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THE ECONOMIC HISTORY OF AMERICAN INEQUALITY

New Evidence and Perspectives

Edited by Martha J. Bailey, Leah Platt Boustan, and William J. Collins

The Economic History of American Inequality

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Conference Report

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Contents

1

Wage Inequality in American Manufacturing, 1820–1940
New Evidence

Jeremy Atack, Robert A. Margo, and Paul W. Rhode

1.1 Introduction

At the start of the 19th century, over 80 percent of the American labor force was engaged in agriculture. Among those not in farming, only a small portion, perhaps 5 percent of the labor force, was engaged in manufacturing for the domestic market. Virtually all this production occurred in small-scale artisan shops, in which a highly skilled proprietor, either on his own or with apprentices, made goods using traditional hand tools. By the end of the 19th century, the share of the labor force in agriculture had been cut in half, to 40 percent, and the share of the labor force in manufacturing rose to 15 percent. While artisan shops remained numerically important, most manufacturing production circa 1900 came from large, mechanized factories, in which the typical production worker was a semiskilled operative using special-purpose, steam-powered machinery while other "nonproduction" workers reported on and managed the flow of output. Subsequently, over the next several decades before World War II, factory production continued to grow while

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steam power was displaced by electricity. These developments greatly altered the absolute and relative demands for various occupational skills in manufacturing as well as the incentives for individuals to acquire and supply them, potentially altering the distribution of manufacturing wages and, therefore, of economic inequality. As Frederick C. Mills would remark in his introduction to Harry Jerome's famous NBER study, "Mechanization . . . in all its countless manifestations reacts upon the volume of employment, the skills and the working methods of the human factors of production" (1934, xxiii).

The consensus view from these changes is that wage inequality in American manufacturing followed an inverted-U path over our period of study (Lindert and Williamson 1976, esp. fig. 1.1, 2016; Williamson and Lindert 1980). The rising portion of this inverted U occurred from the early to the late 19th century, and the decreasing portion from the turn of the 20th century until just before World War II (Atack et al. 2004; Goldin and Katz 1999, 2008; Katz and Margo 2014; Margo 2000). The rising portion of the inverted U has been attributed to "hollowing out"—growing relative demand for factory operatives in the lower tail of the wage distribution and for white-collar nonproduction workers in the upper tail—at the expense of artisans in the middle (Atack et al. 2004; Goldin and Sokoloff 1984; Katz and Margo 2014). The falling portion is attributed to the rapid growth in the supply of skilled labor at the top end of the distribution due to the "high school movement" and to the emergence of "technology-skill complementarity" as electrification reorganized factory production, reducing the demand for low-paid factory jobs at the bottom (Goldin and Katz 1998, 1999, 2000, 2008; Gray 2013; Lafortune et al. 2019).

Since wage labor figures prominently in explanations for both the rise and fall, one might suppose that economic historians have documented the inverted U shape with comprehensive time series on the full distribution of manufacturing wages. Unfortunately, the previously available evidence falls short of the ideal, especially earlier in the 19th century. Instead, scholars have relied heavily upon occupation-specific average wages to produce time series of "skill differentials"—ratios of wages of skilled blue-collar or white-collar to unskilled or semiskilled workers—which broadly trace out an inverted U (Autor et al. 2020; Goldin and Katz 1999, 2008; Goldin and Margo 1992; Lindert and Williamson 1976; Margo 2000; Williamson and Lindert 1980). While such series are highly useful, their correlation with temporal movements in overall wage inequality cannot be established directly for the pre–World War II period. In recognition of that, there have been some attempts to go further using data from the federal censuses of manufacturing and related reports. For the rising portion of the inverted U shape, Atack et al. (2004) used data from samples of the 1850–1880 manufacturing censuses (Atack and Bateman 1999) to show that the distribution of the "establishment wage"—the average wage in individual establishments—became increasingly unequal over time, primarily because of an increase in the density of workers employed in establishments paying lower-than-average wages. While this pattern is consistent with rising wage inequality overall, it presumes that there were no offsetting changes in wage inequality within establishments, which cannot be tested with their data (Atack et al. 2004).

For the falling portion of the inverted U, Goldin and Katz (1999) estimate wage quantiles for a panel of 10 industries in 1890 and circa 1940, from which they construct standard inequality ratios (50–10, 90–50, and 90–10). These ratios are considerably smaller just before World War II than in 1890, consistent with a reduction in overall inequality. However, as they point out, this inference presumes no offsetting changes in interindustry wage differentials. Moreover, with just two end points, it is impossible to determine when the change occurred. In addition, existing studies provide, at best, limited direct evidence on the role of explanatory factors, such as the increasing division of labor and the declining importance of physical strength with increasing use of inanimate sources of power such as steam earlier in the period (Atack et al. 2004) and electricity later (Goldin and Katz 2008).

Our new evidence comes from two sources. The first is recently digitized data from the US Department of Labor's 1899 *Hand and Machine Labor* (hereafter, *HML*) study, which provides detailed data at the production operation level for two different production modes, "hand" (artisan) versus "machine" (mechanized factories) in the manufacture of hundreds of specific goods, called "units" in the study.[1] In previous work (Atack et al. 2019, 2022), we have shown that empirical differences between hand and machine labor in the *HML* study faithfully reflect changes over time in the evolution of labor productivity in 19th-century manufacturing from artisan to factory production. With this as (broad) validation, we use these data to explore the impact of these changes on wage inequality within manufacturing establishments, something not previously possible.

We begin our analysis of the *HML* study data by computing the time-weighted standard deviation of (ln) labor cost (wage of the worker per standardized unit of time) across all operations within the machine or hand labor unit, which becomes the main variable of interest.[2] Compared with hand

1. A unit in the *HML* study refers to two modes of production and the sequences of operations that each involved making a precisely defined (in terms of characteristics, quantity, and quality) product, one using the traditional, "hand" (i.e., artisan) methods, and the other the most advanced factory ("machine") methods then available. Within this unit, the *HML* staff traced and matched production steps across modes. While these data are not, strictly speaking, establishment level, they are sufficiently related to provide useful evidence on the differences in, for example, labor productivity and de-skilling that resulted from the long-term shift from the artisan shop to the factory system (Atack et al. 2022, 2024).

2. "Time-weighted" means that the ln (labor cost) of each operation is weighted by the amount of time needed to complete the operation. Note that if a single worker performs all operations, then *ln* (labor cost) is the same for all operations and therefore the standard deviation is identically zero. As we show, single worker units were disproportionately found in hand labor.

labor, machine labor production utilized a greater division of labor, which required more workers, as well as greater use of special purpose machinery, which was powered inanimately, mainly by steam (Atack et al. 2022). We sketch a simple framework under which greater division of labor will lead to increased dispersion of wages within establishments and hence a higher level of wage inequality. Wage inequality may increase further due to mechanization, as greater use of steam power raised the relative demand for unskilled—and hence low-wage—labor, since the machines being driven by steam required less operator skill than the use of traditional hand tools.

Our main empirical result from the analysis of the *HML* data is that wage inequality was approximately 90 percent higher, on average, within the machine labor units than the hand labor units, a difference that is economically and statistically significant. Regression analysis includes unit fixed effects and so is equivalent to differencing between machine and hand labor, holding the product (the unit) constant. We find that wage inequality was increasing in the use of inanimate power and in the division of labor. On average, use of inanimate power was much higher under machine labor, as was the division of labor. However, in terms of explanatory power, greater division of labor was the more important factor, accounting for approximately twice as much of the higher wage inequality in machine labor production compared with mechanization. Our analysis of the *HML* study data suggests, therefore, that the transition from the artisan shop to the mechanized factory over the 19th century was associated with an increase in wage inequality in manufacturing, due disproportionately to changes in the organization of production that occurred.

