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# Turbulence, Inequality, and Cheap Steel

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**Abstract**

Iron and steel production grew dramatically in the U.S. when mass production technologies for steel were adopted in the 1860s. According to new measures presented in this study, earnings inequality rose within the iron and steel industries about 1870, perhaps because technological uncertainty led to gambles and turbulence. Firms made a variety of technological choices and began formal research and development. Professional associations and journals for mechanical engineers and chemists appeared. A national market replaced local markets for iron and steel. An industrial union replaced craft unions. As new ore sources and cheap water transportation were introduced, new plants along the Great Lakes outcompeted existing plants elsewhere. Because new iron and steel plants in the 1870s were larger than any U.S. plants had ever been, cost accounting appeared in the industry and grew in importance. Uncertainty explains the rise in inequality better than a skill bias account, according to which differences among individuals generate greater differences in wages. Analogous issues of inequality come up with respect to recent information technology.

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## 1.0 Introduction

This paper investigates earnings inequality in the context of the introduction and rapid growth of mass production methods for making steel in the U.S. after 1865. There is an analogy to the appearance and growth of new information technology since the 1960s. In both of these cases, major technological changes had macroeconomic effects: steel principally through its use in railroads, and semiconductors mainly through their application in computers. In both cases earnings inequality rose in an affected population of workers.

In the context of rapid technological change, the Greenwood and Yorukoglu (1997) model and similar dynamic models make predictions which match the evidence presented here. A sharp decline in prices and costs attributable to technological change coincided with a productivity slowdown and a rise in earnings inequality. After the technology matured, productivity boomed. These stylized facts describe both the steel case and the information age case.

This paper presents measures of the dispersion of wages within each of several industries for each year from 1850 to 1881, based on wage data from a survey of establishments conducted by the U.S. Census Bureau. This evidence shows that in the industries producing iron and steel, earnings dispersion increased as the new technologies were adopted. Earnings dispersion did not rise in the other industries at that time.

Uncertainty about the new technology and its effects may have caused this increase in wage inequality in the iron industries. Since they did not know the future of the technology or the industry, employers and workers chose from a variety of possible strategies and made a variety of gambles, whose outcomes varied greatly. Greater variation in choices led to more variability in outcomes, including wages, so there was a greater variance in the distribution of wages at the time of technological turbulence. In this phase of adaptation to the new technology, new skills are developed. This *technological uncertainty* hypothesis fits the evidence on mass production steel well, and may also apply to the computer age.

## 2.0 Iron and steel technology of 1870

Useful iron products in 1870 took three general forms: pig iron, wrought iron, and steel. *Pig iron* has 2.5% to 6% carbon and is the easiest to make from most iron ore. It is *brittle*, meaning it can break when other materials might bend. It can be cast into molds to make, for example, stoves or pots, and so may be *cast iron*. When pig iron is heated to a high enough temperature that carbon and other elements separate away as slag, the chemically near-pure iron product that remains is *wrought iron* or *bar iron*. When bent, it tends to remain bent rather than break. Wrought iron can be forged (pounded) into shapes such as cans, hinges, and rails.

A mixture of pig iron and wrought iron, with approximately 2% carbon, is *steel*. Steel is more *elastic* than other iron materials, so after being bent it tends to return to its previous shape. Various steels are ideal for cutlery, railroad ties, armor plating, and structural elements of buildings.  The labor intensive steel making techniques called *crucible steel* and *cementation steel* were too expensive to make rails profitably, but were used for products with high value per weight like edge tools and cutlery.   Many useful variations of pig iron, wrought iron, and steel were based on the kinds of original ore used, the amount of carbon in the final product, the admixtures (such as manganese and nickel), and other details of the production process.

In the 1850s and 1860s European inventors developed two new approaches to steel making which were suitable for mass production.  In one, the *Bessemer steel* process, molten iron was poured into a giant vessel called a Bessemer converter.  Then pressurized air was blown through the liquid.  The heat and air burned carbon away, and if the air flow were cut off at the right time the resulting mixture would be steel.  Bessemer steel technology was established in Britain by 1859 and experiments with it began in the U.S. in 1863.  After several years and many failures the technology became established and production grew quickly for the rest of the century.  The Bessemer steel process worked quickly but did not create very high quality output.

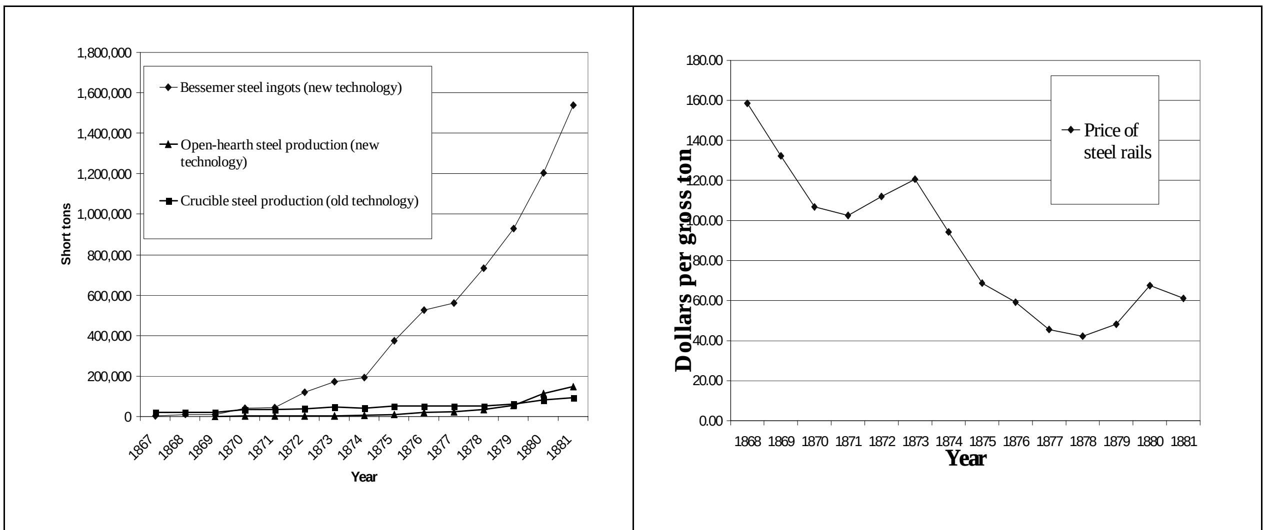
The *open hearth* processes took longer but made higher quality steel.   The *acid open hearth* process produces higher quality but more expensive steel.  It was invented about 1868 and gradually grew in importance.   The *basic* (meaning alkaline) process, introduced in 1878, made open-hearth steel from a different kind of ore.  There were also efforts to use a similar method called *puddled steel*.

Railroads made of steel could sustain heavier trains, and lasted eight or more times as long, as wrought iron rails.  Demand for steel rails was so high that American plants sold all the good rails they could make, and more rails were imported from Britain.  Even so, the price of steel fell during the first twenty years of mass production as the technology of production improved greatly.   The menu of iron and steel materials expanded too.  Some new materials were better than previous ones, and others had niche purposes.  Industrial makers and users knew of many differences among them, but the chemical contents, properties, and mechanisms were not well understood.  Railroads were willing to take some risks to work with steel.  Many innovations in iron and steel production were put to use. By 1920 steel had replaced wrought iron in most applications including the railroads.

Along with the dramatic effects of the introduction of the new steel-making processes, there were a cluster of related changes in the technology and industry.  Iron ore was discovered and mined around the Great Lakes.  Much bigger plants were built, usually near the Great Lakes because ore could be shipped cheaply over water.  These changes in materials supply and technology took place in a context of an ongoing boom in railroad-building which created enormous but volatile demand for iron and steel.

Every year in the 1860s and 1870s steel rails were imported from British firms, at first because their technology was superior, and thereafter because U.S. producers could not satisfy domestic demand.  U.S. firms first sold Bessemer steel in the late 1860s and production became more efficient until it had exceeded the best practices elsewhere.[1] There were several causes for this. (1) There were high tariffs on imports, 45% for steel and most steel products until 1870, then even higher; Temin (p. 173) estimated a rate of 100% by 1877. (2) American producers benefited from enormous domestic demand, especially from the railroads as they crossed the continent. Economies of scale in the newer iron and steel technologies gave American plants an efficiency advantage as well. (3) Iron ore in the U.S. tended to be low in phosphorus, which was required for the Bessemer technology. American ores also had little silicon, which was needed for the open hearth technology. Low silicon ore had to be blown more rapidly through the converter. (Carr and Taplin, pp. 154-155) These input differences drove American designs in slightly different directions from British ones. (4) British safety regulations prevented most uses of steel in buildings from 1859-1877, to an extent that held back Bessemer steel production (Carr and Taplin, p. 162). (5) The U.S. environment supported greater financial risk taking.

U.S. commercial production of Bessemer steel exploded from about 10,000 tons in 1869 to one million tons in 1880 and continued to grow thereafter, as shown in Figure 1. Around ninety percent of this steel went into railroads. The price of the steel fell by about 50% as shown in Figure 2 as production capacity grew and the technology improved. Employment in the steel-making and steel-using industries rose sharply in this period, as shown in Table 10.




**Figures 1 and 2. U.S. steel production quantities and price**
Source is *Historical Statistics of the US.* Table 4 has details.

To summarize: The Bessemer and open hearth processes were invented in the period from 1856 to 1878, and all cheap, mass produced steel from then through 1920 came from these processes. This introduced much variation into the materials and methods of production of iron

[1] By 1874 British expert Isaac Lowthian Bell described some U.S. blast furnaces, Bessemer works, and rolling mills as better than the best British ones (Carr and Taplin, p. 44 and p. 53). French, German, and Belgian ironmakers were also near the technological frontier in 1860. British firms were the leaders, and in the simplified description here, producers outside the U.S. and Britain are left out.

and steel. The variation declined slowly after 1880 as standardization occurred and various aspects of the new production methods became common knowledge.

## 3.0 Wage data from the Weeks report

The statistical hypothesis of interest is that earnings inequality rose during the takeoff of cheap steel. The data to examine this hypothesis come from a survey on wages in manufacturing published with the 1880 Census. It is called the Weeks report for Joseph D. Weeks, the Census special agent who supervised the survey. In the survey, manufacturing establishments reported jobs and the wages paid retrospectively for some set of years up till the time they were asked. The data set has 104,413 observations of wages per job-year, mostly from 1860-1880, but including observations from 1801 to 1884. Colleagues and I have entered and edited the data, which is available online (Meyer, 2004). The survey covered the 48 industries listed in Table 5.

In the Weeks report, establishments reported descriptive information about themselves, including a list of job titles and some information about the wages, salaries, or piece rates paid. Most establishments were also complete firms, but in a few cases two establishments of a single firm are reported to be in different industries. Usually the wage information is the average wage paid by job title, but other times it is the range of wages or a representative wage. Occasionally the number of employees with that job title were reported or implied or other information about them is given. For the purposes of measuring wage inequality, each observation has a wage, associated with a job title, industry, and city or state location. There is often other information about the establishment drawn from the Weeks report or other sources.

The report lists daily wages where possible but some pay was reported on a weekly or monthly basis, or in piece rates such as a specified payment per bushel, ton, or other unit of output. The inequality measures used here require that wages be expressed in a common unit of measure. All the time unit measures were converted to daily rates. Another 3,500 observations, with piece rate wages (such as an amount of dollars per thousand nails produced) were excluded from this study.

The data do not form a balanced panel. Because almost all of the data were reported by firms doing business in 1880, data reported in earlier years has been selected by survival bias and has retrospective bias to the degree that data from earlier years was reconstructed by the firms. The Weeks report did not sample individuals. It surveyed firms, only about half of whom responded, and did so with a partial list of job titles and years. Also one does not know whether a jobholder 1880 was the same person who held the job in 1879. Few statistical adjustments were made here for these issues, which I believe do not bias comparisons of wage inequality between industries.

A more serious problem for measuring earnings inequality is that unskilled laborers were underreported in the Weeks report data. Most establishments reported average wages of workers within a job title (like “Puddler” or “Laborer”), and did not report how many there were, or what the distribution of wages were within the job category. For example, at a particular firm there might be ten laborers but only one manager, yet the firm may have reported one observation per year for each job title. A comparison of the job titles in the Weeks report to the 1880 Census job categories showed that unskilled laborers were definitely underrepresented so each laborer in the data was taken, in the inequality measures, to represent three laborers.[2] This weighting chosen improves the degree to which the data represents the population, but only roughly. It was not clear how much other jobs were underrepresented.

The measure of inequality one would get from a complete census could therefore be systematically different from the measures used here. Some variation is lost because sometimes we have an average wage for a job in place of a full list of wages. Furthermore we do not know how much workers in various occupations were undersampled. The net effect on inequality measures is probably to bias them up, since workers in other low wage occupations, such as helpers, were probably undersampled. They inequality measures are therefore not commensurate with those coming from a representative panel, but it is not clear they are biased for comparisons between two industries at the same time, or the same industry in different years.

## 3.1. Wages and wage predictors

Wages in the Weeks report data averaged $1.92 per day for an adult man, $1.21 for a woman, $.67 for a boy, and $.78 for a girl. The regression in Table 7 shows that holding job title constant, wages rose 1.2% per year in nominal terms. This was similar to the real effect since inflation was near zero overall. During the Civil War there was high inflation and after the Panic of 1873 there was a substantial deflation. These effects are visible in most of the wage series in the Weeks data. By modern standards wages were volatile, and jobs and wages were not protected from depressions.[3] Wages of common jobs are graphed over time in Figure 6.

Job titles were not standardized by the Census Bureau. Going through the data and reading secondary sources, I have created a second job title which is standardized as much as possible. Based on the standardized job titles, 173 jobs have 100 or more wage observations on adult white males. In total there here are approximately 85,000 such observations. Using this definition of occupation, the effect of occupation on wages are stable over time. Standard deviations around the coefficient on the dummy variable for a particular standardized occupations are usually near zero, which suggests we can know the average wage for each job with precision. Job effects by this definition are also stable over time – a regression of the job effects measured in the 1870-1881 data on those in the 1850-1869 period and a constant explains 95% of the variation in the later period. The occupational titles make it possible to hold constant some facets of human capital, or skill, in statistical comparisons. In some regressions to follow, fixed effects are measured with dummy variables on standardized occupations.

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[2] Montgomery (1987, p. 64), cited an estimate that in the 1870s 10 to 20 percent of the workers around rolling mills and converters were day laborers. The fraction rose over the next two decades. The data set has 3211 wage observations on rolling mills in the 1870s, 148 of which are for laborers, so triple-counting each laborer matches both the Census data and Montgomery's estimate.

