48 percent of the mean value of the dependent variable). The regression also reveals a statistically significant, but more modest impact of water power use, possibly because of water's seasonality and storage constraints that limited its sustained flow.

Discussion

We discuss our results in light of the recent paper by Daron Acemoglu and Pascual Restrepo (2018. See also their paper in this symposium) which provides a formal task-based model for analyzing the effects of automation. In Acemoglu and Restrepo's (AR) model, tasks are ordered on continuum along the unit interval from K– 1 to K in terms of the relative productivity of labor relative to capital. There is an assumed threshold value of labor's comparative advantage such that below the threshold a task could be performed either by labor or capital, but above which 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 relative to labor, given labor's comparative advantage. A deterioration in labor's comparative advantage below the threshold (because of improvements in machine quality) or a reduction in capital costs relative to labor costs (holding labor's comparative advantage constant) will induce automation -- capital will perform some tasks that previously were performed by labor.

Their model also allows for new tasks to be created that are superior to existing tasks. The process by which this occurs is independent from changes in capital costs that induce automation. The assumptions in the model ensure that new tasks will appear at K, the right endpoint of the unit interval, while abandoned tasks will come from the left endpoint at K-1. The entire interval moves to the right, as tasks at K-1 are abandoned.

The key implications of AR concern the net impacts of automation and new task creation on labor demand. If automation occurs, there is a displacement effect – capital replaces labor in some tasks below the threshold. However, there is also a productivity effect. If overall output increases sufficiently, demand for labor at non-automated tasks will increase on net. If, on net, new tasks use more labor, labor demand will further increase. However, if new tasks use less labor compared with abandoned tasks, the net impact of task replacement is negative, reducing any positive net effect that automation might have otherwise through productivity gains.

We cannot use the HML data to literally "test" the AR model for three reasons. First, AR order tasks in terms of labor's comparative advantage at performing them. This is not the same as the order that tasks were actually performed in production. Second, we cannot re-order the HML tasks in terms of labor's comparative advantage because this is not observed in the HML data. Third, tasks in the AR model are on a continuum whereas the task descriptions in the HML study are written summaries of discrete activities – in effect, subsets of the tasks in AR's unit interval. Even if the HML staff had somehow channeled the logic of an economic model from 125-odd years into the future and managed to collect information on labor's comparative advantage, this would refer to the discrete activity, not to points (tasks) on AR's unit interval.

Nevertheless, the AR model is still highly valuable, in our opinion, as an interpretive framework. AR's displacement effect is obviously present; inanimately-powered machines did things that were previously done by hand using simple tools. In some cases, the machine task was a sped-up version of what hand labor did – a machine-powered sander or polisher, for example. But, as shown by the N:1 transitions, multiple hand tasks were also consolidated into a single machine task, a complicated transition that cannot simply be described as a faster version of a single hand labor activity. As Marshall (1890, p. 112) observed in his *Principles*, "machinery constantly supplants and renders unnecessary that purely manual skill, the attainment of which was, even up to Adam Smith's time, the chief advantage of division of [labor]. But this influence is more than countervailed by its tendency to increase the scale of manufactures and to make them more complex; and therefore to increase the opportunities for division of [labor] of all kinds." Moreover, the displacement effect must have been largest for the N:1 transitions, because the N hand tasks took nearly twice as long to complete (as a share of total time) than 1 machine task, a far larger amount of "labor-saving" than is evident in the other transitions. The N:1 transitions, as we noted earlier, were the most mechanized – the share of machine tasks using steam or water power – of all the transitions from hand to machine production.

Second, the productivity effect was enormous. While detailed data are lacking, there is little doubt the average annual hours of operation per establishment in manufacturing increased over the nineteenth century (Jeremy Atack and Fred Bateman, 1992, Robert Whaples, 1990). Yet, as the HML study shows, the amount of time it took machine labor to complete a product was a mere fraction of the time it took machine labor. On an average annual basis, therefore, the increase in total output was an order of magnitude larger than the displacement effect per unit of output, implying a very large positive impact on labor demand.

Third, the net effect of the introduction of new tasks on labor demand appears to have been positive. This is because the share of time taken up by new tasks in machine labor was larger than the share of time associated with hand tasks that were abandoned – indeed, five times larger. Among other activities, these new tasks included maintenance of steam engines, foreman supervising large numbers of workers (see below), and workers packaging products for distant markets.