Our second source is newly digitized data from state government reports on manufacturing wages published as tables of so-called classified wages. These give the number of workers whose weekly earnings were categorized ("classified") into bins—for example, from $8.00 to $9.00 per week. These are the same type of data studied by Goldin and Katz (1999), except that our source and reference frame are different—the state versus the federal government, covering many years. Specifically, we use the most comprehensive such series, those for the state of Massachusetts, which cover from the late 1880s to the late 1930s.[3] We have also digitized data on electricity use in Massachusetts manufacturing, which the state collected for selected years.

3. The 1890 federal census of manufacturing (US Census Office 1895b) reported such distributions, by industry, for establishments in select cities, which Goldin and Katz (1999) used in their work. The Massachusetts data come from the state's "Annual Statistics of Manufactures" first taken in 1886 (Massachusetts Bureau of Statistics of Labor, [for the years 1886 and 1887] 1889, 135). It reported classified wage distributions beginning in the 1890 report. Because of how this serial of annual reports was issued, we reference the year of the specific issue in brackets and report its publication date in parentheses. In addition to the Massachusetts reports, we have located similar data in reports for nine additional states (California, Illinois, Iowa, Kansas, New Hampshire, Ohio, Rhode Island, Texas, and Wisconsin). Unlike the Mas-

Our main analysis of the Massachusetts data is based on estimates of the 10th, 25th, 50th, 75th, and 90th quantiles of the classified distribution of weekly earnings for production workers. The quantile estimates are made following the general procedure outlined in Blalock (1960, 55; also used by Goldin and Katz 1999). We present the actual series along with smoothed estimates derived from nonparametric regressions.

Our estimates show a marked reduction in wage inequality in Massachusetts manufacturing over the study period. This was present in the lower tail (50–10 ratio), upper tail (90–50), and the interquartile range (75–25) but, quantitatively, was largest in the lower tail. The compression in lower-tail inequality was modest in the 1890s but accelerated after the turn of the century.

In explaining the decrease in inequality between their 1890 observation and their circa 1940 one, Goldin and Katz (1999) emphasize two factors: the "high school" movement, which compressed the top half of the wage distribution (by reducing the returns to skill, as embodied in education), and electrification, which eliminated many of the low-wage jobs that were associated with the use of steam power, such as shoveling coal (see also Jerome 1934). We use our Massachusetts data to shed further light on the role of electrification. First, we generate a time series of the percentage of horsepower used in Massachusetts manufacturing derived from electricity. While this series is not sufficiently frequent to use for time-series regression, it conclusively shows electrification began in earnest after the turn of the 20th century, accelerating after 1910. In 1895, just 1.5 percent of horsepower used by Massachusetts manufacturing was provided by electric motors. This share had increased to a third in 1920 and then to over 60 percent by 1938.

To examine the impact of electrification on wage inequality, we have compiled an industry-level panel for Massachusetts for two years (1895 and 1920), which covers 42 industries. For each industry-year pair, and following Goldin and Katz (1999), we estimate the 50–10 ratio, which becomes the dependent variable. There are three independent variables—male share of workers, electric horsepower per worker, and nonelectric horsepower per worker. We estimate the regression in first differences, which is equivalent to two-way fixed effects (industry dummies and a year dummy for 1920). We find a statistically significant, negative effect of electric horsepower per worker on the 50–10 ratio, consistent with Goldin and Katz's argument. The

sachusetts reports, however, these cover much shorter periods of time (e.g., New Hampshire's is just for 1916). In discussing the state of information regarding wages in the United States, Nearing (1914, 14) lamented "of the 10 leading industrial states, but three—Ohio, Massachusetts, and New Jersey,—furnish wage data, which merits . . . comment. The statistics for Ohio are excellent, but very diffuse and unconcentrated. The statistics for Massachusetts and New Jersey are, on the other hand, scientifically classified, accurately presented, and in every sense satisfactory and reliable."

effect is large—at the sample means, we can account for nearly all (80 percent) of the decrease in the 50–10 ratio between 1895 and 1920.

1.2 Literature Review: Wage Inequality in Manufacturing, 1820–1940

Less than 5 percent of the American labor force in 1800 was engaged in manufacturing. By the middle of the 19th century, the manufacturing share had reached 15 percent, and it rose to 20 percent by 1900 (Atack et al. 2004, p. 172). The share continued to rise over the first half of the 20th century, reaching slightly more than a quarter of the labor force in 1950. It has declined since, so much so that by 2010, the share (10 percent) was lower than in 1850.

The initial shift of labor into manufacturing coincided with massive changes in industrial organization. At the start of the 19th century, almost all manufacturing took place in artisan shops (see, e.g., US Department of the Treasury 1791; Sokoloff 1982). In such shops, the owner worked either alone or with a partner, and perhaps with a few apprentices. Except for a few industries such as lumber and gristmills that used waterpower, capital was limited to basic, general-purpose hand tools, plus the building. In terms of numbers, these artisan shops would remain dominant at midcentury, but increasingly, production shifted toward larger establishments—places termed factories (US Census Office et al. 1883). These differed from artisan shops in three fundamental ways—a greater use of division of labor; more capital per worker; and, relative to the artisan shop, substantially greater use of inanimate power. Initially the power source was water, but as the century progressed, waterpower was displaced by steam power (Hunter 1979, 1985).

By the end of the 19th century the factory system was dominant, and it continued to grow in importance during the first half of the 20th century as steam was replaced by electricity as the inanimate power source (Devine 1983; Hunter and Bryant 1991). Overall, the consensus view is that these changes in industrial organization dramatically increased output per worker in manufacturing such that, by World War I, the United States was the leading industrial economy in the world (Bairoch 1982; Broadberry and Irwin 2006).

Although the success of American manufacturing in overtaking early industrializers like the British is undeniable, there is less evidence of how the shift from the hand labor of the artisan shop to the machine labor of the factory affected wage inequality in manufacturing.[4] There are two strands to the literature. The first strand measures changes in manufacturing wage inequality using time series of skill differentials—ratios of wages of skilled

4. This question is distinct from the general equilibrium impact of the growth of manufacturing on overall inequality in the economy. The general equilibrium impact would include the effect on inequality between manufacturing and the rest of the economy, including agriculture. The general equilibrium impact is beyond the scope of our analysis.

to unskilled workers—which are interpreted through the lens of (relative) demand and supply. There is a substantial body of work documenting the evolution of skill differentials over the 19th century (Autor et al. 2020; Goldin and Katz 2008; Margo 2000; Williamson and Lindert 1980). The consensus view is that, relative to unskilled labor, the wages of skilled artisans were roughly stable from the early to late 19th century, while the relative wages of white-collar workers increased modestly.

Katz and Margo (2014) document that, over the same period, the share of artisans in manufacturing declined, while the shares of operatives (including unskilled labor) and white-collar nonproduction workers increased. They interpret these shifts as evidence of "hollowing out"—a shift in labor demand in manufacturing toward operatives and managerial or clerical labor and away from artisans. However, if this were the case, one might have expected the relative wage of artisans to have declined relative to unskilled labor, but it did not. Katz and Margo point out that, while relative demand decreased in manufacturing, the construction sector, which was intensive in the use of artisan labor, grew over the century and took up the slack.

Although one can craft a sensible narrative around the evolution of skill differentials, such time series offer, at best, a limited window on overall movements in wage inequality in manufacturing. Because of this limitation, research has turned to evidence from the various 19th-century federal censuses of manufacturing, several of which collected data sufficient to compute the "establishment wage"—the average wage of workers employed in the establishment. Establishment-level samples from the original manuscript records are available for 1820, and for 1850–1880 (Atack and Bateman 1999; Sokoloff 1982). Unfortunately, samples are unavailable for other years either because relevant data were not collected (1830, 1840) or because the original returns have not survived.[5]

Atack, Bateman, and Margo (Atack et al. 2004; hereafter ABM) used samples for 1850 and 1880 to construct measures of inequality in monthly establishment wages. In table 1.1, we expand their original figures by providing inequality statistics for 1860 and 1870 (monthly) and for annual wages in 1820, 1870, and 1880.