[3] For example, S. Allen (1987) documented that wage differences across industries vary from year to year ten times as much before 1890 as they did after World War II. Employment was minimally regulated, contracts were short, and turnover was high. Few employees earned steady salaries.

Workers paid piece rates (that is, linearly by some measures of output) were paid slightly more per day than workers paid by time worked, holding all else constant. Because piece rates align incentives so closely to output measures, it was believed at the time that piece rate pay systems generated more effort, output, and wages.[4] When the survey reported piece rate wages without a daily earnings estimate, these observations had to be left out of this regression.

The materials of work indicate particular roles and skills and therefore predict wages. Job titles were coded as involving wood, metal, or heat based on key words. Common woodworker titles were carpenter, cabinet-maker, wood machinist, wood-chopper, and wood-worker. Over 80 jobs were metal-work jobs, including bar-roller, blacksmith, coppersmith, forger, iron machinist, molder's apprentice, pattern-maker, puddler, sheet-mill roller, and wire-straightener. Both wood and metal categories were skilled work, whose wages show premiums according to the wage regression in Table 8. Woodworking machinery had reached a technological plateau by 1860[5] whereas iron work experienced substantial technological change afterward. Perhaps because of this, metal workers received a slight rise in pay relative to wood workers starting about 1870. Workers who dealt with heat were paid 16% more, holding all else constant, according to the regression results. The phrase "hot work" was used at the time. Pay premiums for the use of heat and metal indicated that proximity to new technology was correlated to higher pay.

## 3.2. Wage dispersion

The uncertainty hypothesis is about the worker's technological environment, not a statement about the worker's own attributes. It can be represented in an individual wage regression. Let there be two time periods, one shortly before and one shortly after a particular technological advance. Imagine a wage regression in which a matrix S has data on worker skills, data matrix *X* contains other attributes of employer, worker, and job role, and $\alpha$ is a constant in the regression. The remaining errors in the model's prediction have mean zero and denoted by u below. The econometrician estimates the regression separately for the two time periods:

$$\ln(wage_j) = \alpha_1 + \beta_1 X_j + \gamma_1 S_j + u_{1j} \quad \text{for the early period} \quad (1a)$$
$$\ln(wage_k) = \alpha_2 + \beta_2 X_k + \gamma_2 S_k + u_{2k} \quad \text{for the later period} \quad (1b)$$

If one found that $\gamma_2 > \gamma_1$, this would support a claim that a skill bias had risen. If variance of $u_2$ were greater than the variance of $u_1$, this would support the claim that there was more economic turbulence in the wage relationship in the second period. Therefore in principle skill bias and uncertainty-driven turbulence could occur simultaneously and be distinguished.

[4] For example, in British steelwork, tonnage rates of pay came out higher than time rates of pay (Carr and Taplin, p. 147). Clawson (1980, p.170) estimated piece rates produced 1/3 higher daily pay than day wages did. A U.S. Commissioner of Labor reported that employers found employees paid by piecework produced 15-25 percent more than those paid by the day, according to Montgomery (p. 150).

[5] Rosenberg (1977) documents important improvements in wood machinery, which occurred mainly before 1850.

In practice, they are not easy to distinguish because the empirical meanings of skill or human capital are subject to dispute. In a wage regression which includes the number of years of formal education spent by each worker, some analysts may treat this as a good proxy for skills. But this measure also incorporates institutional advantages the worker has, unrelated to skill. It is a result, first, of favorable opportunities available to the worker; second, it signals abilities of the worker apart from anything learned through education, and third, it represents certifications that the worker received which make the worker formally suitable for an employment position apart from any ability, skill, or prior advantage in opportunities.

Thus any misspecification of skills could lead an econometrician to misinterpret either phenomenon as the other kind. For example, missing data on a dimension of skill makes it appear that technological uncertainty is present. Going the other way, an econometrician may interpret, as measures of skill, variables which do not represent skill variations, in order to support a skill bias argument when the uncertainty argument is a better characterization.

The same issues arise in this study, where we do not have education but have fairly precise information about job title and content. Job title too has a mixture of path dependent results of opportunity, ability, skills, and certification-like outcomes of a worker's experience. Holding job title constant, as best we can, and comparing wage residuals, is one way of showing that some kind of turbulence increased from one period to the next. Apart from the wage evidence, we will see that previous structural relations and institutions were under strain, and that employers, workers, and investors were exploring new alternatives, opportunities, and risks. We can infer that the rules of their game were changing, and this produced winners and losers on many dimensions some of which appear random. Sometimes we can identify those dimensions, but conceptually some dimensions exist which we could understand but not measure.

Here, we have only one good measure of skills, which is the job title. We can show that residuals from some wage regressions were larger in magnitude in the iron and steel industries after 1870 than before. This tests the hypothesis that wage dispersion in one group rose, with the idea that a noisier $u$ is built into those wages than other wages during this later period.

Earnings dispersion here is measured by the standard deviation of log-wages. This measure has the virtue that it is invariant to changes in the unit of measure, so if inflation caused all wages to grow by the same percentage, the measures of inequality would be unchanged. This makes it possible to avoid using any price index. The Gini index and the coefficient of variation of wages (which is a sample's standard deviation divided by the sample average) are measures of inequality within a group also have these advantages. I have found that the results to be shown do not tend to vary substantively with the choice of inequality measure.

The relevant industries in the data are *blast furnaces*, which make pig iron from ore, and *rolling mills*, which press iron or steel into useful shapes. Only establishments from these industries expanded into steel production. We can test directly whether the iron and steel wages were more unequal, statistically. In the next table we combine all iron and steel wage information into a before and after period, and compare this to all other wages in manufacturing.

First we regress all log-wages on year indicators, to detect cyclical and trend effects. The predicted values based on year are shown in Figure 7 (at the back). They show the effects of (a) rising wages with time, (b) the enormous inflation during the Civil War, and (c) the fall during the depressions after the panics of 1857 and 1873. If we subtract the wage predicted by the year dummy regression from the actual wage, what remains are residuals with mean zero each year, *whose dispersion can be compared between groups of years*. Dispersion is measured by variance here because the standard deviation of a sample variance is known.[6] Table 1a compares these wage residuals in iron and steel before 1869, and after, to wage residuals in other industry groups.

**Table 1a Variation in iron and steel wages versus other manufacturing wages**

| | Average of wage residuals, after year effects removed (sample size in parentheses) | | Variance of wage residuals (standard deviation in parentheses) | |
|---|---|---|---|---|
| | 1850-1869 | 1870-1881 | 1850-1869 | 1870-1881 |
| **Iron and steel establishments** (blast furnaces and rolling mills) | .079 (N=2172) | .064 (N=7251) | **.198** (.010) | **.284** (.007) |
| **All other establishments combined** | -.005 (N=31662) | -.008 (N=58614) | **.292** (.003) | **.278** (.002) |
| Other metal work establishments | .171 (N=5252) | .109 (N=10215) | .163 (.005) | .161 (.003) |
| Food/agriculture/forestry | -.066 (N=4082) | -.063 (N=9338) | .306 (.009) | .298 (.006) |
| Textiles/leather | -.211 (N=12436) | -.196 (N=19396) | .296 (.005) | .317 (.004) |
| Wood work | .231 (N=6157) | .156 (N=12865) | .180 (.005) | .185 (.004) |
| Mining and other materials | .107 (N=3735) | .117 (N=6800) | .338 (.012) | .301 (.007) |

Finding: variation of wage residuals grew most in the iron and steel industries.

[6] The last column has the standard deviation of the measured variance. The sample variance of an estimated variance statistic is computed in Greene (1997, pp. 128-129) by the delta method applied to the sample variance computation. Let $w$ be an observation from a distribution of log-earnings, $n$ be the size of a sample of observations of $w$, $E[]$ be the expectations operator, $\mu_w$ be the mean of $w$, and $\sigma_w$ be the standard deviation of $w$. Then for large $n$, the variance around the sample variance of $w$ is estimated by:

$$\text{AsymptoticVariance}(\sigma_w^2) = \frac{E[(w-\mu_w)^4] - \sigma_w^4}{n}$$

Substituting sample analogs for $E[(w-\mu_w)^4]$ , $\sigma_w^4$ , and $n$ gives an estimate of the sampling variance around the estimated variance of log-wages. The square root of that quantity is the standard deviation and 1.96 times the standard deviation defines bounds for a 95% confidence interval. The derivation of this statistic depends on the assumption that the wages are a random sample of the industry population when in fact they were selected from establishments, which were stable enough to reply to a survey. So using this measure of variance, statistical significance is exaggerated, and no formal statistical significance tests are applied here.

The variance of the residuals in bold toward the top right rose in the iron and steel group but drifted down in the rest of the industries taken together, and in the most of the clusters of industries shown. This shows *the wage distribution spread out in iron and steel but not in other industries*.

Now consider a more substantive regression in which there are indicator variables for the most common occupations after the job titles have been standardized. Residuals from this regression are much smaller. The same effect exists in the residuals which are shown in Table 1b – again, the iron and steel residuals jump after 1870 but the others do not.

**Table 1b. Variation in iron and steel wages versus other manufacturing wages**

| | Average of wage residuals, after regression on year indicators and standardized job indicators (sample size in parentheses) | | Variance of wage residuals (standard deviation in parentheses) | |
|---|---|---|---|---|
| | 1850-1869 | 1870-1881 | 1850-1869 | 1870-1881 |
| **Iron and steel establishments** | -.002 (N=1915) | -.018 (N=5731) | **.090** (.004) | **.112** (.003) |
| **All other establishments combined** | .000 (N=27276) | .002 (N=49932) | **.100** (.001) | **.101** (.001) |
| Other metal work establishments | .044 (N=4988) | .019 (N=9452) | .073 (.002) | .063 (.002) |
| Food/agriculture/forestry | -.013 (N=3392) | -.025 (N=7705) | .160 (.006) | .148 (.004) |
| Textiles/leather | -.029 (N=10602) | -.004 (N=15945) | .097 (..002 | .106 (.002) |
| Wood work | .012 (N=5699 | -.014 (N=12168) | .086 (.003) | .089 (.002) |
| Mining and other materials | .025 (N=2595) | .051 (N=4862) | .108 (.004) | .109 (.005) |

Note: regression includes only white adult men in the standardized jobs.

Changes in measurement methodology seem not change this basic finding. The use of some other metric of inequality makes only small differences. The use of the wage regression in Table 8, with many more substantive variables, reduces the residuals but still it jumps for the iron and steel sector and not elsewhere, as shown in Table 1c.

Thus this effect appears robust to variations in the regressors which include proxies for skill. The remainder of this section considers alternatives in measurement and alternative causes for the result in Table 1. For example, the weighting of the laborers to match their frequency in the population does not make much difference, basically because the variation that affects this measure of dispersion is the variation among high wages. Skipping the step of removing year effects, and simply using a using a time trend, or no adjustment at all to log-wages over time, produces a substantively similar result.

**Table 1c. Variation in iron and steel wages versus other manufacturing wages**

| | Average of wage residuals by industry, after regression on year indicators and standardized job indicators, and other variables (sample size in parentheses) | | Variance of wage residuals (standard deviation of the variance in parentheses) | |
|---|---|---|---|---|
| | 1850-1869 | 1870-1881 | 1850-1869 | 1870-1881 |
| **Iron and steel establishments** | .006 (N=2172) | .000 (N=7251) | **.097** (.004) | **.145** (.004) |
| **All other establishments combined** | -.002 (N=31662) | .006 (N=58614) | **.120** (.002) | **.121** (.001) |
| Other metal work establishments | .045 (N=5252) | .027 (N=10215) | .075 (.002) | .069 (.002) |
| Food/agriculture/forestry | -.024 (N=4082) | -.022 (N=9338) | .168 (.006) | .154 (.003) |
| Textiles/clothing/leather | -.049 (N=12436) | -.016 (N=19396) | .119 (.002) | .136 (.002) |
| Wood work | .034 (N=6157) | -.003 (N=12865) | .099 (.003) | .102 (.002) |
| Mining and other materials | .050 (N=3735) | .090 (N=6800) | .149 (.005) | .146 (.005) |

The regression from which these residuals come is shown in Table 8. It includes all observations from 1850-1880 with measures of daily earnings. $R^2$ of the regression is .60. Laborers were weighted as three observations each.

Perhaps any substantively sensible wage regression on this data will have this property – that its residuals will be larger for the iron and steel industry after 1870 than before, and that this is not the case for other industries. This suggests there is a link to the technological change. We consider below how instead it might be caused by misspecifications.

One would get similar results in such comparisons if there were a long-lasting trend toward increasing inequality in the iron and steel business, even if there were no special change in or around 1869 in particular. Atack, Bateman, and Margo (2000) find in the Census of Manufactures that the presence of larger and larger firms seemed to be related to rising income inequality in this period. Certainly this is possible among the iron and steel firms, whose average size grew rapidly throughout the period. The Weeks report does not have enough direct information about firm size to address this hypothesis in particular, but Table 2 addresses the general possibility that there was a long lasting trend rise in iron and steel in particular. It has the results of a regression in which wage inequality, measured by the standard deviation of log-wages within an industry in one year, is the dependent variable. Holding constant a time trend, and a post-1869 indicator variable, and a time trend for the iron industries, the iron-making industries had a rise in earnings inequality as of about 1869. This evidence supports the finding of a structural break in 1869-70 rather than a trend.

**Table 2. Predictors of wage dispersion within industry-years**

| Predictor | Coefficient | Robust standard errors | p-value |
|---|---|---|---|
| Year (1855 to 1881) minus 1869 | .0003 | .001 | .813 |
| Post-1869 indicator | .022 | .018 | .206 |
| Minerals and mining industries | -.062 | .021 | .003 |
| Woodwork industries | -.044 | .019 | .023 |
| Agricultural or food processing industries | -.028 | .021 | .180 |
| Textiles and clothing industries | .075 | .022 | .001 |
| Metal production and use industry (incl. iron and steel) | -.083 | .019 | .000 |
| Iron and steel (blast furnace or rolling mill) | .027 | .033 | .414 |
| **Year trend for iron and steel only** | **-.004** | **.005** | **.354** |
| **Iron blast furnace or rolling mill after 1869** | **.120** | **.050** | **.017** |

Notes: The dependent variable is standard deviation of weighted log-wages within industries each year. There are 1047 industry-year observations of this variable (27 years of 48 industries, excluding industry-years with fewer than 10 wage observations). An excluded category of industries is those making building materials. The coefficient on the constant is not shown. R-squared: 0.14.