The upshot is that the transition from hand to machine labor led to a vast expansion in the size of the manufacturing labor force, in absolute number and as a proportion of the national aggregate. This was because, not in spite of, an equally vast increase in productivity, such that by the end of the nineteenth century, output per worker in US manufacturing was twice the level in Britain or Germany (Stephen N. Broadberry, 1998). As we have noted, a long literature in economic history and economics asserts that the diffusion of steam power was a major factor behind the increase in productivity, but never, until the regression analysis in this paper, has this been demonstrated for individual production tasks.

However, our analysis also shows that steam power was not the full story. In our earlier paper (Jeremy Atack, Robert A Margo and Paul W Rhode, 2017), we studied the overall difference in productivity between machine and hand labor at the unit, rather than task level. Because we were analyzing differences across units rather than across tasks within units, we could include measures of the overall division of labor in the relevant regressions. We found that direct measures of the division of labor – specifically, the fraction of total tasks performed by the average worker and the number of tasks – fully account for the positive effects of overall scale, as measured by the number of workers. Unlike the regressions in Table 2 of this paper, those in our earlier paper do not control directly for steam (or water) power, but instead have a dummy variable for hand production. The coefficient of this dummy variable is positive and significant, implying that, once we control for the division of labor, other factors associated with machine labor compared with hand labor, such as greater use of steam power, contributed to overall productivity gains. Our results in Table 2 here are fully consistent with this interpretation.

The point we wish to make here is that, as useful as it is as an overall framing device, the AR model omits a fundamental feature of historical industrialization – namely, its extensive division of labor. As far as the AR model is concerned, the individual workers who perform tasks before and after automation could be the same people.

In point of fact, however, they were not the same people. In the tiniest shops that are iconic depictions of hand production in early manufacturing, the artisan was 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 the business. In the transition to machine labor, the artisan shop was displaced by the factory, which was different in many ways that could perhaps be summarized as "more" of everything – more capital, more labor, and more output. Establishments grew in size and complexity, an evolution that spawned the rise of a white collar labor force to oversee it – a "visible hand" in Alfred Chandler's memorable phrase (Alfred Dupont Chandler, 1977).

Our concern here is not so much the rise of the modern corporation *a la* Chander but rather what labor historians call "de-skilling". Examples of deskilling are everywhere to be found in the data from the Hand and Machine study. We have already cited the example of shoemaking; another example is blacksmithing—who were making rakes (unit 30), most of the assorted carriage and wagon products (units 140-185), tools and various other metal goods. The "village smithy," fashioning metal objects like pots, pans, plows, and numerous other objects from iron, 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 in making plows, rakes, and hoes and related tools. Faced with such competition, blacksmith shops either shifted away from making objects to fixing them by offering repair services, or simply disappeared. The job of blacksmithing was once considered sufficiently numerous to warrant its own industry classification, but by the very end of the nineteenth century it was dropped from the manufacturing census as no longer the worth the trouble to enumerate.

The point we are emphasizing, however, is not deskilling per se, but rather that the extent to which individual workers might be specialized in allocating their labor across tasks has important implications. The massive division of labor documented front and center in the HML 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. Earlier in the nineteenth 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 human capital investment problem facing the prospective manufacturing worker in the 1890s was quite different. 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, and such mastery might be gained 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 this 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 artificial intelligence. This is perhaps the sense in which the history how technology affects jobs is not repeating itself, and "this time" really is different.

Concluding Remarks

To understand the effects of automation on jobs, a number of 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 automated with capital. 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 the US Department of Labor's Hand and Machine Labor (United States. Department of Labor., 1899) study. The study has been long known by economic historians —but almost never used because the data were, until recent advances in information technologies, too complex to analyze. Our analysis of the HML data confirms the modern view that the "machine age" was transformative. It also reveals, however, that current task-based models of automation need elaboration to account of certain effects of mechanization on labor that were historically relevant, like the division of labor.