These statistics are the 10–50 and 50–90 differentials in the natural logarithm of the establishment wage, the coefficient of variation, and (the closely

5. The 1810 census is generally judged to be too poor in quality to be useful and, in any case, most of the original records were destroyed by the British in 1814 (Fishbein 1973). For 1820 we use the digital file originally created by Sokoloff (1982), which is a complete count of all establishments in 45 randomly chosen counties in the Northeast; this is compared with observations from the Northeast in 1870–1980 (see table 1.1). No census was taken in 1830 and the Census of 1840 collected no data on wages. The Treasury Department's McLane Report for 1832 (US Congress, House 1833) contains wage information for manufacturing and were digitized by Sokoloff and Villaflor (1992) to estimate establishment wages in the Northeast, but their computer file is no longer extant. Records of the 1890 and 1900 censuses were destroyed in the early 20th century.

Table 1.1 Establishment wage inequality in American manufacturing, 1820–1919

A. Monthly establishment wage in manufacturing, inequality statistics

Sample screens	Full sample	Full sample	Full sample	Urban & Brissenden industries	Urban
Type	Ln(50/10)	Ln(90/50)	COV	COV	COV
1850	**0.62**	**0.50**	**0.467 {0.45}**	**0.506**	**0.498**
N, establishments	5,214	5,214	5,214	941	1,291
N, workers	43,093	43,093	43,093	16,145	19,105
1860	**0.72**	**0.41**	**0.481 {0.46}**	**0.487**	**0.468**
N, establishments	5,172	5,172	5,172	1,265	1,671
N, workers	47,994	47,994	47,994	21,222	26,377
1870	**0.70**	**0.58**	**0.507 {0.53}**	**0.451**	**0.474**
N, establishments	3,641	3,641	3,641	600	863
N, workers	43,467	43,467	43,467	13,930	20,518
1880	**0.94**	**0.56**	**0.571 {0.60}**	**0.544**	**0.542**
N, establishments	6,904	6,904	6,904	2,075	3,397
N, workers	83,613	83,613	83,613	44,177	60.585

B. Annual establishment wage in manufacturing, 1820, 1870–1880, and 1919: Coefficient of variation

Sample screens	Full sample	Northeast, 10% trim	Urban & Brissenden industries	Urban
1820		0.403		
N, establishments		801		
N, workers		8,620		
1870	0.521	0.406	0.435	0.470
N, establishments		1,451		
N, workers		25,966		
1880	0.596	0.516	0.570	0.563
N, establishments		2,767		
N, workers		43,819		
1919 (Brissenden)			0.335	

Note: Full sample: to be included, establishments must report positive values of total labor (males + females in 1850 and 1860, males + females + children in 1870 and 1880), capital invested, and $500 of gross output; $4.76 < average monthly wage in 1850 < $190.5; $4.93 < average monthly wage in 1860 < $197.33; $7.20 < average monthly wage in 1870 < $314.67; $5.20 < average monthly wage in 1880 < $208. See Atack et al. (2004, table 1) for explanation of sample screens on average monthly wages in 1850 and 1880; 1860 and 1870 are similarly calculated. Panel A: Monthly wages in 1850 and 1860 are total monthly wages divided by total labor; monthly wages in 1870 = (Annual wage bill/months of operation)/number of workers; monthly wages in 1880 = (Annual wage bill/full-time equivalent months)/number of workers. COV: coefficient of variation of average monthly wage. {}: standard deviation of *ln* (average monthly wage). Panel B: Northeast, 10% trim: restricted to establishments in the Northeast, observations with annual establishments wages between 10th and 90th percentiles in the full distribution, among establishments reporting positive annual wage bill. Sources: 1820: Sokoloff (1982); 1850–80: Atack-Bateman-Weiss national samples (see description in Atack and Bateman 1999, 2004; Atack, Bateman et al. 2006); 1919: (Brissenden 1929).

related) standard deviation of the (ln) establishment wage. It is important to note that all measures in the table are weighted by the number of workers at the establishment, as was the case in the original ABM study. Sample sizes (number of establishments and number of workers) are also shown. As a further point of comparison, we also show the coefficient of variation of annual establishment wages for 1919, based on a proprietary sample from the 1920 census analyzed by Brissenden (1929) that is otherwise unavailable.[6]

As can be seen in table 1.1, in the columns labeled "Full sample" (which have the largest sample sizes), there was a steady upward trend in inequality in monthly establishment wages from 1850 to 1880, most of which occurred due to a rise in the 10–50 differential, that is, a rise in inequality below the median wage. The evidence is more limited for annual establishment wage inequality, but the general pattern is consistent with an inverted U, rising from 1820 to 1880 and then falling at some point after this, as indicated by the (much) lower level of inequality in 1919 than in 1880.

To understand the increase in establishment wage inequality between 1850 and 1880, ABM analyzed the establishment wage data in a two-step procedure. In the first step, ABM estimated regressions of the log of the establishment wage on establishment characteristics. Their main findings were twofold—first, that the establishment wage was a negative function of the number of employees; and second, that the establishment wage was a positive function of the log of capital per worker and of the use of steam power. ABM interpreted these patterns using a simple framework borrowed from Goldin and Katz (1999)—the negative correlation with the number of workers is consistent with a lower average skill level as the number of workers increases—de-skilling—whereas the positive effect of capital intensity and use of steam power can be read as both variables boosting the demand for skilled labor in these establishments.

In the second part of their paper, ABM used the data to compute a decomposition of the overall change in establishment wage inequality between 1850 and 1880. This decomposition is performed on the 10–50, 50–90, and 10–90 differential in the log establishment wage, in terms of the portion explained by changes in the distribution of the independent variables in the regressions, the regression coefficients, and residual wage inequality. The regressions used for this purpose contain just establishment-size dummies. The results show that, overall, establishment wage inequality increased substantially between 1850 and 1880 because of a growing concentration of employment in establishments with below-average wages. These were

6. Brissenden's (1929) estimates did not claim to be a nationally representative random sample of establishments but instead are for a sample of 8 cities and approximately 20 industries. Due to sample size limitations the best match we can make to Brissenden for 1850–1880 is to restrict the analysis to urban observations in the two-digit SIC industries which contain those studied by Brissenden (for a definition of "urban," see Atack and Bateman 1999). It is not possible to match Brissenden to 1820 because several of the cities in his sample did not exist in 1820 and because the available sample size for the rest is too small.

relatively large establishments in terms of the number of workers, and the reason they were low wage on average is that the establishment wage was a decreasing function of the number of workers. ABM argue that this is consistent with a relative demand shift in favor of less-skilled operatives, who increasingly dominated manufacturing employment as the factory system grew in importance.

There are three significant limitations to ABM's analysis. First, none of the extant samples from the federal censuses of manufactures provides direct evidence of the division of labor; the presumption is that such division was an increasing function of the number of workers employed by the establishment, but the census cannot be used to verify this directly because of the way that the original data were collected and reported. Second, while the increase in establishment wage inequality is clear enough, for wage inequality to have also increased across workers—as opposed to across establishments on average—it is also necessary that wage inequality within establishments did not decrease. ABM argue this was so but have no direct evidence of the evolution of wage inequality within manufacturing establishments. Third, while ABM show that average establishment wages were increasing in the use of steam power, the effect of the shift to steam on wage inequality remains unclear.