Earnings inequality was higher in the industries making iron or steel, defined in the last row of Table 2, than in those same industries in the past or in other metals industries. If there were a longstanding trend in the inequality within these industries it should appear in the second to last row, but there does not seem to be any significant trend.

Many establishments appear first in the data in 1870 and the apparent break at 1870 could be partly an artifact of the data. Partly this is because so many firms reported retrospectively back precisely to 1870, both in iron and steel and in other industries. Outside iron and steel, there is a rise of 31% in the numbers of firms and wage observations in the data from 1869 to 1870. Within iron and steel, 84% more establishments and 145% more wage observations are reported in 1870 than in 1869. See Tables 5 and 6 for more specifics on the distribution of the data by industry and year. I have not adjusted for this, partly because new plants starting up in the context of a new steel technology are part of the phenomenon of interest. Analogously, new information technologies in the 1970s and 1980s created opportunities for a wave of startups.

## 3.3 Labor demand, not labor supply

One might think there were great changes in labor supply and that this effect has to do with the kinds of workers available. Indeed there was great immigration to the United States at this time. Estimates made in 1890 found that 55% of iron and steel workers were U.S.-born whites, 4% were U.S.-born blacks and 30% were born in Germany, Britain, or Ireland (Montgomery, p.25).

Immigrants from eastern European made up a growing but still small fraction of the iron and steel work force.

It is not clear whether immigration affected the iron and steel sector more than other industries. Table 9 compares the literacy levels of various subsets of workers based on 1850 through 1880 Census data. By any measure, the iron sector employed a growing fraction of the workforce, as shown in Table 10. Iron workers were somewhat more literate than the working population. Table 9 shows that the generally speaking, the populations of iron workers and of American workers in general became more literate with time. Too few respondents in these Censuses answered questions about citizenship and birthplace to make clear whether there was a change in the extent to which iron workers or the population at large were native born or citizens.[7] The evidence does not suggest there were distinctive changes in the workforce of iron and steel. Instead the inequality change is likely to be related to the technology change.

To summarize: earnings inequality rose in the industries making iron and steel around 1870, when the new technologies of cheap steel arrived. Inequality did not rise in other manufacturing industries generally. This seems not to be a result of changes in the workforce, but could be a result of changes related to the technology.

## 4.0 Sources of the rise in inequality

We have seen that there was dramatic technological change in the iron and steel sector, and a contemporaneous rise in earnings dispersion within just these industries. There are overlapping theories about why inequality would rise in response to technological change. Two of these ideas are *skill-biased technological change*, and the *uncertainty hypothesis*.[8]

Both can be framed in the Greenwood-Yorukoglu (1997) model. It describes how a technology change which continually lowers capital equipment prices over time could cause employers to temporarily (a) invest more in capital, (b) exhibit lower productivity and earn lower profits, and (c) increase earnings inequality in the workforce. In that model, the rise in earnings inequality comes from variation in skill that makes workers differ in their capacity to adapt to the new technology. Knowing this, employers using new technology strongly prefer to hire skilled workers. This generates a rise in earnings inequality. Investment in wages for these individuals,

[7] This evidence is not shown here but is available from the author.

[8] There is also the *Kuznets curve*. Kuznets (1955) characterized industrialization as a process where a population shifts from low-wage agriculture to higher-wage industrial work. Workers all have similar low wages at the beginning of the process and similar high wages at the end, so only in the transition phase is there a high measure of inequality. Findings of this kind regarding nationwide income distributions have been reported and also disputed. In any case, an analogous transition could occur on the microeconomic, industry level if there was a transition from a well-defined previous earnings distribution for 1860 iron and steel work to a well defined one after the diffusion of new technologies (Rogers, 1995). A Kuznets curve may be fairly predictable if it is clear what the previous and future earnings distributions are. The situation described in this paper was too much in flux for a Kuznets-type description to apply, since that would describe a transition between two stable distributions.

and associated investment in experimentation with fast-obsolescing equipment raises costs without raising immediate revenue. Thus measured productivity declines at first; there is a productivity slowdown. Still, investments in equipment is optimal for the employer because it maximizes long run profits, compared to taking higher short run profits but becoming technologically obsolete later. The Greenwood-Yorukoglu account matches the evidence presented here – there was great investment into the iron sector, a rise in earnings inequality in that sector, and at least some evidence of a productivity slowdown, to be discussed later.

Since in the model employers preferred to hire skilled individuals, the rise in inequality of earnings was generated by a skill bias assumption: that workers with certain preexisting skills apply the new technology more productively than individuals without the skills. Another way this has been put is to take skills and employers' understanding as given, and then say that the technology is skill-biased. In modern regressions, skill is often measured by years of formal education. We have no such information on individuals in the Weeks report, only what is implicit in their job titles. To some analysts "skill" is defined to include the ability to adapt to new circumstances, but if so it is hard to measure it or know if it was learned, and so here we do not call that a skill.[9] A skill-bias might not be accompanied by technological or market uncertainty. It may be predictable, and a worker may be able to prepare. Skill is an attribute of the worker, not of the worker's context. Only demand for skill would vary by context.

This story can remain almost the same with an uncertainty hypothesis. Uncertainty is the state of not having enough knowledge to predict the future. The term *technological uncertainty* describes an environment in which the future production process is hard to predict. The uncertainty associated with innovative activities is greater than that associated with other economic activities such as trading, according to Dosi (1988): "[Innovation] involves not only lack of knowledge of the precise cost and outcomes of different alternatives, but often also lack of knowledge of what the alternatives are." The relevant uncertainty is greater if the players think future profits could be high. If instead profits are sure to be low, choices matter less. Malerba (1985, p. 32) characterized technological uncertainty well: "In a situation of uncertainty and change, firms cannot have a perfect knowledge of either the objective random distributions of technological opportunities in the industry, or of the change of these distributions over time." They depend on prior probability distributions "which are highly subjective and based on few, if any, observations." Not knowing what is possible, they guess, and place bets.

Here one assumes that because the environment has changed and adaptation is required, that there will be differentiation in productivity and wages among the population, whether correlated to individual attributes or not. Participants foresee that new technologies are likely to

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[9] Therefore this account of skill bias is restrictive, and does not account for all versions that appear in the economic literature. Recent works by Bresnahan, Brynjolfsson, and Hitt, for example, treat worker skills as useful for adaptation. This definition partly bridges the gap between what the description here calls the skill bias account and the uncertainty account. Because it depends on skills associated with workers, without institutional factors, it looks like the skill bias story depicted above. Because it is a temporary phenomenon, linked to the transition not the subsequent long-lasting state, it looks like the uncertainty account.

outcompete existing ones but cannot take over yet because too little is known.[10] A learning process gradually reduces the uncertainty – improving each technology through experience, and testing out and selecting among technologies, materials, and ways of organizing work processes within and among firms. So if in the history of the period we see various players (investors, firms, or workers) making extra efforts to obtain information, we have evidence that they were responding to uncertainty. One difference between the hypotheses is that skill-bias might be entirely predictable, whereas if technological uncertainty were also important, then productivity and wages are uncertain too.[11]

A story of the social process of technology change underlies the uncertainty hypothesis. In the Tushman and Anderson (1991) account, a *technological discontinuity* is a break between underlying technologies that creates a new product class, or has the prospect of radically improving the performance of existing products or processes. A period of technological uncertainty follows. There is a kind of gold rush toward new opportunities. New businesses start up and bid for employees. They try to make relevant products as the new technology becomes the basis of an industry. In this period of ferment, various players face new opportunities, choices, and problems. Their ability to forecast the outcomes is poor. Because they make divergent choices, some do poorly and others well. Underlying the wage determination process, for example, beliefs vary about the probability of possible outcomes. During this period, early customers get a sense of what the technology is useful for and what can be expected from it. Eventually a standardized *dominant design* emerges for the product category (Abernathy and Utterback, 1978) and there is a shakeout of producers in the industry. With time the dominant design becomes well understood and user-friendly. Reliable forms of the technology are incorporated into standard operating procedure. Producers and users then experiment less, so outcomes and wages are more predictable than they were during the uncertainty phase.

Variations in outcomes could be a function of the circumstances, not differences among workers per se, since different forecasts about tomorrow's market, customers, technologies, products, or prices would drive employers to make different choices. Some take new opportunities while others compete against them. The appearance of new opportunities and varied responses produces winners and losers, bringing about a rise in wage inequality among workers who may be similar ex ante.

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[10] The term comes from Tushman and Anderson (1986, p. 44) and Rosenberg (1996). Tushman and Anderson (1986) measure this uncertainty by the forecasting errors of industry analysts predicting demand growth in the industry. They show that a technological discontinuity is followed by an expansion in these errors. After the dominant design appears, further innovations change the production process more than the product design.

The word "uncertainty" applies when there is qualitative or unanticipated variation in possible outcomes such as the form of a product or process. The more common economic language of *risk* presumes that the outcomes are quantitatively measurable and comparable to one another. (Rosenberg, 1996; Dosi, 1988).

[11] Other formal models using an uncertainty-like assumption, under various names, include Caselli (1997), Rubenstein and Tsiddon (1998), Galor and Moav (2000), and Aghion (2001). In all these, something like variation in ability leads to a rise in the dispersion of productivity and wages among workers during a new technology's takeoff. Schultz (1975) discusses the ability to adapt to economic disequilibrium situations, perhaps like technological uncertainty. Evidence presented there implies that education predicts this ability.

To sum up, the skill-bias hypothesis depicted above is that:

New technology appears → Better-skilled workers make relative wage gains

Whereas the technological uncertainty prediction is:

New technology produces divergent choices, under uncertainty → earnings inequality rises
As the technology grows older → Producers standardize and customers have more complete information → Earnings inequality declines

Levels of inequality need not be the same before and afterward. Only an increase in inequality, then a decrease, is predicted by any of these paradigms.[12]

These theories are not specified sharply enough to distinguish between them with a single statistical test. But the uncertainty hypothesis suggests that productivity measures would be noisy, and wages hard to predict. A skill-bias hypothesis instead suggests that if we could identify the key skills, the importance of those skills would rise, but wages need not be less predictable. So we will look at residuals from wage regressions.

## 4.1 A statistical test of uncertainty

During times of technological uncertainty, measures of skill level should predict wages less well than during times of technological stability. To test this, Figures 2a and 2b display the average squared deviation of the log wage from the amount predicted by the regression in Table 8, which had measures of year, state, business-cyclical factors, job content, and rank. These residuals will be high when the predictive power of the wage regression is low.

Figures 3a and 3b show that in the industries in which the Bessemer process was applied -- blast furnaces and rolling mills -- the wage predictions fit less well after 1870; but this is not the case in other industries. If employers had different information sets, and guessed at production technologies and wages, wages would be less predictable, analogous perhaps to a period of volatility in asset prices. In a predictable transition as described by a Kuznets curve or a pure skill-bias theory, this would not be the case.

[12] For completeness, the Kuznets curve prediction is: Earnings distribution is stable, then new technology appears → Workers on new technology earn more → Old technology is abandoned → All workers use new technology and earnings distribution is stable.

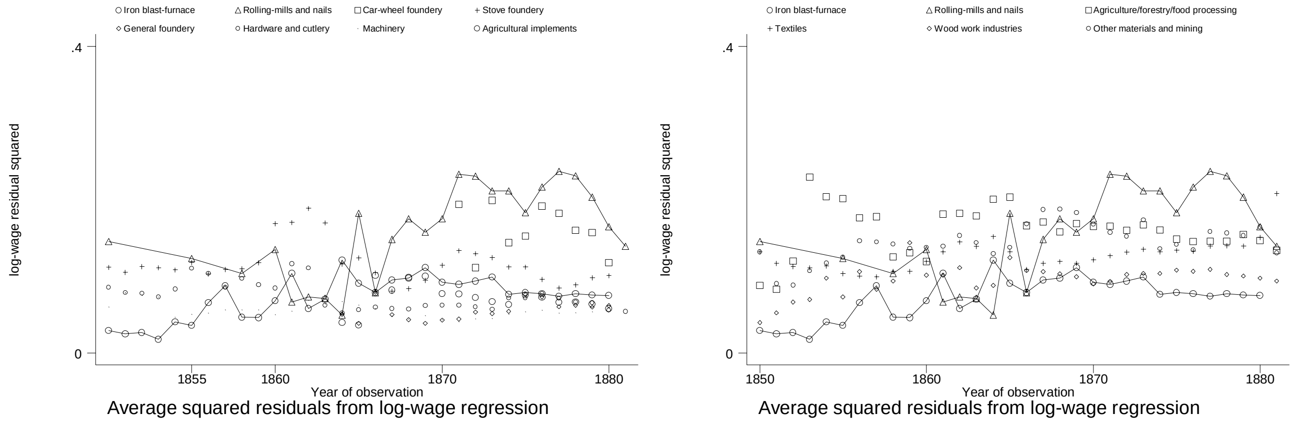


Figure 3a and 3b. Yearly-averaged squared wage residuals in (a) metalwork industries, (b) iron and steel versus other sectors. Blast furnaces and rolling mills are the industries with lines connecting them. In rolling mills particularly, wages were less well predicted by the regression in Table 8 after 1869 than they had been before. We do not see the same phenomenon for other industries.

This fall in the predictive power of the wage regression could have been evident using data up through 1874. A forecaster applying the Greenwood-Yorukoglu idea could have foreseen a productivity slowdown, even during a period where prices were falling and output growing. Taking the steel case as a prototype, a model of uncertainty could be applied prospectively.

# 5.0 Occupations and institutions relevant to the steel market

## 5.1 Ambiguity about the product

The definition of steel was ambiguous in the 1870s. By one definition, steel could be distinguished from wrought iron by chemical attributes -- these material would be defined by their content of iron, carbon, and other elements. An alternative, physical definition, was that a material would be considered steel if it responded in certain ways to compression, twisting, and other mechanical tests. The U.S. military preferred this approach and took a lead in mechanical testing. A third possibility was a process definition according to which an iron material would be called steel if it had been completely molten ("fused") during its creation.[13]

There was substantive debate among chemists, metallurgists, and engineers about which definition was appropriate. Financial forces were in play too. Interested firms took explicit positions in the debate, and funded advocates for their preferred position. For example, railroad

[13] This discussion is drawn from Misa (1995) and Gordon (1996), pp 11-25. There are analogous definitional problems in the information age, such as whether algorithms and genetic material are patentable, whether cryptographic programs represent freedom of speech and are legal to export, and whether software-making should be categorized as manufacturing or service. After standardization, definitions are clearer.

interests were served by a process definition since the key feature at issue for rails was whether they would crack, and a "fused" (homogeneously melted) material would tend not to crack, whether it had the carbon content we now associate with steel or the lower carbon content of wrought iron. Whether a material was iron or steel would affect the import duties levied on it, which led to some allegedly scientific opinions.