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. For example, the steam engine was revolutionary in its time, and in retrospect it is clear that it "destroyed" some jobs but created many others. However, the extent to which the disruptive effects of the mechanization of the past serves as a prologue to the technologies of the present or future , or whether the modern technologies of robotics and artificial intelligence are fundamentally different in some way, remains an open question. It is intriguing to imagine how artificial intelligence might reduce the cost of reassigning and reorganizing tasks, allowing for more efficient dynamic optimization of production in response to changing conditions. Models that allow for such shifts of tasks and alterations in the division of labor may pay a useful role in understanding the technological shifts to come.

Table 1: Tasks Transitions, Hand to Machine Labor

Panel A: Hand Labor

Transition	Share of Tasks, Equal Weights	Share of Tasks, Time Weights	Share using Steam Power, Equal Weights	Percent Using Steam Power, Time Weights	Percent Using Water Power, Equal Weights	Percent Using Water Power, Time Weights
1:0	0.044	0.030	0.003	0.002	0.002	0.0004
1:1	0.674	0.605	0.014	0.009	0.017	0.020
1:M	0.135	0.191	0.023	0.008	0.005	0.006
N: M, N>1, M>1	0.040	0.053	0.0004	0.00002	0.010	0.003
N:1	0.107	0.120	0.010	0.031	0.018	0.019
Total	1.000	1.000	0.014	0.011	0.014	0.016

Notes to Panel A: unit of observation is a task, as described by the HML staff. Basic sample size in Panel A is 7,148 hand tasks from 610 production units; sample size is slightly smaller using time weights because of missing data.. Computed from digitized version of the HML study, see text and (United States. Department of Labor, 1899). 1:0 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. Equal weights: observations count equally in determining the average task shares within units. Time weights: observations are weighted by completion time in determining the average task shares within units.

Panel B: Machine Labor

Transition	Task Shares, Equal Weighs	Task Shares, Time Weights	Share using Steam Power. Equal Weights	Share using Water Power, Equal Weights	Share using Steam Power, Time Weights	Share using Water Power, Time Weights
1:1	0.458	0.563	0.436	0.029	0.461	0.033
1:M	0.146	0.172	0.558	0.058	0.538	0.068
N: M, N>1, M>1	0.025	0.038	0.593	0.070	0.518	0.068
N:1	0.037	0.070	0.756	0.052	0.764	0.060
0:1	0.334	0.157	0.360	0.012	0.330	0.020
Total	1.00	1.00	0.444	0.030	0.477	0.040

Notes to Panel B: see Panel A for source information and definition of row headings. 0:1: new tasks under machine labor. Unit of observation is a task as described by the HML staff. Basic sample size in Panel B is 12,471 machine labor tasks from 610 production units; sample size is slightly smaller using time weights because of missing data.

Table 2: The Productivity Effects of Steam Power in Machine Tasks: 1:1 Task Transitions

Dependent Variable	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)		-0.36 (28.95)
Machine task uses steam – Hand task uses steam	-1.13 (28.83)	-0.84 (22.91))
Machine task uses water – Hand task uses water	-0.35 (3.56)	-0.28 (3.11)
Adjusted R2	0.52	0.61

Note: sample consists of tasks in the 1:1 transition category for which there was complete information on the regression variables (N = 4,257). The mean value of the dependent variable is -1.74. Regression includes unit fixed effects.

Online Exhibit 1A

Unit 71: Hand labor production of "100 pairs men's medium grade, calf, welt, lace shoes, single soles, soft box toes"

Operation number.	Work done.	Machine, implement, or tool used.	Motive power.	Persons necessary on one machine.	Employees at work on the unit.							Operation number.
					Number and sex.	Occupation.	Age.	Time worked.	Pay of labor.		Labor cost.	
								h. m.	Rate.	Per—		
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

This is a section of the original record for Unit 71. Source: (United States. Department of Labor., 1899, v2, pp. 544-47)

Online Exhibit 1B

Unit 71: Machine labor production of “100 pairs men’s medium grade, calf, welt, lace shoes, single soles, soft box toes”

Operation number.	Work done.	Machine, implement, or tool used.	Motive power.	Persons necessary on one machine.	Employees at work on the unit.							Operation number.
					Number and sex.	Occupation.	Age.	Time worked. h. m.	Pay of labor. Rate.	Pay of labor. Per—	Labor cost.	
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