The second component of the consensus view is that wage inequality in manufacturing decreased from the turn of the century to 1940. Here, the main analyses are provided by Goldin and Katz (1999, 2008). Specifically, Goldin and Katz (1999) compare adjusted wage distributions for manufacturing operatives in particular industries reported in the census of manufacturing data for 1890 (US Census Office 1895b) with similar distributions from Bureau of Labor Statistics surveys in the late 1930s. These comparisons show a decrease in wage inequality within the given industries over the period.

Goldin and Katz attributed some of the decrease in wage inequality to electrification, which reduced the demand for very low-skilled workers in manufacturing. Annual time series of skill differentials over the period suggest that the bulk of the decrease in wage inequality occurred prior to 1920, which is consistent with the timing of electrification. There are, however, two limitations to Goldin and Katz's argument. First, they acknowledge that their evidence on wage inequality is within industry. It is possible that overall wage inequality in manufacturing was rising (or stable) if interindustry wage differences were increasing, although they discount this explanation. Rather more importantly, the precise timing of changes in wage inequality cannot be determined from Goldin and Katz's analysis of wage inequality with just a starting and ending date. Relatedly, Goldin and Katz present no evidence directly linking the rising use of electricity within manufacturing to decreases in wage inequality across manufacturing workers. The analyses in the next two sections are our proffer addressing the limitations of both ABM and Goldin and Katz.

1.3 The *HML* Study and Wage Inequality Within Manufacturing Establishments

The student of American manufacturing who wishes to document the evolution of wage inequality within establishments in the 19th century has limited choices for evidence. The so-called Weeks and Aldrich reports (US Congress 1893; Weeks 1886), which have been previously used to construct wage series, are one possibility, as both are establishment based. However, while these reports do contain some within-establishment information on wages, the evidence is limited to occupational averages and thus does not fully capture the variation at issue.[7] Another possibility is the 1900 census report on "Employees and Wages" (US Census Office and Dewey 1903), which provides so-called classified wage distributions (see section 1.4) at the establishment level in the late 19th century for a subset of industries in groups of states. However, this report, as well as either the Aldrich or the Weeks data, provides no direct evidence on the underlying causal factors at issue, such as the division of labor or mechanization.

The source that we use, the US Department of Labor's *Hand and Machine Labor* study (1899), is quite different. This source contains information on wage inequality pertaining to production workers in large, mechanized factories—all from the late 1880s to the mid-1890s– as well as wage inequality among production workers within small nonmechanized artisan shops. These were the typical production entities earlier in the century, although about a quarter of the observations in the *HML* study were from businesses still in operation in the 1890s. Differences in wage inequality between these two types of production—"machine" (factory) versus "hand" (artisan) labor—provide important insights, we argue, into changes in wage inequality within establishments over the 19th century, as well as the factors behind them.

Published in two volumes totaling almost 1,600 pages, the *HML* study detailed the production operations involved in the manufacturing of what the study termed "units"—specific quantities of precisely defined goods such as "50 dozen regular taper, triangular saw files, 4 inches long, tapering 23/64 inch" (US Department of Labor 1899, 1:241–46, 2:1026–29). The overall report covered 672 units in various economic sectors including 626 (units 28–653) in manufacturing. The units from manufacturing covered almost the entire range of broadly defined manufactured goods (i.e., two-digit SIC codes 20–39 (US Executive Office of the President, 1987), including those common in both the first Industrial Revolution and the second.[8]

7. Wesley Mitchell (1903) reported an 1860 classified wage distribution in manufacturing. However, this distribution—based on underlying data from the Aldrich report pertaining to establishment-occupation averages—fails to capture fully the within-establishment variance.

8. An important exception were products that were introduced late in the 19th century, such as bicycles, that were never produced by hand methods.

The *HML* data, however, should not be viewed as a representative sample of manufacturing industries at the time—a limitation of our analysis that should be kept in mind when extrapolating our findings to the whole of the manufacturing sector (Atack et al. 2022, table A1). We stress that the *HML* data pertain solely to wage inequality among production workers. The observed difference in wage inequality between machine and hand labor units in the *HML* from this comparison, however, will understate the true difference in the establishments from which the original data were collected because the share of nonproduction labor was higher for factories than artisan shops, and white-collar wages, on average, were higher than for skilled blue-collar workers.

For each unit, the *HML* staff actually collected production data from four establishments, two each that were using hand labor or machine labor methods, selecting "the better and more complete" accounting of each mode for publication (US Department of Labor 1899, 1:1). To maintain confidentiality, the *HML* staff anonymized the information in the published report so that we do not know the names of the establishments or their location.[9] The *HML* staff was clearly aware of the widely held belief that the machine methods yielded a lower-quality product than the hand methods, and they expended great efforts to find units producing factory goods that were *not* of inferior quality to artisan products so this argument cannot be used to impeach our results.[10] Our procedures in making these data amenable for econometric analysis are described in Atack et al. (2019, 2022, 2023, 2024).

In two previous papers, we used the operations-level data in the *HML* study to evaluate modern models of automation (Atack et al. 2019) and to estimate the impact of inanimate power use on the study's measure of labor productivity, which is the amount of time that it took to complete the same operation—for example, polishing a piece of metal—in the production of the same product by hand and machine labor, but where, under machine labor, inanimate power powering a specific machine might have been used (Atack et al. 2022). Specifically, Atack et al. (2022) demonstrate that the average difference in labor productivity between the hand and machine methods was of a magnitude that accurately tracks the evolution of productivity growth in manufacturing over the century due to the long-term shift from one type of production to the other.

The empirical analysis in Atack et al. (2022, 2024) focuses on the subset of production operations that overlapped between hand and machine labor, thus excluding operations under hand labor that were abandoned as well as those novel operations specific to machine labor. Here, instead we focus

9. A small number (15) of hand units were located outside the United States and identified as such in the published *HML* study. These are excluded from our analysis.

10. The text of the *HML* study discusses quality differences, from which we were able to categorize whether the staff thought the quality was better for product when made by hand or vice versa; or no difference was detected, or no opinion was expressed; see Atack et al. (2022).

primarily on the unit, and the outcome of interest is the standard deviation of the natural logarithm of "labor cost" across operations within the unit by production mode. For each operation we know the wage of the worker(s) performing the activity, as well as the amount of time the activity took; labor cost is the wage per standardized unit of time. Using this information, we can compute the standard deviation of *ln* (labor cost), where each operation is weighted by its completion time. The operative assumption is that differences in wage inequality between hand and machine labor can inform the debate over the course of wage inequality within establishments as manufacturing shifted from the artisan shop to the factory, analogous to our previous analysis of labor productivity differences.

A key advantage of the *HML* study for this paper is the information that it contains on potential explanatory factors. Of these, the two of greatest interest are division of labor and use of inanimate power. To motivate our use of this information in the regression analysis, we sketch a simple framework linking both factors to within-establishment wage inequality.

As a point of departure, imagine an artisan shop engaging in hand labor in which all production operations are performed by a single worker; that is, the artisan is both sole worker and proprietor (i.e., providing managerial direction). There are $N + 1$ such operations—N of which are actual production operations and a single overall task of "management" (nonproduction). We will assume that the opportunity cost of the artisan's time, say a day's worth of labor, is w. Because there is only one worker, observed wage inequality in these firms is, by definition, zero.

Although the artisan is skilled by virtue of being able to complete all the myriad production operations, the artisan—like everyone else—will have a comparative advantage at some operations, and a disadvantage at others. Now, imagine that, instead of doing all tasks himself, the artisan specializes in one task—"management"—and hires N workers, each of whom performs a single operation. Array tasks in increasing terms of the skill required to perform them, and let $w(n)$ be the wage for task $n = 1, \ldots N$. So long as at least some of the skill levels are strictly increasing, wage inequality within the establishment will increase through division of labor.