It was clear however that British-made Bessemer steel rails were definitely better than iron ones. A related financial effect was that a material would have a much higher price if it could be labeled steel, and a railroad's appeal to investors would increase if the rails it laid were steel. "Adopting steel rails," noted one financial analyst, "was an effective strategy to inflate the value of rail stock for speculative purposes."[14]

To steel producers, quality control was a pressing issue. Steel makers were among the early users of chemical tests of iron inputs. By contrast, foundries still had experienced employees ("blenders") who selected and mixed the iron inputs on the basis of experience, not chemical analysis, for many years afterward.[15]

By 1880, steel had a standard definition -- the fusion definition distinguished between steel and other categories of iron, but steels would be distinguished from one another by chemical attributes.[16] Railroads also specified a chemical composition in their contracts to buy rails. In 1881 Carnegie's firm published a handbook that defined standard steel product lines (Misa, 1995, p. 73), clarifying a previously chaotic market. Iron columns were sometimes used in structures, but it was not still well understood which steels were safe to build structures and ships with until the 1880s (Misa, 1995, and Nelson, 1995, p. 15).

Since steel was not well defined at the beginning of this period, there was literally technological uncertainty about the product. Many purchasers of iron or steel could not test its chemistry or microstructure but would buy on the basis of what ore had been used and who the iron master was (Gordon, pp. 5 and 11). These were only meaningful locally, and declined in importance over time in an increasingly national-scale market. Thus the price of steel probably had more variation than it did later, and its market may not have been well defined as it was later.

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[14] Misa, p. 37. Likewise in the dot-com boom, a company could show its commitment to the Web by putting ".com" in its name. This alone might lift its stock price. Cooper et al (2001) found that "A mere association with the Internet seems enough to provide a firm with a large and permanent value increase." The value attributed by investors in both cases may reflect their recognition that in unpredictable ways these technologies were likely to improve dramatically. The official commitment to the new technology represented by the name change is then informative and could signal an actual change in value.

[15] *Foundries* use pig iron to make wrought iron or castings. In 1893 it was forecast that foundries would follow steelmaking and replace instincts of blenders with chemical analysis (Gordon, 1983, p. 624-5).

[16] A 1913 metallurgy textbook did not find the subject closed yet. "At the best, however, the definition of steel is in a shockingly bad condition, and has been brought to it by a series of events which shows the carelessness of the buying public and the greed of men who will appropriate the name for their product that will bring them the best price without regard to whether the name really fits or not." (Stoughton, 1913, p. 7)

## 5.2 Innovators: from hobbyists to formal R&D

No American iron and steel firms had a research department in 1866. The great inventions in the technology if iron and steel during this period came from isolated inventors. During the period under study, shared institutions of collective invention arose (Meyer, 2003). By the end, systematic firm-sponsored research and development was established at every large iron or steel firm.

The new steel technologies were first invented by isolated or idiosyncratically trained inventors, principally in Britain, who were not backed by major firms. Their financial returns from these inventions varied greatly. Examples:

- British inventor Henry Bessemer had no history in the iron industry and little experience with iron production, but he was inspired in 1856 to adapt an invention he had applied to glassmaking. It happened that Bessemer used a particular iron input with the right mixture of elements to produce a good output. Partly because of his determined self-promotion, his invention was recognized. It did not always work however, and a number of licensees gave up. Bessemer started his own firm in Sheffield, England, improved the invention, undersold competitors, and became a millionaire.
- Kentucky ironmaster William Kelly "boiled" iron like Bessemer, without actually making steel. He held an essential patent.
- Metallurgist Robert Mushet solved a problem in Bessemer's process which made its output brittle. Mushet depended on a Welsh ironmaking firm to renew his British patent but the firm blundered and did not. Mushet lost all subsequent British proceeds from his invention, and was poor the rest of his life.[17]
- Sidney Thomas worked as a London court clerk full time, but was fascinated by chemistry. He became determined to find a way to make open hearth steel out of iron with phosphorus impurities, though experts had failed at this. He ran experiments in the evenings at home. After six years he persuaded an ironworks chemist to help him. By 1878 the process worked.[18]

"Thomas solved a problem that had engaged the attention of some of Europe's most highly trained engineers for years. He was one of the last and perhaps the most important of the line of tinkerers that had made the Industrial Revolution. After him, the professionals just about had the field to themselves." (Landes, 1969, pp 258-9)

[17] Carr and Taplin, p. 23. Mushet's struggle is starkly illustrative. His contribution was essential and yet he lost out almost totally while Bessemer made millions. If Mushet had run his own firm or been an established professional employee, perhaps he could have protected himself. In recent high tech period, Tim Paterson's case is analogous. Paterson wrote an early PC operating system and sold it for $50,000 in 1980 to Microsoft. Microsoft adapted it to make MS-DOS which became enormously profitable, eventually earning billions of dollars and market power. Also analogously, Tim Berners-Lee invented the World Wide Web, but did not own it, and the financial benefits went mainly to others. Uncertain environments characteristically produce these extremely dispersed outcomes. When well-established institutions dominate, outcomes vary less. That happened in the Bessemer steel case after 1880.

[18] A prestigious metallurgist did not accept that Thomas had done it. (Carr and Taplin, 1962, p. 99.

Relatedly, in the 1860s, the general perception in the U.S. industry was that chemistry was not of any industrial use. No chemists were employed in the U.S. iron and steel business, and metallurgical and chemical knowledge there was poor. Two U.S. books by experts from the 1850s asserted incorrectly that phosphorus impurities in iron would not prevent steel from being made from it (Gordon, 1983, p. 616). British experts knew the opposite was true, and that this fact was crucial in choosing ores and technologies in steelmaking.

In the U.S. a number of institutions arose starting in 1866 to make it possible for various organizations and individuals to work together to advance the new steel technologies. Among the pathways of shared effort were:

- a pool of patents held in common by the new Bessemer Association
- an expert engineering consultant, Alexander Holley, working for and representing the Association's. Holley helped design most of the early Bessemer plants, and recommended employees to employers and vice versa (McHugh, p. 260).
- other common consultants, meetings[19], and high turnover between plants which resulted in shared information, and
- several new professional associations and technical journals related to iron.[20]

Such institutions of collective invention or aspects of the environment sustained investment, experimentation, and discovery.[21] During this intermediate period chemists first appeared in the iron and steel business. One reason they were needed was that the processing of materials was increasingly mechanical. There was less and less human participation to correct imbalances in materials. For example, puddling is a mechanical craft in which an expert carefully watches the bubbling iron, but in a Bessemer converter the operators have little ability to see what is happening or to control it. Yet it was not clear that chemists, examining the input materials, could help in time. The variation of opinion is illustrated by two key quotes. In 1872, the general manager of a substantial iron works wrote

> The president of our company thinks we ought to follow the fashion and have a chemist. To my mind it is a waste of money. When I want an analysis I can have it made – and that is very seldom; for the furnace manager who needs a chemist to tell him the quality of ore or limestone, or whether his pig-iron is soft or hard, had better resign and go to farming. However, if the president says chemist, chemist it is. My object in writing is to know if you can recommend a young man competent to fit up a laboratory and take charge of it. . . . [It] is desirable that he should be a gentleman. My wife plays the piano and I do a little on the flute; and if we can get a chemist who plays the violin, we could have some music evenings. If you can suggest a man who combines these qualifications,

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[19] Managers and technical experts moved between firms and "the five or six top engineers of the industry [met frequently] to discuss common problems." (Temin, 1964, p. 133).

[20] In 1871 the American Institute of Mining Engineers began its journal *Transactions,* which was the most important one for steel development. In 1879 a professional journal of mechanical engineers began publication, and in 1880 a journal of charcoal iron workers began.

[21] This argument is made in detail in Meyer (2003a) which makes the case that the phenomenon has occurred in several cases of technological uncertainty, and that when the technology is better understood, such institutions tend to be replaced by private research and development. The term *collective invention* comes from Allen (1983).

> I could employ him. I do not know what a chemist would expect; but I should not care to pay more than $10 a week.[22]

This point of view was dying out. Around the same time Andrew Carnegie wrote:

> We found . . . a learned German, Dr. Fricke, and great secrets did the doctor open up to us. [Iron ore] from mines that had a high reputation was found to contain ten, fifteen, and even twenty per cent less iron than it had been credited with. Mines that hitherto had a poor reputation we found to be now yielding superior ore. . . . Nine-tenths of all the uncertainties of pig iron making were dispelled under the burning sun of chemical knowledge.
>
> What fools we had been! But then there was this consolation: we were not as great fools as our competitors. . . . [They] said they could not afford to employ a chemist. Had they known the truth then, they would have known they could not afford to be without one.[23]

Carnegie was overoptimistic – a chemist could not dispel 90% of the uncertainty – but had identified a basic truth. The previously quoted manager seems dramatically mistaken. By the end of the decade managers would not write so flippantly about the issue. Hiring chemists was a gamble which sometimes paid off. Proper adaptation might require hiring experts.[24] The Wyandotte, Michigan company attempting to use Kelly's patent and process employed a chemist briefly (Temin, p. 156). Pennsylvania Steel hired a chemist by 1868 (Misa, 1995, p. 34). A Connecticut crucible steelworks in 1868 seeked to hire "a qualified 'scientific' man to operate [the] steelworks." (Gordon, p. 628) Carnegie's firm hired a chemist by 1872. These were early adopters. An observer reported that "until about 1875 the fact that iron smelting was a chemical process was not generally accepted." (Temin, 1964, p. 156) Instead some thought the process was strictly physical – that iron and other metals were just melting out of the ore under tremendous heat. In fact, several chemical reactions create slag, gases, and iron from the ore. It was not well understood at this time, but both its chemistry and its microstructure of the resulting metal affect its strength and other properties. (Gordon, 1996)

Once the technology progressed to be profitable on a large scale, the large firms had a financial incentive to form their own research laboratories. This changed the innovative environment permanently. After 1880, all significant inventions in this field came from experts in the major firms and laboratories.[25] Chemists conducted systematic research at the leading iron and steel works and many had been promoted into management.[26] Uncertainty about

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[22] McHugh, p. 185. This wage seems implausibly low. There are no chemists in the Weeks data to compare it to.
[23] Misa attributes this to Livesay's 1975 book on Andrew Carnegie, p. 114.
[24] In the recent period this is better understood. Bartel and Lichtenberg (1987) looked for implications of the assumption that "when a new product or process has been recently introduced, there is 'more (remaining) to be learned' about the technology, and there is a greater premium on the superior 'signal-extraction' capability of educated labor." They reported empirical results in which the introduction of new technology (measured by the introduction of new equipment) correlates with relative demand for educated workers, and that this difference was seen more strongly in R&D-intensive industries.
[25] An analogous change occurred in recent years. There was a flow of desktop computer hardware innovations from hobbyists and startup firms in the 1970s and 1980s but few since then.
[26] Swank, p. 154; Temin; McHugh.

technological direction had been reduced by strategic investments in research and development, with well-defined training and professional standards and practices. Technological change continued and productivity and industry profits improved in the succeeding decades.

To review: in the mid-1860s, lab chemistry was perceived to be unimportant and the great inventions came from amateurs by surprise. In an intervening period, professional associations and journals arose and innovations were generated collectively. Toward the end of the period, chemists were established at all the large firms. Chemists arrived in response to opportunities and dangers their employers perceived. Employers did not share a common expectation in advance about whether the gamble would work out well.

## 5.3 Occupations: puddlers, rollers, and inside contracting

Extreme variation in incomes was possible because of a special kind of labor contract. Skilled workers in iron and steel (including puddlers and rollers, discussed below) were usually *inside contractors*. Negotiations between contractors or their union and the firms determined the piece rates of pay to the group. Contractors hired and organized their own employees, agreeing to pay each one some percentage of the income.

The inside contracting system was common in the iron and steel industry and in interchangeable parts manufacturing, possibly because the contracting system was flexible in response to circumstances and these were the most technologically advanced kinds of manufacturing. Because they were paid by the piece, contractors had strong financial incentives to improve the technology and organization of work. They made many innovations. As prices fell and production efficiency improved over the years, establishment managers negotiated the pay rates down. Contractors attempted to hide their technology and cost information so as to improve their bargaining position and worsen the outcome for the firm if they failed to come to agreement. But the establishment could hire the contractor's employees away from him and get the information that way. Negotiations usually occurred annually, but when demand was high, employers allowed inside contractors to make extraordinary incomes, and waited to renegotiate until demand was lower and the contractor was in a weaker position.[27]

Consider now two skilled iron and steel production jobs. The job of a *puddler* was to stir liquefied pig iron in a furnace for hours while impurities either burned off or separated away as slag. The resulting bar iron was highly valued. Puddling was the iron and steel craft requiring the highest skill, by many accounts.[28] If pure skill bias were an important factor in the technology change, an observer at the time might incorrectly have predicted puddlers to gain from it. In fact, improving mass production technologies competed against them.[29]

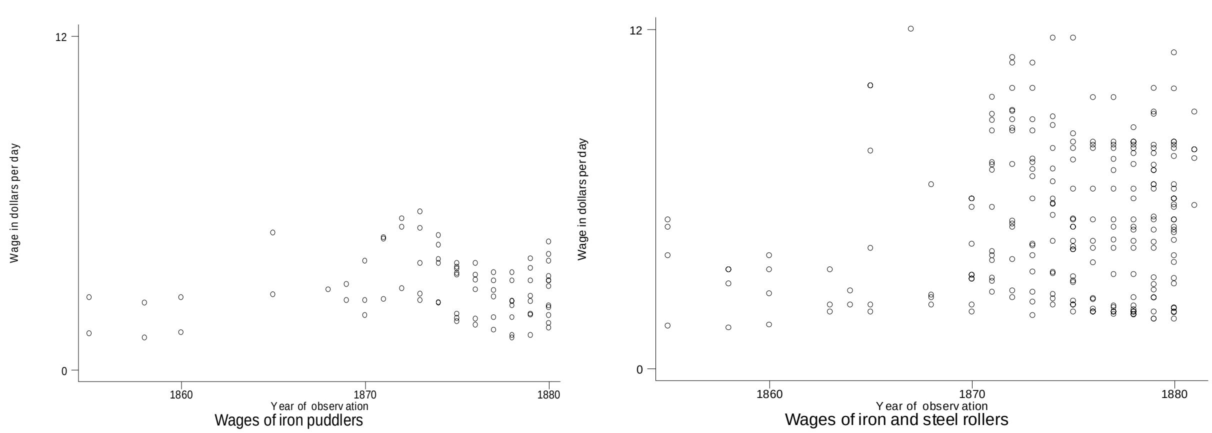
[27] This section on inside contracting is drawn from especially from Clawson (1980), and also from Nelson pp 38-39, Montgomery, Stone, Fitch, Brody, [and Englander]. These sources generally agree on the facts and issues.
[28] Jardini estimated the numbers of years of apprenticeship and training various iron workers had. Puddlers had more than any other occupation. All sources seem to agree, e.g., Clawson pp 139-141; Nuwer; Gordon; Davis.
[29] In Jardini's study (pp 177-182) the skill levels of the Bessemer converter crew were measured to be much lower than those of wrought iron workers (puddlers).