This is a section of the original record for Unit 71. Source: (United States. Department of Labor., 1899, v2, pp. 544-47)

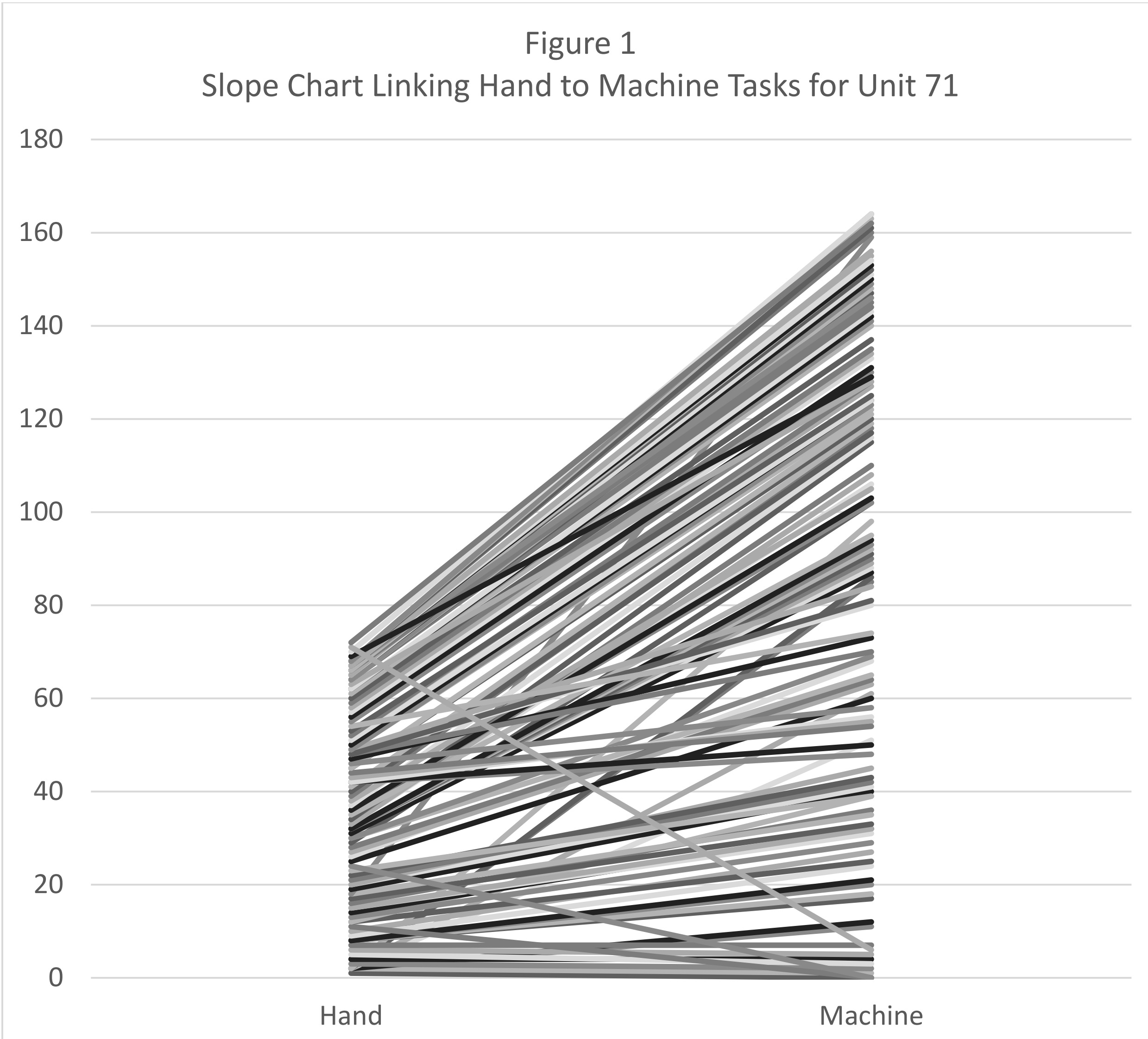
Figure 1
Slope Chart Linking Hand to Machine Tasks for Unit 71
180
160
140
120
100
80
60
40
20
0
Hand
Machine

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