In addition, wage inequality may have been affected by the shift to steam power. Here, there are two possible effects. First, the shift to steam may have induced greater division of labor (Atack et al. 2008, 2024) among existing tasks. Second, and likely more important, the shift to steam would have created new tasks associated with the operation of steam engines. Some of these tasks—for example, installation and maintenance of steam engines—were highly skilled, while others—moving raw materials (e.g., coal to fuel it) and transferring intermediate inputs around the shop floor—were unskilled. Indeed, not surprisingly, there is a sharp increase in the need to move intermediate product between production "stations" as the division of labor increased. In either case, wage inequality should have risen.

Table 1.2 **Sample statistics: *Hand and Machine Labor* study observations (*N* = 496)**

Type	Standard deviation of *ln* (labor cost)	Fraction of time devoted to mechanized operations	*Ln* (# of different workers)	*Ln* (# of different operations)	One worker unit
Hand labor	0.142	0	1.202	1.853	0.270
Machine labor	0.282	0.553	2.806	2.495	0.010
Difference, machine – hand	0.140	0.553	1.604	0.642	–0.260

Source: *Hand and Machine Labor* study (US Department of Labor 1899, as described in Atack et al. 2019).

1.3.1 Regression Analysis

Table 1.2 reports sample statistics for our regression analysis of the *HML* study data. We restrict attention to those units in which no inanimate power was used at any point in hand labor and where steam or waterpower was used in machine labor.[11]

On average, the standard deviation of *ln* labor cost was about twice as high in machine labor production than in hand labor production, a level difference of 0.140 that is highly significant (s.e. = 0.013). About 55 percent of the production time under machine labor used inanimate power. On average, machine labor production employed more workers, allocated over many operations, implying a much higher degree of division of labor (Atack et al. 2022).[12] Twenty-seven percent of the hand labor units employed a single worker, compared with hardly any (1 percent) of the machine labor units. As noted, in single worker units, there was no division of labor by definition and, therefore, the standard deviation was identically zero.

Regression results are reported in Table 1.3. All regressions include unit fixed effects.

For comparison purposes, the second column reports the coefficient of a dummy variable for machine labor, $\beta = 0.140$. This is the mean difference in the standard deviation of ln labor cost. In column 3, we include the share of labor time devoted to operations that were mechanized using either steam or waterpower, the natural log of the number of workers, and the natural log of the number of operations. Collectively, these three variables "over-explain" the mean difference (by about 29 percent), as the coefficient on the machine labor dummy is now negative—$\beta = -0.040$—although statistically insignificant.

The signs of the variables are as expected and two of the three—the fraction of labor time in powered, mechanized operations and the number of workers—are highly significant. An increase in the fraction of production

11. This sample restriction approximates the comparison that the *HML* study was attempting to make; see Atack et al. (2022). There are 496 units that meet these sample criteria.

12. We include the natural logarithms of the number of workers and the number of operations separately as flexible controls for the division of labor.

Table 1.3 Regression and decomposition analysis: Standard deviation of *ln* (labor cost)

Variable	Coefficient	Coefficient	Percentage explained	Coefficient	Percentage explained
Machine labor = 1	0.140	–0.0400	–28.5	–0.030	–21.4
	(0.013)	(0.029)		(0.028)	
Fraction of time devoted to mechanized operations		0.107	42.3	0.086	34.3
		(0.043)	[32.8]	(0.042)	[28.3]
Ln (# of different workers)		0.061	69.8	0.046	52.7
		(0.009)	[54.2]	(0.009)	[43.4]
Ln (# of different operations)		0.035	16.1	0.036	16.1
		(0.020)	[12.5]	(0.020)	[13.3]
One worker unit				–0.100	18.3
				(0.025)	[15.1]
Adjusted R^2	0.296	0.448		0.474	

Note: In brackets: relative percent explained excluding the percent explained by the machine labor dummy (relative percentages within the brackets sum to 100 down a column).

Source: See table 1.2.

time using inanimate power is associated with greater wage inequality, as is greater division of labor—more workers and more operations. In column 5, we include a dummy variable for units in which a single worker performed all operations; in effect, this tests for a spline at exactly one worker. This coefficient is highly significant, which has the effect of reducing the magnitudes of the coefficients of the fraction of production time that was mechanized and the *ln* (# workers), although the reductions are relatively small.

Column 4 computes the "percentage explained" of each variable, which is the coefficient multiplied by the difference between machine and hand labor in the mean value of the independent variable, divided by the mean difference in the standard deviation of ln labor cost. As noted, collectively the variables overexplain the difference; however, if we scale each variable's contribution by the overall percent explained, mechanization accounts for about 28 percent to 32 percent of the higher average wage inequality within machine labor units, depending on the inclusion of the dummy variable for single worker units. It follows that the division of labor variables were relatively more important (68 percent to 72 percent). In sum, while mechanization contributed to greater wage inequality, the growing division of labor associated with the ascendancy of the mechanized factory was more important quantitively.

1.4 The Evolution of Wage Inequality in Manufacturing, 1890–1940: State Reports on Classified Wages

In this section we make use of state government reports on so-called classified wages for manufacturing in Massachusetts. Wages are said to be "classified" because these reports give the number of workers whose labor earnings—typically measured on a weekly basis—fell within given intervals. The first reporting of such statistics appeared in 1888 as a part of the 1885 Massachusetts Census (Massachusetts Bureau of Statistics of Labor, 1888, 233–62 on towns, 1115–26 on industries). What (or who) motivated this initial inquiry is unclear; however, it would subsequently become a regular feature of the Massachusetts "Annual Statistics of Manufactures," beginning with the state's fifth report for 1890 but also covering 1889 (Massachusetts Bureau of Statistics of Labor 1890, 142–61).[13] These annual statistics were intended to "fully portray the conditions of the industries" and "accurately show the trend of business from year to year" (Massachusetts Bureau of Statistics of Labor 1890, xiii).[14]

In all, Massachusetts reported classified wages for 43 individual years between 1885 and 1938, although the regular annual reporting of the data was eventually discontinued. Instead, in 1940, the bureau published a retrospective synopsis, with annual data from 1920 to 1924 and biennially thereafter to 1938 (Massachusetts Department of Labor and Industries 1940, table 6, 75ff.). This line of inquiry appears to have inspired periodic emulation by sister agencies in other states.[15] It also seems plausible (but not certain) that

13. Data collection was authorized by the Massachusetts legislature (see Massachusetts. Bureau of Statistics of Labor, [for the years 1886. 1887] 1889, 135–37) beginning April 29, 1886. Data on 12 specific topics (stipulated in section 1 of the act) were to be collected by mail of every manufacturing establishment in the state by mid-December with returns due before the end of the year. While the bureau complied with the law, the first data collected under it were not reported until 1889. Reasons for the delay were spelled out by Commissioner Wadlin (Carroll D. Wright's successor at the Massachusetts Bureau) in his introduction to his first report where he also provides a summary history of the collection of statistical data by the state (Massachusetts Bureau of Statistics of Labor [for the years 1886, 1887] 1889, xi–xix). The first classified wage series appeared in 1890 with a column comparing the same establishments in 1889 and 1890. As noted in the text, it is unclear what motivated their collection—or even their precise source as the data that they represent was not among the authorized and stipulated questions. Furthermore, Massachusetts law authorized destruction of the underlying returns on a regular basis—see, e.g., chapter 31 of 1889 Acts and Resolves (https://archive.org/details/actsresolvespass1889mass, p. 1365). The commissioner indicated the intent was to simplify the reporting burden on manufacturers by superseding the state's census in years ending in "5," although these too continued. The *Annual Statistics of Manufactures* volumes used for this study may be found either at https://archive.org or https://hathitrust.org.