The new steel methods did not directly affect the craft of puddling except competing with its output, bar iron. Bessemer steel was sometimes cheap enough, and open hearth steel was usually good enough, to compete against bar iron. At the time it was widely believed that that open hearth steel would displace bar iron for most purposes. This was correct, but it took longer than many people expected. By 1905, puddling was permanently in decline.

*Rollers* had another skilled job. They received iron or steel slabs which were usually still hot from their creation in a furnace or Bessemer converter. The rollers sent this input material slabs through slits between turning rolls of metal to compress the input material, squeeze away slag, and shape it into rails for the railroads, sheets, or some other product. Rollers and coworkers sent the material several times through the rolls, controlling it with tongs, and adjusted the gap between the rolls by hand or with hand tools. Technology changes affected them and they affected the technology change in several ways. The new steel materials affected them directly, because steel was tougher than bar iron and broke the rolls designed for iron in the early efforts (McHugh, 1980). There were several ways of adapting. One was to make larger, heavier, rolls. Another was to leave more room between the rolls so that the input material would not be reshaped as much in a single pass. This then required many more passes between the rolls. In the long run, the equipment was designed to have many rolls with pre-set gaps between them, on a long conveyor belt so less individual handling of each slab was required. Rollers were intimately tied up in these technological changes.

In the Weeks report one firm distinguished iron rollers from steel rollers, and the steel rollers were paid much higher – about twenty percent more, per day. The piece rate difference was greater than that, because steel rollers made less output per day.

Figures 4a and 4b display nominal wages of puddlers and rollers, including their helpers, in the Weeks data. The dispersion of pay rose visibly among the rollers in the later part of the period. For comparison, Figure 6 compares these to other jobs, and Figure 7 shows that high inflation during the Civil War period raised nominal wages generally and the depression following the Panic of 1873 lowered wages through 1878.




**Figures 4a and 4b. Wages of puddlers and rollers, including their helpers**

The Weeks report is not the only evidence of this change. In 1882 a puddler near Pittsburgh complained to the *Pittsburgh Post* that puddlers made $3.00 to $3.50 per day, but rollers made $10.00 to $15.00.[30] The Pennsylvania Bureau of Industrial Statistics reported that rollers were paid an average of 50% more than puddlers in 1874, but 200% more in 1887, and that rollers made 100% more than roughers in 1874 but 250% more in 1887.[31]

This interaction can be analyzed as an information game. After each negotiation was complete, contractors had strong incentives to improve the technology and organization of work. If they succeeded at this, they could earn a lot in the short run. But as production rose, output prices fell, and furthermore any innovations by the contractors seeped into the possession of management. So external circumstances pressed against contractors in succeeding negotiations. Thus technological or organizational improvements made by contractors gradually and permanently became the property of the establishment. The short-run negotiation produced as a side effect a permanent change in the technology in general use.[32]

After 1880, inside contracting was decreasingly common. One possible explanation is that the technology had stabilized and establishment managers did not gain further from trying to extract further discoveries from the inside contractors. (Clawson, 1980, p. 28). Instead of giving production workers extraordinary incentives, managers carefully controlled the production process, and expanded formal research efforts.

The work content of rolling and steel production changed with time, away from hand-managing the process. With greater mechanization and speed, Bessemer converter men and rollers had to monitor continuous or frequent mechanical processes, rather than use manual skills. Costs were high if they failed since breakdowns could affect processes before and after it in the production line.[33] Historians of technology Michael Nuwer and David Jardini tried to define "diagnostic skills" to characterize this (Nuwer; Jardini, 1997, p. 171) but the term "skills" here breaks down under analysis since the key issues were whether the men were attentive, loyal, and careful with the equipment. Their accounts include the idea of "strategic workers" who were somehow well positioned, or used their positions well as managers and monitors of machines.[34] Here an efficiency wage thesis fits the qualitative evidence better than skill bias

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[30] Montgomery, p. 32, citing the April 14, 1882 *Pittsburgh Post*.

[31] Montgomery, p. 34. *Roughers* assisted rollers. They received something from a rolling mill and might send it back through the mill. They were usually employees of the roller in the inside contracting system. See also Jardini, pp 186-191.

[32] Like inside contracts, modern-day stock options give strong incentives to work well with a team, and to produce technology which will become the employer's property. The inside contract has short-term incentives. Stock options, too, have explicit time limits and also as firms mature, they give out fewer options, and these are less valuable since the stock's greatest rise will be over, and its volatility normally declines. Both inside contracts and stock options are special labor contracts which give financial incentives to workers to improve the firm's technology and have been used at times of special technological opportunity.

[33] With computerization a hundred years later steel work took another step in this direction. For example, by one account, when processes like these are computerized the operator is no longer even physically looking at the steel material directly but monitors production processes through video screens and instrument panels. (Shaw, 2002)

[34] Jardini, p. 191.

At the time, puddling was the most highly skilled of the iron professions. Skill bias did not help them. A clearer relationship between the technological change and the earning inequality is that both puddlers and rollers had strong incentives to improve the technology under inside contracting, but for the puddlers it was not possible to improve it much. Rollers had more opportunities, risks, and random outcomes.

Each of the several skilled iron and steel occupations had a long history as a craft, and had its own union in the 1860s. Because of the turbulence and reorganization in the industry, the various craft unions combined in 1876 to form the Amalgamated Association of Iron and Steel Workers, which continued to expand its membership to include less and less skilled workers, and to include blacks in 1881. This was an early industrial union, replacing the very concept of a craft by a larger entity, more flexible in response to technological change, and potentially more powerful in bargaining.[35] Though this change from craft to industrial unions seems to be a significant indicator of technological uncertainty it is not clear how it affects the available wage data directly. Clearly rollers were not prevented from forming favorable contracts.

## 5.4 Location effects

U.S. iron and steel plants supplied local markets in the 1860s. Colonial and state governments had taken an active interest in getting a local iron industry started. Practically every state had iron furnaces, forges, rolling mills, or foundries. Small-scale enterprises did not need the most advanced technology to be viable. Charcoal-fueled furnaces, which tended to be small, produced more and more during the 1800s even as mineral coal fuel was taking over.[36] During the 1800s, growing fractions of the production came from large firms and firms using recently developed technologies.

New iron ore resources were discovered along the Great Lakes especially on Michigan's upper peninsula. Michigan iron ore grew as a fraction of national production from 4% in 1860 to 23% in 1879 (Warren, p. 43). Because transportation was a large fraction of iron and steel production costs, and water transportation was cheaper per mile than any kind of land transportation, it was cheaper to produce steel along the edge of the Great Lakes than elsewhere. Over this period, steel production grew around the Great Lakes cities of Pittsburgh, Cleveland, and Chicago, which took over from previously leading areas such as Scranton, PA, and Troy, New York.

Pittsburgh was well located for iron and steel work because it was near great coal fields and because it had access to the Great Lakes for iron ore. More tons of coal than tons of iron ore is needed to make pig iron, and Pittsburgh producers benefited from nearby sources of coal.[37] The Bessemer steel process did not require coal, but it was most efficient for the Bessemer converter to

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[35] Montgomery (1987) and Fitch (1989) describe this turbulent transition in detail.

[36] Hundreds of blast furnaces and rolling mills started up in the 1800s, in practically every U.S. state. *Rolling mills* press iron or steel into shapes to make a product, including rails for the railroads.

[37] *Coke* is the fuel produced from bituminous coal, and was the main fuel in the Pittsburgh area. Half of the nation's coke production in 1890 came from the Connellsville area near Pittsburgh (Warren, pp 43-49).

receive hot pig iron from nearby blast furnaces which did need great amounts of coal. Making steel near Pittsburgh lowered transportation costs.

Iron and steel workers near the Great Lakes were paid much more than in the east. Some wage inequality can be accounted for by the difference between wages in this area and others. This is not principally a difference in skills; presumably there is no particular skill to living there. Rather the arrival of the industry and its workers around the Great Lakes was a response to opportunities that had been discovered. It is the result of a learning process, partly accidental, in which it became clear that Pittsburgh and the other cities would be steel centers.[38]

The location effects discussion illustrates that gambles taken under technological change may not have been actively chosen by an actor. Founders of establishments in the 1850s who were choosing locations probably did not systematically take into account the possible subsequent invention of steel mass production methods. They may not have forecast the growing availability of iron ore resources in Michigan and Minnesota, the rise of coal mining and processing in southwestern Pennsylvania, and the creation of a national market that followed from all these and the growth of railroads. These changes put them in the position of making a new gamble on their own preselected location.

In the case of an iron plant, its location is a heavy institutional commitment. Physical location can also serve analysts of technological change as a metaphor for other institutional commitments, which can be subject to new strains under the turbulence brought by new technology. Institutions like firms, unions, professions and schools have rules, philosophies, or scripts which are subject to change in the new environment. The gambles that economic actors took under technological change were reframed (or more problematically "caused") by the new environment which might dramatically change the constraints, competitors, and opportunities. The change in environment created new risks and opportunities even for players who had not changed their behavior. These must have been temporarily sources of differentiation and therefore greater inequality.

One such example is that the circumstances of a worker or merchant familiar with iron, and continuing to work with iron, have changed once there is competition from steel. Small businesses in the iron and steel sector continued (Ingham), but in various ways adapted to make way for the large scale establishments. Another example is of the unions. In the iron and steel sector, craft unions were replaced by a national industrial union in the 1870s. Partly this was because workers had lost control of work rules and the length of the work day, and in other ways craft ethics seemed to be under strain. (Montgomery). It is not clear from the data at hand that we can measure any effect on wage inequality here, but there may exist data by which to detect the effects of institutions under strain, producing erratic outcomes, and therefore greater inequality.

[38] A regression predicting part of the rise in inequality overall as a result of higher wages along the Great Lakes and increasing numbers of workers there would be helpful. The data is complicated however. Not every establishment is identified with its city. More to the point, one finds positive effects on wage from being located in Pittsburgh, Cleveland, or Chicago regardless of industry, and negative effects in Buffalo. But Buffalo is also along the Great Lakes. Is there an explanation, or is the data noisy, or is this the outcome of a random process of location selection? I am continuing research on this point.

## 5.5 Strategy: Cost accounting, consultants, and the science of management

One of the difficult issues in the iron industry at the time was whether and how to manage a large plant. Andrew Carnegie was a key player and innovator. Pittsburgh had already been the dominant center of iron production in the U.S. (Ingham; Warren) but had not made steel at all yet by 1875. Yet within five years it was a fast growing center and dominated steel production for many decades afterward.[39] Part of the reason for this was its physical location, but another part, not easily distinguished, came from informational factors: the presence of so much skilled iron and steel labor and expertise, and also the great efficiency enforced in the Carnegie plants through cost accounting. Pittsburgh steelmakers also benefited from the experience that steel plant designers (particularly Holley) had developed by designing and studying other plants. Holley personally participated in the design of eleven of the first thirteen plants and was personally an information-sharing institution between each plant and its successors.

Most iron firms at the start of the period were small, had local customers, and were organized on the basis of artisan or craft principles, without detailed attention to costs.[40] Partly because of the presence of inside contractors, even large blast furnaces and rolling mills did not know their own costs well. (Nelson, p. 41) Workers made basic production decisions, including their use of materials, tools, and inventory. The history of the iron businesses had shown that this kind of management was entirely sufficient and it took some time for other managers in the industry to understand that the rules had changed. Partly the new situation came about because of the much larger plants, the resulting management challenges (for example the greater costs of breakdowns), and also the opportunities to be more efficient through economies of scale. (Nelson, pp 8-10).

Carnegie, a railroad executive, acquired an iron rolling mill in 1864, then gradually over the course of decades took more and more control of the steel industry. The success of the Carnegie firms was due largely to their systematic study and management of production costs. Cost accounting was already standard in the railroads partly because they were such big employers. The Pennsylvania Railroad had one thousand managers and fifty thousand employees in the mid-1870s. The largest manufacturing establishments in American industry in the 1870s made iron and steel.[41] Cambria Iron was the largest, with about 4000 employees in the mid-1870s (Montgomery, 1987, p. 54). They had not adopted careful cost accounting. Part of the reason for this was that inside contracting already aligned incentives and it had not been seen necessary to do anything more precise. But in addition, both iron and steel had been regional businesses, not facing enormous

[39] Houpt (2002) carefully argues that the same learning process was prevented in Spain. There the monopoly steel producer was not well located but was too strong to be dislodged, so costs of making Bessemer steel there were always high. Houpt finds there was a negative effect on Spanish industrialization in general. In the U.S. context there was diverse competition and many locations were tried.

[40] Ingham; Warren.

[41] Firm sizes are discussed in Nelson, pp. 6-10; Chandler p. 259; and Montgomery p. 28. New iron and steel plant buildings were larger than any previous industrial buildings. They had internal railroads and used conveying devices and cranes to move materials. (Nelson, p. 19). Plant designers paid more and more attention to efficient design of these large plants (Chander, pp. 260-262, and McHugh, 1980).

competition.  With larger and larger plants, the industry became national, facing more precise competition, but also with the potential for gigantic profits.

Managers in Carnegie-controlled plants submitted regular reports to the top management with the amounts and costs of materials and labor used in their departments.  Carnegie studied these and compared the performance of each plant with other plants, with its own past performance, and information on costs at competitors.  This made it practical to distinguish between more and less profitable contracts.  Carnegie's rail mills were highly profitable in the late 1870s, partly because of the innovation of bringing this approach from the railroads to the factories.[42]

During the period under study, Carnegie's plant paid much higher wages than other firms did.  "[Carnegie] was willing to pay a higher scale and grant his workers the eight-hour day" (Ingham, p. 66).  Workers at the Carnegie-owned Lucy Furnace were among the highest paid at blast furnaces, according to the Weeks report data.  Carnegie carefully avoided labor trouble throughout the period of the data.  Carnegie's high profits represented a surplus, attributable to Carnegie's systematic management of information and successful focus on profitability, which was shared with the workforce.  Carnegie extracted part of this surplus by taking control away from workers who were accustomed to autonomous craft work but had to deal with invasive and controlling management.  Carnegie's understanding of costs and benefits was (correctly) that the costs of downtime for the plant was much greater than any possible gain from beating workers in a conflict.  At least this was the case while the technology was new.  In later decades he encouraged his superintendents to handle workers and unions harshly.

Cost accounting is an approach to locating information and opportunity (Clawson, p. 186). According to the uncertainty interpretation, the workers received a temporary wage premium because of temporary opportunities.  As the industry stabilized, these premiums declined.

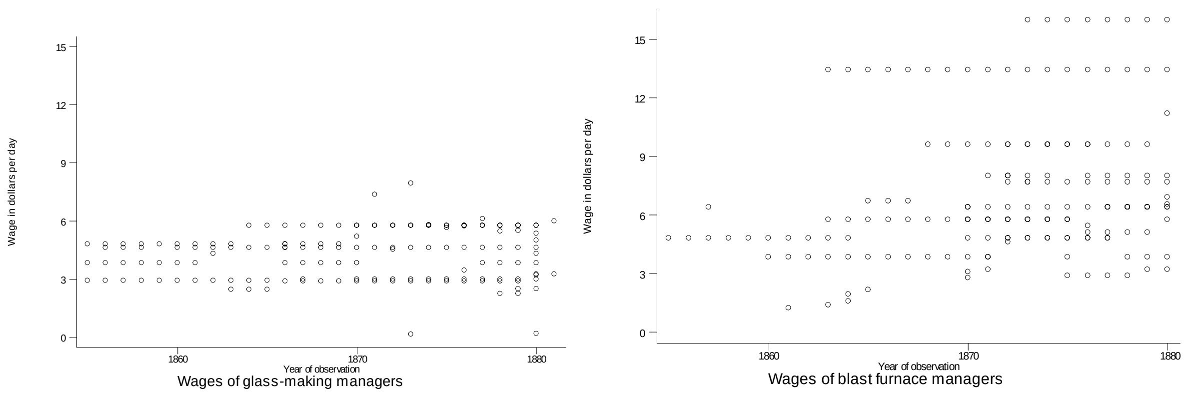
This interpretation is supported also by the beginning of a journal literature about management in the 1870s, in technical engineering journals (Litterer, 1961).  Owners and managers discussed the problem of managing large, complex firms in writing.   They did not all agree on its importance: "Articles on bookkeeping [began] by explaining why employers should keep records and how they could make use of them (since most employers did not understand bookkeeping and tended to dismiss it)."  (Clawson, p. 183)

Management consulting also arose out of steel work in the 1880s.  Frederick Taylor was an apprentice steel patternmaker and machinist at Midvale Steel until 1878.  Taylor became a manager and instituted a bureaucratic system of control there in the late 1870s (Chandler, p. 560). He then called himself the first management consultant, advocating "scientific management." His approach, later called Taylorism, was to bring in a team analyze the exact tasks of workers in a production process and to reorganize the work to specialize each worker's role to maximize speed and reduce the decisions the workers would have to make.  Taylor wrote that the work of cutting metals at high speed, using the optimally chosen equipment, was a problem of such

[42] Chandler (1977), pp. 269 and 258.

complexity that individual workers could not be expected to solve it (Taylor, 1911). Workers usually found this to be alienating and many said it destroyed any satisfaction in craftwork. Taylorism was an extreme extension of cost accounting, and it arose after the period under study was over. Outside consultants compared costs and compensation between firms (Clawson, p. 188). Thus management consultants were information carriers, whose role arose because the technology and necessary organization were new and uncertain. The consultants and managers were trying to standardize work processes and reduce uncertainty and idiosyncrasy.

The Weeks data include wages of managers only from the glass-making industry and the iron blast furnace industry. Figures 5a and 5b compare them. There appears to be a rise in inequality in the iron sector. Presumably the high wages were paid in large firms though this is not clear from the Weeks data. The observations at the same level each year were stable salaries in particular firms. Taking this into account, there are not many independent observations.




**Figures 5a and 5b. Wages of managers**

In a wage regression with fixed effects for each year and each job, one can add also dummy variables for each establishment. About .70 of the establishment effect in the later period is predicted by the establishment effect in the earlier period, both in the iron sector and outside it. Among new firms, variation in the establishment effects of the iron sector is not as great as the variation outside the iron sector. This data is not shown but is available by request. So establishment effects measured this way do not directly account for the differences in earnings dispersion of the different industries.

In the case of the one Carnegie plant that is identified in the data, its manager was paid near the top of the scale, and the establishment effect is near the highest of them. This evidence conforms to the standard accounts about Carnegie's approach, which was to pay high wages. The Weeks report has estimates of the labor cost portion of all production costs for eighteen blast furnaces. These are shown in Table 11. Here too we see the evidence supporting the standard account of the Carnegie plants – Carnegie's Lucy furnace appears to have lower labor costs per unit of output than did other plants. The plant was efficiently designed and capital-intensive, which explains how it was possible to have low labor costs while paying high wages to managers and workers. This would turn out to be a winning structure.

## 5.6 Transition from craft unions to industrial unions

Until 1876, there were separate unions for several of the skilled iron work crafts. Puddlers, rollers, molders, and nailers had separate unions. In 1876 they joined formed a single group called the Amalgamated Association of Iron and Steel Workers. In the next decade the Amalgamated union expanded much further to include more jobs, unskilled workers, and allowed blacks to join. This transition from small, craft-based unions to a large, industrial-scale union, arose as a response by union members to three related phenomena:

- Bigger, higher-throughput plants were built. Some managers of larger plants (like Carnegie's) insisted on more control over tools and working hours. These demands conflicted with the inherited craft rules. Furthermore, the high-volume producers were large employers, potentially having great bargaining power.

- The national market for iron and steel grew because of the improving and expanding transportation networks, especially the railroads. Local, regional, or otherwise narrowly-defined institutions were therefore declining in importance. For example, local steel prices were affected very much by events in Pittsburgh, not by local events.

- Plants applying new technologies of Bessemer and open-hearth steel might reshape ironwork jobs, by, for example, reducing the importance of puddlers, expanding the number of laborers who were not in the union (Montgomery, p. 24), and potentially mechanizing away some other existing kinds of work (although this had not much happened by 1876). Individual inside contractors, including union members, were actively experimenting with alternative labor arrangements (Montgomery, p. 9 and pp 20-21).

Facing these forces, union members could see that small, narrowly based occupational or regional unions would lose its relevance and its bargaining power. Their response was to unite into the Amalgamated union and then to expand its membership further (to include more crafts, to include blacks, and to include the unskilled) from 1876-1891.

All three of these forces were partly attributable to effects of the transition to Bessemer steel. Thus the technological changes resulted in reshaping of the unions, as well as other institutions. This change in the unions was not guaranteed to work; it was a gamble which was a response to a changing environment. Here too, the iron industry was a leading case. Other industries also developed more rationalized managements, national markets, and changing technologies.

## 5.7 Summary of aspects of technological uncertainty

After 1880, the U.S. industry was producing millions of tons of steel annually, and the industry was consolidating. Craft unions had declined and industrial-scale unions appeared in their place. The relevant professions were well defined, and technological changes in the production process came primarily from the large firms or other formally certified research and development sources. Barriers to entry were raised and consolidation was underway. Outsiders were no longer sources of technological surprises. Large plants became the dominant design for steel production.

**Table 3. Environment of strained or reconstructed institutions**

| Late 1860s | Around 1880 |
|---|---|
| No mass steel production in the U.S., though the Bessemer converter invention was known | Over one million tons of Bessemer steel produced in 1880, and still growing |
| Industrial definitions of steel ambiguous | Industrial definition clear |
| Major inventions and discoveries made by isolated nonspecialists (Henry Bessemer, Sidney Thomas) | Chemists and mechanical engineers do R&D in the big firms; all improvements are made by specialists with established sources of funding |
| Bessemer patents dispute results in licensing Association (1867) with low barriers to entry | Association raises barriers to entry (1877). Association sets prices (1881). Carnegie controls basic (alkaline) patents (1879). |
| Holley's Association newsletter distributed freely, starting 1868 | Association newsletter distribution restricted to members (1877) |
| New startups make iron or steel (late 1860s); Railroad executive Carnegie branched out, acquiring iron plant (1864) | Industry consolidating and integrating vertically into mining, railroads, and shipping. Merger forms Carnegie Steel (1881) |
| Scattered iron and coal mining. Mineral coal moved to the iron ore. | Huge, established, ore extraction industry around Great Lakes and growing shipping industry to move the iron ore to the coal. |
| Increasingly diverse methods of steel-making (Bessemer, puddled, cementation, crucible, acid open-hearth (1867), basic open-hearth (1878)) | All were understood; Bessemer and open-hearth were growing industries; puddled and cementation process may have disappeared |
| No full time chemists in the iron industry | Large firms have chemists doing R&D |
| No design standards for iron/steel structures | 1881 handbook defines widely accepted standards |
| Separate craft unions for puddlers, rollers, nailers, molders, and other crafts; no union for laborers | Lasting national cross-job and cross-industry Amalgamated union formed (1876); includes laborers in the early 1880s |
| Productivity growth sinking | Productivity growth rising |

Thus we see that much redefinition of the iron and steel sector occurred, in resources, methods, products, firms, prices, and markets. It was a turbulent, hard-to-predict, period.

## 6.0 The long run: inequality decline and productivity boom?

If a temporary uncertainty phenomenon caused a rise in earnings inequality, earnings inequality should have fallen after some period when the technology becomes understood and standardized. The Weeks report data does not extend far enough to test this but there is evidence that after 1890 earnings inequality was declining in the industry. (Stone, pp. 126-7, citing

Doeringer.) One institutional cause for this was that after 1880, inside contractors were slowly replaced by employees. Most worked for piece rates, and there was an associated rise in managerial attention to measuring the output of each worker separately from the others (Stone, 1973, 127-133). Such distinctions among workers become possible once the technology of production is standardized and worker innovations are not an important source of innovations or differences among workers. Other rollers were put on salary (Montgomery, p. 32). By 1902, an industry manager said the technology was straightforward enough that it would be easy to teach a laborer to be a steel melter. (Stone, p133) Brody and Jardini have further evidence supporting the proposition that wage dispersion declined with time.

Regarding productivity, experimentation with new technology may improve the capital equipment of establishments without contributing directly to output. For example, firms pay research and development costs of developing new technologies before the new better technology is available, and if they are not carefully distinguished in the accounting, exaggerate the costs associated with the earlier technology. More importantly, an organization may reorganize to use a new technology, then discover that because it did not have experience, it did not make a good choice, and must reorganize again. These costs can be large. External to a plant, different methods and markets compete with one another before standardization of products, markets, methods, and customers is worked out. This design competition is necessary but delays the benefits of some economies of scale, scope, and interoperability of suppliers, competitors, and customers.

For these kinds of reasons, in the Greenwood-Yorukoglu (1997) model a new technology brings about a temporary productivity slowdown along with a rise in income inequality. Experimentation also exposes information useful to people searching for jobs, such as where one had to live to work in the developing steel plants, and which jobs were safe. Broadly, society collectively explored the effects of the new form of steelmaking to steel on new supply, demand, and search in labor markets, product markets, and so forth. Gambles and mistakes meant much of the effort did not directly raise output so measured productivity seemed low.

There is scattered evidence of a temporary productivity slowdown in the steel episode. It took years for a Bessemer plant to come up to speed even after the technology was firmly established and understood (Jardini p. 177-179). Part of this delay came from learning by doing and adjustment costs. Allen (1979, pp. 916-7) measured total factor productivity growth of the industry by output growth not directly accountable for by changes in employee count, capital services as measured by mechanical horsepower installed, metallic inputs, or fuel. By this measure output productivity growth was low in rolling mills from 1860 to 1879, rising only 2.6% in the 1860s and less than 2% in the 1870s. Then it jumped 15% in the 1880s. Labor productivity improved faster, 29% from 1860-1879, then 50% in the 1880s, partly because of sharp rises in measured capital.

These measures illustrate a possible productivity slowdown during this period of technological turbulence perhaps analogous to the measured U.S. productivity slowdown from 1973-1996. During these periods, a variety of technologies and organizational designs competed with one another. With time and standardization, the improvements in steel had a large effect on the economy. Fishlow (1966, esp. pp 630-645) evaluated the effect of various innovations on the productivity of railroads in the late 1800s and found that improvements in steel were more influential than any other identifiable innovation. Steel railroads survived ten times as much stress as iron ones (p. 639) and did not have to be replaced as often. They could also handle heavier and more efficient trains which became standard over the period 1880-1910. Railroad productivity rose sharply during this period and this affected indirectly the price and productivity of all other goods. Here too there is an analogy to recent semiconductors, which lowered prices and raised productivity through a variety of external effects.. For both cheap steel and semiconductors, the productivity boom arrived long after the inventions.

## 7.0 Conclusion

With the arrival of the new steel technologies to the U.S, the quantity of steel produced grew dramatically and its price fell. Earnings inequality rose within the iron and steel industries but not within other industries. Residuals from wage regression in the iron sector were greater in magnitude in the 1870-1881 period than in the 1850-1869 period. Table 2 showed that this was not a trend in the iron sector but rather a one-time change, and Table 1 showed that no comparable change occurred in the other measured sectors. Technological change was a likely cause for this since the quantity of steel rails produced grew dramatically while they fell in price, and improved in quality.

Players in the iron and steel production game – suppliers, investors, employees, managers, and customers – faced various kinds of turbulence during this period. The product called steel was growing in importance at the beginning of the period but was not well defined. The greatest innovations (Bessemer steel and both acid and basic open hearth steel) came from outside the industry. Scientific investigation did not yet play a regular, consistent role within the industry. Craft unions and small firms predominated. Large, centralized firms were not yet the iconic institutions they would become, and cost accounting was not yet common. Iron, steel, and coal production was scattered, not yet centered on the Great Lakes region. Inside contractors were paid a lot if they improved the production technology. This had the effect of encouraging them to experiment, and invent new skills and ways of organizing. All these aspects of the industry changed fundamentally in the 1866-1881 period, in ways that surprised some people.