14. The Chief of the Massachusetts Bureau of Statistics of Labor, Horace G. Wadlin, reported that the data collection excluded the smallest (and most numerous) establishments (i.e., it was not a census despite being called that in the law) because "the condition of manufacturing in the commonwealth can be accurately portrayed by returns that do not include the small and comparatively unimportant concerns" (Massachusetts Bureau of Statistics of Labor [for the year 1890] 1890, xix). His claim was apparently based on a (unreported) comparison between the restricted Massachusetts data and that collected at the Eleventh Census. Access to these data presumably reflected the close collaboration that had long existed between personnel at the Massachusetts Bureau of Statistics and federal census officials beginning with the Bureau of Labor Statistics' second commissioner, Carroll D. Wright, who played a leading role in the 10th Census before becoming the first US commissioner of labor (North 1909). We note that the data were to be collected during the week of maximum employment during the year and, therefore, comparisons across years should not reflect short-run fluctuations within years in hours worked per week.

15. Indeed, New Jersey explicitly adopted the Massachusetts Annual Statistics of Manufactures model in 1896 (New Jersey Bureau of Statistics 1897, 50).

the 1885 Massachusetts inquiry prompted inclusion of such a query as a part of the 11th Federal Census in 1890, appearing as item 6 of "General Schedule No. 3" of the Census of Manufactures to be asked of all respondents (US Census Office 1895a, 13; Wright 1900, 362). The federal census, however, made little use of these data. No summary tabulation of them by state was ever published and they only appear in the volume of statistics on cities (US Census Office 1895b). The federal data did, however, provide the starting point from which Goldin and Katz (1999) estimated wage inequality statistics among adult males at the industry level for 10 industries in 1890. These are matched by industry to analogous statistics reported by the US Bureau of Labor Statistics in its *Monthly Labor Review* (1999, 31).

For our purposes there are three advantages of the Massachusetts data. First, and foremost, their temporal coverage far exceeds that of any other state—effectively, the same timeframe, the 1890s to the late 1930s, covered by Goldin and Katz (1999), but on an annual or biannual basis. Second, contemporaries such as Nearing (1914) thought very highly of the quality of the Massachusetts data, which was not the case for all states that attempted to collect information on classified wages. Third, the data refer to production workers only, allowing a cleaner comparison over time, compared with Goldin and Katz's (1999) use of federal census data.[16] Fourth, we can construct an industry panel (see below) that allows us to explore the empirical impact of changes in electrification on wage inequality, as hypothesized by Goldin and Katz (1999).

Against these advantages one must keep in mind certain limitations. The Massachusetts industrial structure differed from that of the rest of the nation in that it had more of the "first Industrial Revolution" staple industries (e.g., textiles, boots, shoes) and less of those in the second, such as automobiles, although its industry data cover a broad swath of activities. While Massachusetts experienced electrification like the rest of the country in its broad contours and timing, the extent of coverage in manufacturing by the late 1930s fell somewhat below that of the rest of the country. Third, and related, a variety of factors local to Massachusetts—for example, the nature of its labor legislation, immigration, and labor strife, among others—may have affected wage inequality in the state's industries in ways that could have differed from elsewhere.[17]

The Massachusetts data give the number of workers whose nominal

16. As Goldin and Katz (1999) discuss extensively in their paper, the federal census data from the 1890 census cover all production and nonproduction workers. Goldin and Katz make certain assumptions to eliminate the latter from the 1890 distribution, allowing an "apples-to-apples" comparison with the Department of Labor reports from the 1930s, which pertain to production workers. The assumptions are plausible, but ideally it would be better to not have to adjust the data.

17. As we point out in the text, the Massachusetts reports, while very detailed, do not contain sufficient information to allow us to construct a continuous time series for adult males (Goldin and Katz's 1999 calculations of wage inequality pertain to adult males). That said, we do control for the male percent of workers in our analysis of the industry panel.

50 MANUFACTURES — 1907. [Pub. Doc.

TABLE III. CLASSIFIED WEEKLY WAGES: BY INDUSTRIES—1907.

Industries and Sex.	Total Number of Wage-earners	Classified Weekly Wages (For Week of Employment of Greatest Number of Wage-earners): Under $3	$3 but under $5	$5 but under $6	$6 but under $7	$7 but under $8	$8 but under $9	$9 but under $10	$10 but under $12	$12 but under $15	$15 but under $20	$20 but under $25	$25 and Over
THE STATE.	**604,390**	**5,876**	**31,021**	**39,924**	**54,509**	**59,472**	**60,961**	**69,046**	**88,176**	**88,040**	**78,187**	**20,494**	**8,684**
Adults (21 years of age and over):													
Males, ...	371,156	1,713	4,154	6,594	12,898	23,835	32,076	45,653	64,759	76,313	74,664	19,980	8,517
Females, ...	147,677	2,149	8,816	15,122	23,301	23,788	21,512	18,546	20,086	10,507	3,214	472	164
Young persons (under 21 years of age), .	85,557	2,014	18,051	18,208	18,310	11,849	7,373	4,847	3,331	1,220	309	42	3
Agricultural Implements.	*929*	*4*	*13*	*10*	*34*	*90*	*122*	*136*	*196*	*197*	*107*	*16*	*4*
Adults (21 years of age and over):													
Males, ...	878	2	9	7	24	78	110	130	194	197	107	16	4
Females, ...	-	-	-	-	-	-	-	-	-	-	-	-	-
Young persons (under 21 years of age), .	51	2	4	3	10	12	12	6	2	-	-	-	-
Arms and Ammunition.	*3,756*	-	*106*	*168*	*219*	*250*	*206*	*416*	*549*	*873*	*766*	*124*	*79*
Adults (21 years of age and over):													
Males, ...	2,973	-	-	26	50	83	138	351	499	860	763	124	79
Females, ...	213	-	-	46	64	50	8	16	26	3	-	-	-
Young persons (under 21 years of age), .	570	-	106	96	105	117	60	49	24	10	3	-	-
Artisans' Tools.	*5,776*	*23*	*109*	*166*	*239*	*279*	*392*	*624*	*970*	*1,303*	*1,225*	*276*	*170*
Adults (21 years of age and over):													
Males, ...	4.954	4	28	67	108	146	285	513	896	1,252	1,214	271	170
Females, ...	148	-	13	16	26	18	15	29	18	12	1	-	-
Young persons (under 21 years of age), .	674	19	68	83	105	115	92	82	56	39	10	5	-

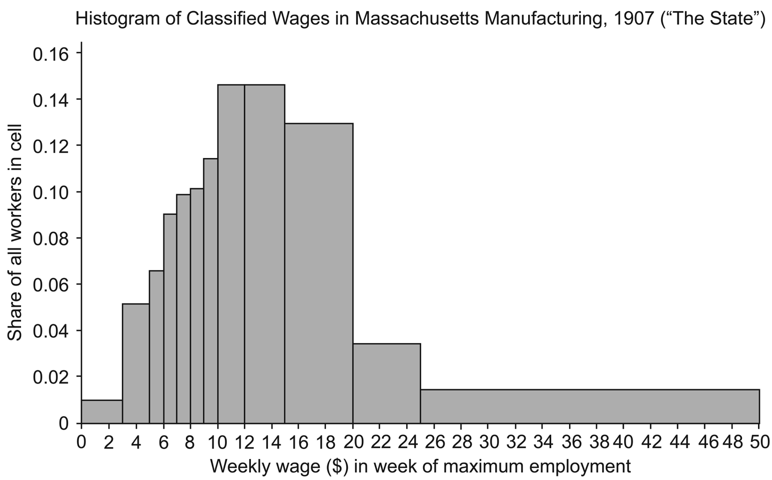

Figure 1.1 Extract from table 3, "Classified weekly wages: By industries—1907": Massachusetts manufacturing

Source: Massachusetts Bureau of Statistics of Labor [for the year 1907] (1908), 50. Courtesy of the State Library of Massachusetts Digital Collections. https://archives.lib.state.ma.us/server/api/core/bitstreams/393f6f0c-9569-4565-9002-3b82e2d59009/content.

weekly wages fall (i.e., are "classified") into specified wage intervals. The first interval is always bounded below at zero (e.g., "Under $3.00"), while the top interval is open; that is, for wages that exceed a certain amount there is no specified upper bound (e.g., "$25.00 or more"). In between, there are closed intervals of a specified but not identical absolute width—for example, $8.00–$8.99 ($1 width) or $12–$14.99 ($3 width). Figure 1.1 shows an extract from the table in the 1907 report and a histogram of the same (Massachusetts Bureau of Statistics of Labor 1908).