The uncertainty argument is that workers, employers, investors, and customers responded to new opportunities with diverse choices, gambles, and adaptations. At the beginning they did not know which kinds of work were safe and efficient, and which institutions would last. They chose among technologies such as Bessemer steel, open hearth steel, crucible steel, puddled steel, and wrought iron for various applications. Their predictions and choices varied from one another. The work of rollers changed over time and among plants, with varying ways of organizing the workers and various kinds of equipment. Ore and coal sources were discovered and applied. Gambles were intrinsic to the changing environment, which partly explains the increased wage inequality.

The uncertainty idea links this evidence on wages to the breakdown of existing institutions and the rise of new ones. Here are examples. Larger plants were built than any that had ever been built in the U.S. Previously acceptable locations were discovered to be uncompetitive, and new plants were built in places with water access to the Great Lakes. New professional associations appeared. Craft unions merged into an industrial union. The inherited craft and management traditions were partly outmoded -- instead, cost accounting and industrial research were perceived as essential in a large plant.

The players understood that key technologies were changing dramatically and that steel prices would continue to fall. This informational situation fits the Greenwood-Yorukoglu type of theory in which earnings inequality rises at the same time that there is heavy investment in the industry and lowered productivity.

Consider again the skill bias idea. Perhaps pre-existing skills received higher payoffs because of the changing technologies such as the new steel methods, new sources of ore, and improved metallurgy. But the investigations in this paper did not find this. It does not appear for example that the high pay some rollers received was a systematic return to being a roller. Instead, it was a chaotic result of insider contracting and its strong incentives and the opportunities available for new technology and reorganization. The increase in professional research and development brought in *new* skills, not higher-paid existing skills. One might say there was a set of analytic or diagnostic skills or abilities that received a greater payoff. But ex ante, the players did not know this. They confronted an environment of technological change in which they did not share a common expectation of what skills would pay off. So skill bias does not help us understand the behavior of the players at the time. Perhaps the most cogent point about skill bias is that it does not suggest an association to institutional breakdown.

The term “skill bias” also creates a rhetorical conflict. Mass production methods reduced the value of previous craft skills, so historians have described them as “*de-skilling*” (Nuwer, 1988 p. 833). But the skill bias story is that technology change *enhances* the productivity and payoff of skills. One resolution is to reject skill bias, and say instead that technological uncertainty produces a turbulent adaptation process which temporarily induces more inequality, because the transition from one production and industrial structure to another involves creative destruction, experimentation and gambling. Eventually new institutions, skills, and pay levels stabilize.

Thus the concept of *technological uncertainty* has some value for labor economics and the history of technology. It describes an economic environment in which there is a flow of new information which could permanently change production. Players respond opportunistically. Their responses are gambles whether they wished to gamble or not, and we have evidence that this phenomenon brings about episodes of increased earnings inequality.

## Table 4. U.S. iron production

Compiled by AISA, and drawn from *Historical Statistics* and the series cited in Swank (1883) pp. 127-9 (which is pp. 863-5 of the larger Census volume it is contained in).

| | Bessemer steel ingots, in net tons | Bessemer steel rails, in net tons | Total open-hearth steel production, in net tons | Crucible steel production, net tons |
|---|---|---|---|---|
| 1867 | 3,000 | 2,550 | | 19,000 |
| 1868 | 9,000 | 7,225 | | 22,000 |
| 1869 | 12,000 | 9,650 | 1,000 | 22,000 |
| 1870 | 42,000 | 34,000 | 2,000 | 34,000 |
| 1871 | 45,000 | 38,250 | 2,000 | 35,000 |
| 1872 | 120,018 | 94,070 | 3,000 | 37,000 |
| 1873 | 170,652 | 129,015 | 4,000 | 49,000 |
| 1874 | 191,933 | 144,944 | 7,000 | 43,000 |
| 1875 | 375,517 | 290,868 | 9,050 | 52,000 |
| 1876 | 525,996 | 412,461 | 21,490 | 50,000 |
| 1877 | 560,587 | 432,169 | 25,031 | 52,000 |
| 1878 | 732,226 | 550,398 | 36,126 | 51,000 |
| 1879 | 928,972 | 683,964 | 56,290 | 62,000 |
| 1880 | 1,203,173 | 954,460 | 112,953 | 81,000 |
| 1881 | 1,539,000 | | 147,000 | 93,000 |

# Table 5. Industries represented in the Weeks report sample

| Industry group | Industry name | Number of establishments | Number of wage observations |
|---|---|---|---|
| Iron and steel | Iron blast furnaces | 41 | 5496 |
| | Rolling-mills and nails | 25 | 6762 |
| Other metal work | Pins | 2 | 148 |
| | Car-wheel founderies | 8 | 421 |
| | Stove founderies | 13 | 2650 |
| | General founderies | 6 | 677 |
| | Hardware, cutlery, and edge tools | 17 | 2357 |
| | Machinery | 39 | 7623 |
| | Tin and sheet iron works | 3 | 304 |
| | Agricultural implements (and Bells) | 12 | 1422 |
| | Bridgebuilding | 2 | 140 |
| Agricultural and forestry products processing | Canning | 3 | 121 |
| | Cigars/tobacco | 22 | 2048 |
| | Flour and grist mills | 46 | 3500 |
| | Pork packing | 3 | 89 |
| | Ice | 2 | 326 |
| | Paper manufacture | 36 | 6800 |
| | Sugar-refining | 1 | 216 |
| | Breweries and distilleries | 9 | 406 |
| Textiles , clothing, and leather | Carpets | 3 | 742 |
| | Cotton manufacture | 37 | 13596 |
| | Hemp and jute manufacture | 1 | 160 |
| | Silk | 4 | 1159 |
| | Wool | 36 | 10385 |
| | Tanneries | 22 | 2620 |
| | Hats | 3 | 661 |
| | Clothing | 5 | 605 |
| | Boots and shoes | 13 | 2278 |
| | Belting | 4 | 151 |
| Wood work | Cooperage | 4 | 93 |
| | Furniture | 41 | 5807 |
| | Saw-mills and planing-mills | 52 | 6835 |
| | Ship-carpentry | 4 | 437 |
| | Pianos and organs | 4 | 1142 |
| | Carriage and wagon works | 26 | 4411 |
| | Car-works | 6 | 476 |
| Mining and other materials work | Brickmaking | 10 | 1638 |
| | Iron mining | 6 | 262 |
| | Coal mining | 8 | 624 |
| | Copper mining | 4 | 228 |
| | Silver mining | 2 | 96 |
| | Stone quarrying | 11 | 486 |
| | Powder (explosive) | 2 | 23 |
| | Paints and white lead | 5 | 321 |
| | Marble | 3 | 299 |
| | Glass | 17 | 5191 |
| | Gas/gas coke | 6 | 303 |
| | Pottery and earthenware | 23 | 1793 |
| Total: 6 groups | 48 industries | 652 establishments | 104413 observations |

## Table 6. Reports by year in the Weeks data

The text argues that there is a change in the inequality measures in iron and steel around 1870. There are many more reports from establishments starting then, especially in iron and steel. Comparing the 1870-1881 period to the 1850-1869 period for iron and steel, 84% more establishments report and 145% more wage observations are available in the later period. In other industries taken together, 31% more establishments and wage observations are available in the later period. The number of observations would not bias the inequality measures but the new firms appear to be substantively different from the earlier ones.

| | Iron and steel industries (Blast furnaces and rolling mills) | | All other industries | |
|---|---|---|---|---|
| Year | Establishments reporting | Wage observations | Establishments reporting | Wage observations |
| 1850 | 5 | 72 | 66 | 761 |
| 1851 | 3 | 21 | 58 | 653 |
| 1852 | 2 | 20 | 63 | 676 |
| 1853 | 2 | 20 | 73 | 745 |
| 1854 | 4 | 27 | 79 | 845 |
| 1855 | 6 | 83 | 100 | 1000 |
| 1856 | 6 | 51 | 96 | 980 |
| 1857 | 9 | 67 | 103 | 1035 |
| 1858 | 8 | 102 | 111 | 1145 |
| 1859 | 7 | 54 | 118 | 1218 |
| 1860 | 10 | 148 | 157 | 1740 |
| 1861 | 8 | 99 | 148 | 1626 |
| 1862 | 8 | 90 | 154 | 1632 |
| 1863 | 15 | 173 | 163 | 1716 |
| 1864 | 17 | 199 | 185 | 2005 |
| 1865 | 21 | 230 | 218 | 2345 |
| 1866 | 14 | 135 | 234 | 2687 |
| 1867 | 14 | 144 | 245 | 2809 |
| 1868 | 21 | 257 | 260 | 2968 |
| 1869 | 19 | 180 | 268 | 3067 |
| Total 1850-1869 | 28 | 2172 | 307 | 31662 |
| 1870 | 35 | 442 | 350 | 3996 |
| 1871 | 38 | 529 | 377 | 4200 |
| 1872 | 45 | 565 | 414 | 4615 |
| 1873 | 48 | 690 | 437 | 4803 |
| 1874 | 48 | 654 | 462 | 5096 |
| 1875 | 50 | 735 | 502 | 5607 |
| 1876 | 47 | 678 | 512 | 5778 |
| 1877 | 50 | 669 | 522 | 5861 |
| 1878 | 51 | 705 | 525 | 5956 |
| 1879 | 54 | 756 | 527 | 5991 |
| 1880 | 57 | 801 | 552 | 6502 |
| 1881 | 3 | 27 | 23 | 209 |
| Total 1870-1881 | 66 | 7251 | 576 | 58614 |
| Grand total | 66 | 9423 | 577 | 90276 |

## Table 7. Trend in wages, holding job title fixed

This regression had a year trend, 173 job category indicators, and a constant.
N=99906. $R^2$ was .48. Source: Weeks report data

| Predictor of log(daywage) | Coefficient | Robust standard error | p-value |
|---|---|---|---|
| Year of observation (1850 to 1882) | .012 | .0002 | 0.00 |
| 173 job categories | Not shown | | |
| Constant | Not shown | | |

Conclusion: Holding job titles fixed, wages trended up about 1.2% per year.

## Table 8. Wage predictors

Dependent variable is log of daily wage of weighted sample. Coefficient on constant is not shown. There are 99699 observations, including a number which are not in one of the standardized jobs. $R^2$ of regression: .60. Figures especially relevant to iron or steel work are highlighted.

| Predictor of log(daywage) | Coefficient | Robust standard error | p-value |
|---|---|---|---|
| Year indicators (1850 to 1881) | Not shown | | |
| Job indicators (173 jobs) | Not shown | | |
| Months worked (a business cycle indicator) | .012 | .001 | 0.00 |
| **Payment practices** | | | |
| Worker receives pay not counted here | -.028 | .002 | 0.00 |
| Piece rate (pay by measured output, not time) | .029 | .007 | 0.00 |
| Paid partly in merchandise ("in truck") | -.060 | .005 | 0.00 |
| **Region (as distinct from South)** | | | |
| In Northeast (in Maryland or northeast of Pennsylvania) | .022 | .005 | 0.00 |
| In Pennsylvania | .034 | .005 | 0.00 |
| In Midwest or West | .059 | .005 | 0.00 |
| Urban (one of 1880's largest nine cities) | .126 | .004 | 0.00 |
| **Job content** | | | |
| Wood work (job title contains "wood," "carpentry," etc.) | .127 | .025 | 0.00 |
| Metal work (job title contains "bar", "metal", "iron", "shear", "smith", "roller", etc.) | **.098** | .016 | 0.00 |
| Hot work | **.123** | .027 | 0.00 |
| Paper work (bookkeeper, clerk, draughtsman) | .282 | .038 | 0.00 |
| **Worker demographics** | | | |
| Is a woman | -.356 | .016 | 0.00 |
| Is a girl | -.583 | .013 | 0.00 |
| Is a boy | -.965 | .011 | 0.00 |

## Table 9.   Literacy of workers, from U.S. Censuses 1850-1880

Three cross-cutting definitions of the groups are used in the table:

- the occupation determined at the time the Census was taken.
- the individual's industry category as recoded by the Census according to their 1950 industry definitions;
- the occupation category per the 1950 Census occupation definitions;

Respondent was described in the Census as literate (able to read and write), not literate (could not read or write) or sometimes in an intermediate category (could read or write, or did not answer). Literacy was higher than average in the iron sector, and increased over time. Laboreres and the general working-age population are shown in the last rows for comparison with iron and steel workers. Data source: online IPUMS U.S. Census data at http://www.ipums.umn.edu. Figures shown are unweighted, and would be slightly changed if Census weights on individual observations were incorporated.

| | | 1850 | 1860 | 1870 | 1880 |
|---|---|---|---|---|---|
| Iron/steel works operatives (occupation 191) | yes | 85.8% | 85.2% | 85.7% | 91.1% |
| | other | 8.8% | 10.9% | 4.0% | 6.5% |
| | no | 5.4% | 3.9% | 10.3% | 2.4% |
| | N | 204 | 359 | 700 | 1070 |
| blast furnace, steel works, and rolling mill operators (industry 336) | yes | 92.8% | 76.0% | 74.8% | 93.3% |
| | other | 4.4% | 10.4% | 5.1% | 2.4% |
| | no | 2.9% | 13.6% | 20.1% | 4.4% |
| | N | 69 | 336 | 472 | 757 |
| furnacemen, smelters, and pourers (occ1950 641) | yes | 86.5% | 84.0% | 71.1% | 88.2% |
| | other | 9.4% | 12.0% | 3.9% | 4.1% |
| | no | 4.2% | 4.0% | 25.0% | 7.7% |
| | N | 96 | 75 | 128 | 416 |
| Molders (occ1950 561) | yes | 83.3% | 88.2% | 97.6% | 97.0% |
| | other | 10.0% | 10.7% | 1.4% | 0.5% |
| | no | 6.7% | 1.1% | 1.0% | 2.5% |
| | N | 90 | 187 | 289 | 403 |
| Machinists (occ 197) | yes | 87.7% | 93.3% | 98.1% | 98.6% |
| | other | 11.4% | 6.8% | 0.4% | 0.2% |
| | no | 0.9% | 0.0% | 1.4% | 1.2% |
| | N | 228 | 474 | 700 | 934 |
| Steam boiler makers (occ 248) | yes | 85.0% | 88.0% | 92.9% | 97.4% |
| | other | 15.0% | 5.0% | 3.5% | 0.9% |
| | no | 0.0% | 7.5% | 3.5% | 1.7% |
| | N | 20 | 40 | 85 | 117 |
| Laborers (occ 39) | yes | 69.4% | 73.4% | 68.4% | 66.8% |
| | other | 14.3% | 10.7% | 5.3% | 4.0% |
| | no | 16.3% | 16.0% | 26.4% | 29.2% |
| | N | 6015 | 7953 | 9766 | 17270 |
| general population aged 15-70 | yes | 72.4% | 74.6% | 79.7% | 83.0% |
| | other | 18.9% | 18.4% | 3.9% | 3.1% |
| | no | 8.7% | 7.1% | 16.3% | 13.9% |
| | N | 114,328 | 161,504 | 227,717 | 302,450 |

## Table 10. Numbers of iron workers and metal workers

Three overlapping definitions of the groups are used in the table: the individual's industry category according to the 1950 Census industry definitions, the occupation category per the 1950 Census occupation definitions, and the 1880 occupation definition.

| | Percentage of U.S. population | | |
|---|---|---|---|
| **Group** | **1860** | **1870** | **1880** |
| Blast furnace, steel works, and rolling mill workers (industry 336) | .11% | .14% | .15% |
| Furnace men, smelters, and pourers (1950 occupation 641) | .02% | .03% | .08% |
| Iron/steel works operatives (occupation 191) | .15% | .16% | .22% |
| Machinists (occupation 197) | .17% | .16% | .19% |
| Molders (1950 occupation 561) | .07% | .08% | .08% |
| Steam boiler makers (occ 248 or 1950 occ 503) | .01% | .02% | .02% |

Occupations affected by innovations in iron and steel grew faster than the population.
Source: IPUMS (Ruggles, Sobek, et al 1997)

# Table 11. Labor costs in iron blast furnaces

Some iron blast furnaces reported the fraction of their production costs that went to wages of furnace labor. The respondents may have interpreted the question somewhat differently from one another, since the reports vary so much. Reported charcoal furnace costs seem to be related to the difficulty of obtaining charcoal from wood, which is not strictly furnace labor. The non-charcoal furnaces used mineral coal fuels -- anthracite or bituminous coal. The table leaves out years in which only one establishment reported. Six additional establishments, not included, reported labor costs as a fraction of the *price* of the output. Source: Weeks report (1886).

The point: The Lucy Furnace Company, co-owned by Andrew Carnegie, had among the lowest labor costs per unit of output although it paid high wages. This evidence is consistent with other historical evidence that the Carnegie firms used capital-intensive methods.

| | 1860 | 1865 | 1866 | 1868 | 1870 | 1871 | 1872 | 1873 | 1874 | 1875 | 1876 | 1877 | 1878 | 1879 | 1880 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cherrie & Co., Menominee, Michigan (charcoal furnace) | | | | | | | | 7.8% | 7.8% | 9.9% | 9.9% | 9.9% | 7.5% | 7.5% | 6.5% |
| **Lucy Furnace Co., Pittsburgh, Pennsylvania** | | | | | | | | | | **7.0%** | | | | | **8.0%** |
| Benwood Iron Works, Martin's Ferry, Ohio | | | | | 10.0% | | | | | 9.0% | | | | | 8.0% |
| An establishment in Pennsylvania | | | | | | | | | | | | | 9.0% | 9.0% | 9.0% |
| Struthers Iron Co., Struthers, Ohio | | | | | | | | | | | | | | | 9.0% |
| Thomas Iron Co., Hokendauqua, Pennsylvania | 10.9% | | | 13.2% | | | | | | 10.5% | 10.1% | 11.1% | | 11.4% | 9.7% |
| Jefferson Iron Works, Steubenville, Ohio | | | 23.2% | | 21.2% | | | | | 11.3% | | | | | 11.4% |
| An establishment in Alabama (charcoal furnace) | | | | | | | | | | 11.2% | | | | | 12.9% |
| An establishment in Pennsylvania | | | | | | 16.0% | 16.0% | 16.0% | 16.0% | 16.0% | 13.0% | 13.0% | 13.0% | 13.0% | 13.0% |
| Himrod Furnace Co., Youngstown, Ohio | | | | | | | | | 11.3% | 13.1% | 10.8% | 11.1% | 13.1% | 12.9% | 13.6% |
| North Western Iron Co., Mayville, Wisconsin (charcoal furnace) | | | | | | | | | | | | | | | 14.0% |
| Pratt & Co., Buffalo, NY | | | | | 12.7% | 12.7% | 12.7% | 12.7% | 12.7% | 14.0% | 14.0% | 14.6% | 14.6% | 14.6% | |
| An establishment in the state of New York | 14.0% | 14.0% | 10.0% | 13.0% | 12.0% | 11.5% | 11.0% | 10.0% | 9.0% | 10.0% | 10.0% | 12.0% | 11.0% | 13.0% | |
| William Ellicott & Son, Baltimore, Maryland (charcoal furnace) | 30.0% | | | | | | | | | | | | | | 18.5% |
| The Cherokee Iron Co., Cedartown, Georgia (charcoal furnace) | | | | | | | | | | | | | | | 56+% |
| D. Hillman, Centre Furnace, Kentucky (charcoal furnace) | | 75.0% | | | 80.0% | | | | | 90.0% | | | | | 65.0% |
| Salisbury Iron Manufacturing Co., Sailsbury Furnace, Virginia (charcoal furnace) | | | | | | | | | 90.0% | | | | | | |
| Eastery Kentucky Railway, Greenup, Kentucky (charcoal furnace) | | | | | 95.0% | | | | | 95.0% | | | | | 95.0% |

**Figure 6a**. These are among the most common occupations in the data set. The figures for N are the numbers of observations since 1855 of the named occupation in the sample from the Weeks report data set. Some observations:

- The highest paid occupations were in metal work – pattern-maker, molder, and blacksmith.
- Wages in the data rose by 1.5% per year.
- Nominal wages rose sharply during the Civil War inflation of 1861-65.
- Nominal wages fell in most occupations during the depression of 1873-1879.
- Apprentices were paid much less than persons in other listed occupation and their wages were relatively unresponsive to business conditions. Perhaps a major part of an apprentice's earnings were in the form of human capital or social capital, in the form of the right to be promoted into a craft or profession.

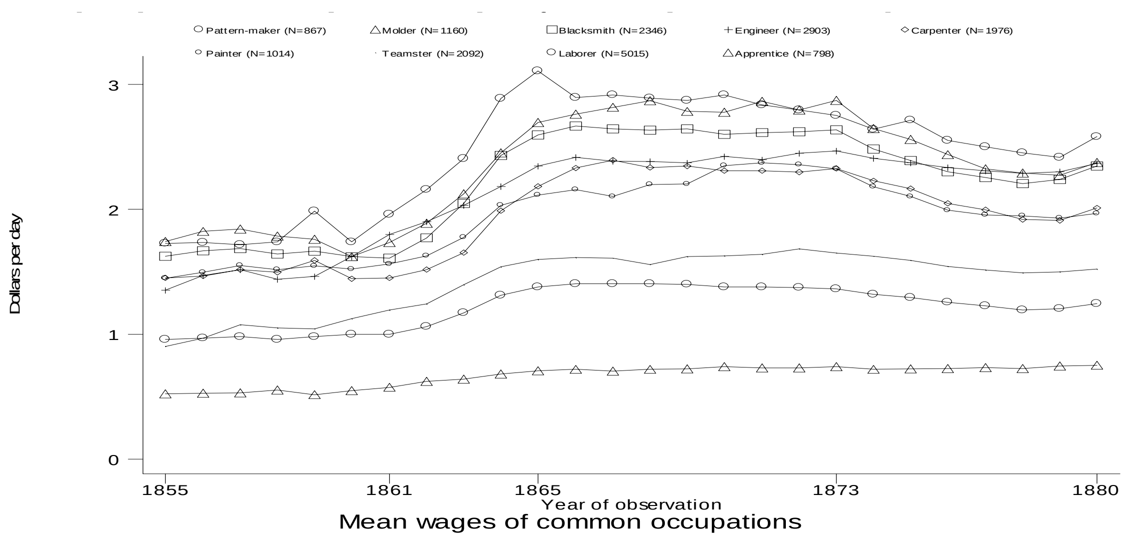



**Figure 6b**. Average wages behaved similarly over time in the different industrial sectors.

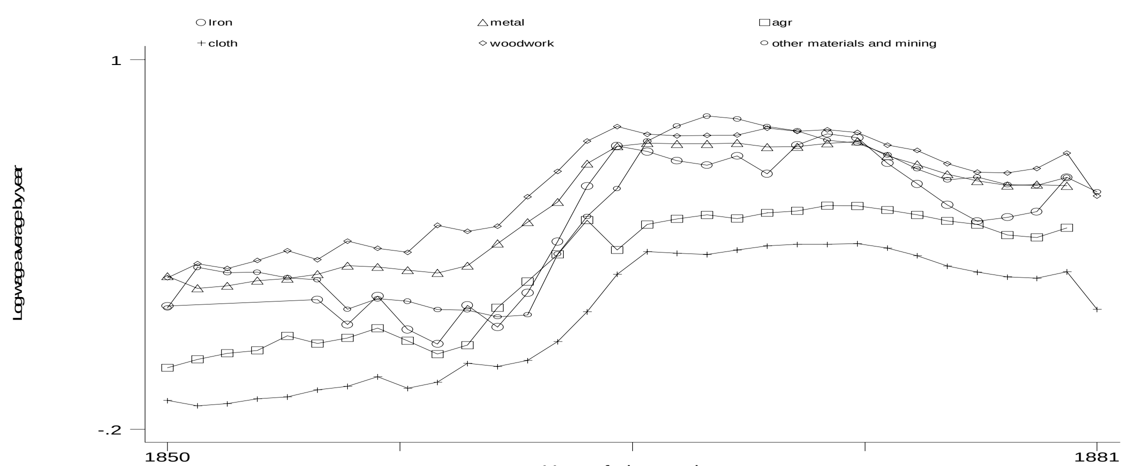
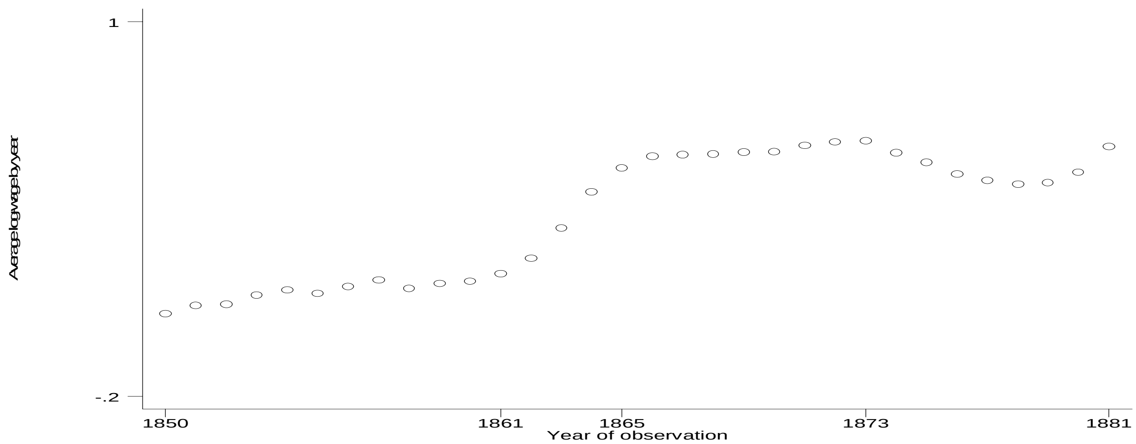


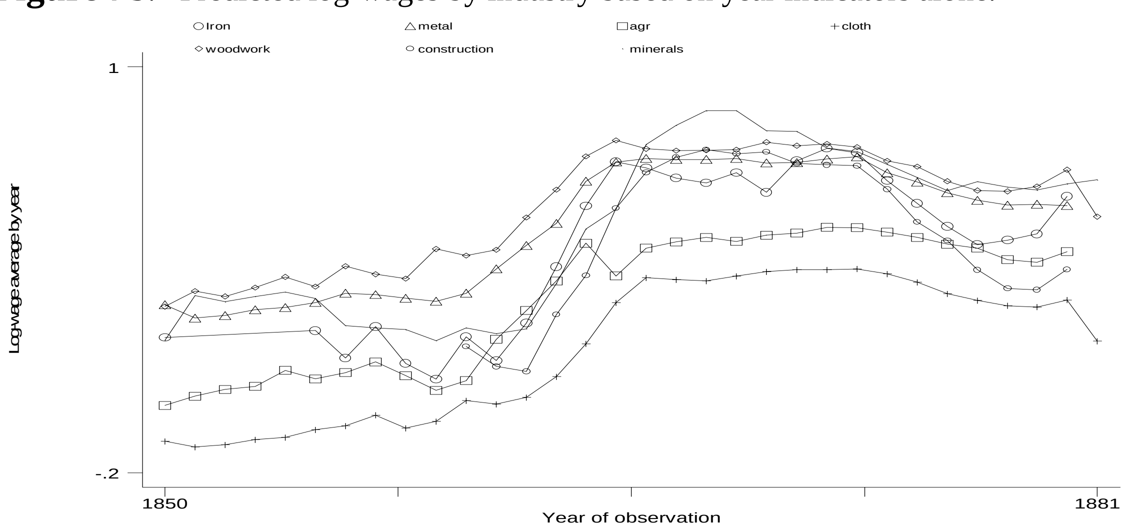
**Figure 7a**. Predicted log-wages based on year indicators alone.

These predicted values show the effects of (a) rising wages with time, (b) the enormous inflation during the Civil War (1861-1865), and (c) the fall during the depression after the Panic of 1873. There was a boom starting in 1878. The text takes out these time effects by subtracting this predicted log-wage level from all log-wages, in order to isolate technological effects by industry. Adjusted $R^2$ of this regression is 0.55.




Effects of inflation and depression on wages did not vary much by industry. This supports the technique used later of having year indicators draw out business cycle effects. Iron work seemed to have responded more strongly to depressions and booms than others did, perhaps because iron went into durable goods. Food and forestry industries and clothing industries paid less than average throughout the period. Mining and minerals, woodwork, and metal work paid more than average. Points representing fewer than 30 observations are not shown.

**Figure 7b**. Predicted log-wages by industry based on year indicators alone.



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