The classified wage tables are of a kind found in numerous government documents, historical to the present, in which observational units are categorized into bins. Blalock (1960) is a standard reference for methods applied to binned data to estimate distributional statistics, such as the mean or variance, and quantiles. The approach used by Goldin and Katz (1999) follows Blalock, and so we have also used it, although it is not perfect. In particular, it assumes that the distribution of observations within bin intervals is uniform as opposed to, say, being distributed within them in a way that more closely approximates the distribution across bins (see, e.g., von Hippel et al. 2017). Using Blalock's approach, however, it is straightforward to calculate the cumulative distribution function because the total number of observations in the table is always known and the resulting inequality metrics usually compare favorably with those derived from more complex processes (von Hippel et al. 2017).[18]

Once we know the cumulative distribution function, we can determine which bin intervals include the various quantiles. If the interval containing the quantile is closed at both ends with a nonzero lower bound, the uniform assumption implies that we can calculate the quantile using linear interpolation within the bin.

For the 10th quantile, there is the possibility that it will fall into the first interval, which is bounded below by zero. This, in fact, is the case for all years prior to 1906, for which the first interval is "$5.00 or below." Strictly speaking, we could use linear interpolation between 0 and 5, but it is not credible to assume that the support of the distribution is bounded from below by zero weekly earnings. Instead, we assume that the lower bound of the support is $3.00 per week for 1890–1905—that is, we treat the first interval as $3.00–5.00.[19] For the 90th quantile, the estimated values fall into a closed interval in all years except for 1919 and 1920 (where wartime and postwar inflation almost certainly played a role); for these two years we assume that the upper bound of the support is $50 per week.

For our base estimates, we focus on the distributions for all production workers, as these are reported for all years covered in the Massachusetts data, unlike for adult males. Figures 1.2–1.4 show our estimates of the 50–10 (fig. 1.2), 90–50 (fig. 1.3), and 75–25 (fig. 1.4) ratios, each indexed at 100 to its respective value in 1890. Also shown are nonparametric polynomial smoothing regressions of the indexed ratios on observation year, along with the associated 95 percent confidence intervals around them.

18. Von Hippel et al.'s (2017) analysis shows a clear advantage to these other approaches only if the true mean of the distribution is known—which it is not the case with the Massachusetts data.

19. In 1906 the first interval became "$3.00 and below" and the second interval was "$3.00–5.00". For the pre-1906 observations, the true lower bound of the support is less than $3.00, implying that our estimates of the 50–10 ratio are biased downwards—and, therefore, we are understating the downward trend in the 50–10 ratio from the 1890s to the 1930s. We have experimented with switching to a first interval of $2.00–$5.00 for the pre-1906 observations, which has only a modest effect on the estimated values of *q10*.

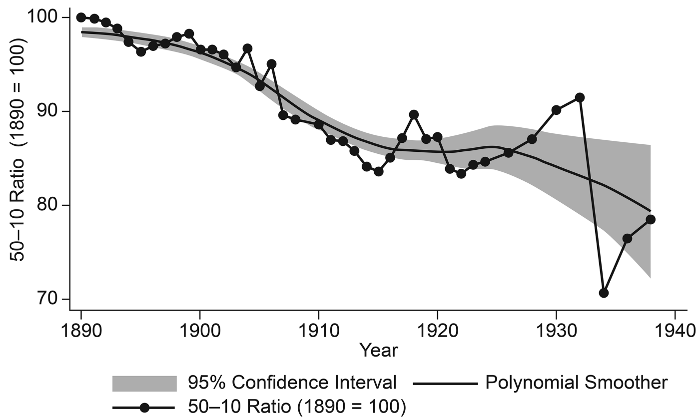

Figure 1.2 50–10 ratio: Weekly earnings in Massachusetts manufacturing, 1890–1938 production workers

Source: Computed from annual data for 1890–1919 from Massachusetts Bureau of Statistics of Labor and the available data for years from 1920–38 in Massachusetts Department of Labor and Industries (1940).

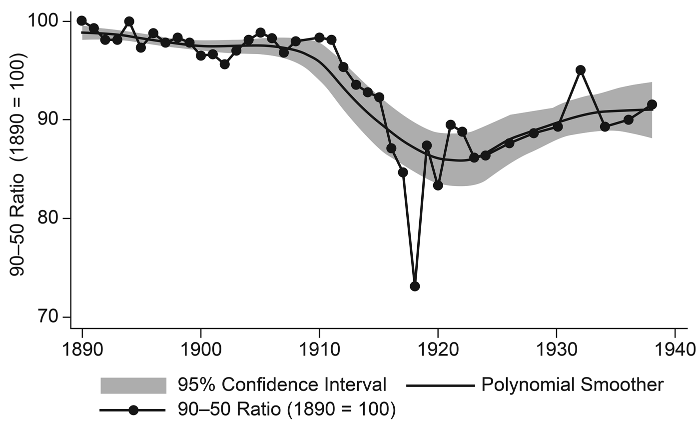

Figure 1.3 90–50 ratio: Weekly earnings in Massachusetts manufacturing, 1890–1938 production workers

Source: Computed from annual data for 1890–1919 from Massachusetts. Bureau of Statistics of Labor and the available data for years from 1920–38 in Massachusetts Department of Labor and Industries (1940).

These figures provide clear and compelling evidence of statistically significant, declining wage inequality. The data suggest modest compression in the 1890s, which then accelerates after the turn of the century. There is also evidence that period effects during World War I and the onset of the Great Depression appear to disrupt the broader secular forces at work. By the late 1930s, the 50–10 ratio—the left tail of the distribution—had narrowed by

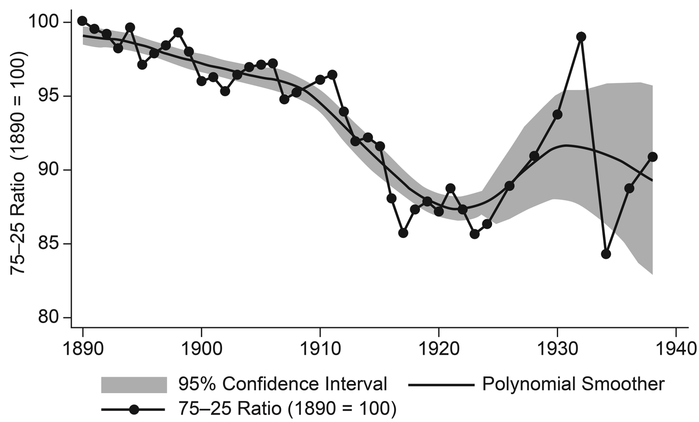

Figure 1.4 75–25 ratio: Weekly earnings in Massachusetts manufacturing, 1890–1938 production workers

Source: Computed from annual data for 1890–1919 from Massachusetts Bureau of Statistics of Labor and the available data for years from 1920–38 in Massachusetts Department of Labor and Industries (1940).

approximately 20 index points, or about –0.22 log points. The narrowing in the 90–50 ratio and the interquartile range was smaller, about 0.10 log points, or about 10 index points (from 100 to 90).

1.4.1 The Role of Electrification: Panel Estimates

The shift to steam-powered production (from hand or water) was one of the central features of the transformation of manufacturing over the second half of the 19th century and is, of course, captured in the *HML* study. Beginning in the late 19th century, the source of inanimate power began to shift from steam to electricity. The 1890 Census, for example, reported the use of over 15,500 electric horsepower in manufacturing with Massachusetts (#2), New York (#1 by a small margin), and Pennsylvania (#3) leading the way (US Census Office 1895a, 759). The shift began in earnest the 1890s and then accelerated swiftly after the turn of the 20th century (Du Boff 1966, 1979, esp. table 3, 427). As figure 1.5 shows, Massachusetts manufacturing followed this general pattern. By 1910 about 10 percent of horsepower used in Massachusetts manufacturing was generated by electricity. The electricity began rising steeply thereafter, reaching 60 percent in the late 1930s.

One of Goldin and Katz's (1999) main hypotheses is that electrification reduced wage inequality in the lower tail of the distribution. Shop floors were reorganized in response to electrification, reducing the demand for a wide array of low-wage jobs on the factory floor (Devine 1983), as materials handling was more easily electrified and as the production process was "linearized" (Jerome 1934). They were unable, however, to test for an effect of electrification directly because they did not have an annual time series of

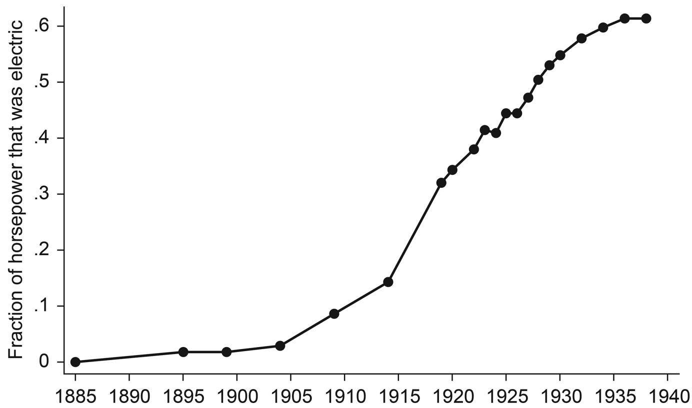

Figure 1.5 Electric Power as Share of Total Primary Horsepower, Massachusetts Manufacturing, 1885–1938

Source: 1885, 1895: Massachusetts and Wadlin (1898, 342–43). 1889–1919: US Bureau of the Census (1923, table 219, 471). 1920–38: Massachusetts Department of Labor and Industries (1940, 132).

wage inequality statistics matched to a similar time series on electrification, nor did they have an industry panel of classified wages matched to power use.

Following Goldin and Katz's (1999) lead, we estimate wage inequality at the industry level using the Massachusetts classified wage distributions. For two years, 1895 and 1920, we also have corresponding industry figures on power use (Massachusetts and Wadlin 1898, 575–84; US Bureau of the Census 1920, 636–47). The industries are identified at the three-digit SIC level, and we have constructed a matched panel of 41 observations for 1895 and 1920. We follow the same protocols regarding cut-offs and procedures with these industry-level data as for the aggregate data to estimate *q10* and *q50*.

We specify a two-way fixed effects model, with fixed effects for year (1920) and industry. Because there are only two years, we estimate the model in first differenced form. The regression specification is

$$\Delta\, Ln(q50/q10) = \alpha + \beta^{*}\Delta\, Elecwkr + \gamma^{*}\Delta\, Non\text{-}Elecwkr + \delta^{*}\Delta Pct\ Male + \varepsilon,$$

where *Elecwkr* = electric horsepower per worker, *Non-Elecwkr* = nonelectric horsepower (e.g., steam) per worker, and *Pct Male* = percentage of male workers. Because the industries differ greatly in employment, we weight observations by the average number of workers in the two years.

The regression results are shown in table 1.4. The hypothesis at issue is the sign of β. If it is negative, then electrification contributed to the compression in the lower half of the wage distribution. As can be seen, the coefficient is negative. It is also quite stable across the three columns, which add the other two independent variables. The magnitude of the coefficient, –0.128 in the

Table 1.4 **Regression analysis of Massachusetts industry panel, 1895 and 1920**

Variable	Sample means	Coefficients	Coefficients	Coefficients
Elecwkr	1.204	–0.127*	0.132*	–0.128*
		(0.034)	(0.036)	(0.038)
Non-Elecwkr	–0.486		–0.019	–0.017
			(0.032)	(0.033)
Pct Male	–0.028			–0.070
				(0.240)
Adjusted R^2		0.242	0.229	0.210

Note: Mean value of dependent variable (weighted by average employment) = –0.192. *Significantly different from zero at the 1% level. Source: Panel of 41 industries constructed from data in Massachusetts 1895 Census (Massachusetts and Wadlin 1898, 575–84) and data for Massachusetts in the Fourteenth Federal Census (US Bureau of the Census 1920, 636–47).

last column, is quite large. If we multiply this coefficient by the mean value of *Elecwkr*, the predicted change in the dependent variable is –0.154, which accounts for 80 percent of the change (–0.192) in the dependent variable. This result supports Goldin and Katz's (1999) argument that electrification contributed to the decrease in wage inequality in manufacturing before World War II.

1.5 Concluding Remarks

According to the conventional narrative, wage inequality in US manufacturing followed an inverted-U pattern from the early 19th century to just prior to World War II, a period that encompassed the transition from the artisan shop to the steam-powered factory and then electrification. This chapter fills in two important gaps. For the rising portion of the inverted U, the previous literature (see, e.g., Atack et al. 2004) was unable to measure changes in wage inequality within establishments, while for the falling portion, the precise time-series pattern of change from 1890 to 1940 could not be documented (Goldin and Katz 1999). For both parts of the evolution, a role for mechanization has been hypothesized, but previous work could not examine the role directly.

Here, we show that for the rising portion of the inverted U, we can use operations-level data from the US Department of Labor's 1899 *Hand and Machine Labor* study to study differences in wage inequality between "hand" (artisan) and "machine" (factory) production of specific manufactured goods. We show that wage inequality was much higher across operations in machine production than in hand production. In terms of explanatory power, the greater division of labor in machine production was responsible for about twice as much of the higher level of wage inequality than mechanization. We again emphasize that the evidence from the *HML* study pertains solely to the direct effect of mechanization on wage inequality among production workers. There is little doubt that the diffusion of steam power directly increased establishment scale, leading to an increased demand for nonproduction workers (Atack et al. 2008; Katz and Margo 2014) and, therefore, increased overall inequality in manufacturing. Steam power had an indirect effect on wage inequality by facilitating the transportation revolution, which increased market access and, therefore, the division of labor (Atack et al. 2011; Donaldson and Hornbeck 2016), a pathway that cannot be assessed with the *HML* data (because we lack information on where the units were produced).

Second, by digitizing and analyzing data from reports produced by the Massachusetts Bureau of Statistics of Labor, documenting so-called classified wages in manufacturing as well as the extent of electrification, we confirm a substantial narrowing of wage inequality across production workers, starting in the 1890s and accelerating after the onset of electrification. More concretely, we construct an industry panel for two years that allows us to estimate the impact of electrification on wage inequality directly, focusing on the lower half of the wage distribution. Consistent with Goldin and Katz (1999), we find a strong negative effect of electrification—as the use of electric power increased, absolutely and relative to other sources of power, wage inequality in the lower tail compressed significantly.

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