SHORTER HOURS AND PRODUCTIVITY:

EVIDENCE FROM BITUMINOUS COAL

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July 2022

ABSTRACT: At the turn of the twentieth century, advocates for shorter working hours often claimed that workers were so fatigued by the end of the workday, that shortening daily hours from ten to eight would have little effect on output. This study examines the record for coal mining, analyzing both state-level and mine-level panel data during the transition to the eight-hour day. The hypothesis of zero effect is easily rejected. In fact, output declined almost proportionately with hours, but advancing technology made up for the lost output fairly quickly. There is some evidence that employment increased when the eight-hour day was adopted, as unionists hoped, but the effect is not precisely measured.

KEYWORDS: productivity of working hours; coal industry; United Mine Workers; eight-hour day movement.

ACKNOWLEGEMENTS: Thanks are due Turner Cotterman, Peter Orazem, Joshua Rosenbloom and seminar participants at Drake University for helpful comments on a previous draft.

> "Among other arguments for shorter hours, it is alleged, on the one hand, that they tend to the absorption of the mass of unemployed workers by diminishing the output per man, and, on the other hand, that a man can do as much physical labor in 8 hours as in 10." (U.S. Industrial Commission, 1901, volume 12, p. XXIX).

1. INTRODUCTION

Daily hours of work for American workers declined substantially in the late nineteenth and early twentieth centuries and have remained roughly constant since then (Rosenbloom and Sundstrom, 1994; Costa, 2000; Whaples, 2001; Huberman, 2004). Market forces may have caused this decline (Kniesner, 1976; Owen, 1978; Whaples, 1990), but many observers believe unionism and government policy played an important role, especially in well-organized sectors such as the building trades (Cahill, 1932; Friedman, 1992; Rosenbloom and Sundstrom, 1994).

Certainly, the long campaign for shorter hours held the attention of unionists and social reformers for decades. Advocates all agreed that shorter hours would improve the health and welfare of workers and their families (Goldmark, 2012; Frankfurter et al., 2016). More controversial was the effect of shorter hours on productivity. Some advocates claimed that shorter hours would reduce unemployment by requiring employers to hire more workers to produce the same output (Dembe, 2011). Many more advocates claimed that workers were so fatigued at the end of each shift that shorter hours would have little effect on total output or profits—in effect, that the local elasticity of output with respect to hours of work was zero (Fisher, 2011, p. 257; Goldmark, 1912; Frankfurter et al., 2016, p. 636; Lauck 1920, p. 11).

Opponents of shorter hours took the former position. Early in the hours debate in England, Nassau Senior (1837), arguing against legislation for shorter hours, famously claimed that textile factories would be financially ruined if hours were shortened. His argument assumed unitary elasticity of output with respect to hours, fixed costs of plant and equipment, and no change in the prices of inputs or outputs. After the legislation passed, however, and daily hours in textile factories were shortened from twelve to ten in 1848, English Factory Inspectors were somewhat surprised to hear from some factory owners that there was no loss of output. Factory owners attributed this result mainly to increased energy of the workers but partly to increased speed of the machinery (Factory Inspectors Office, 1849, pp. 3-4), which suggests the need to control for technical change when measuring the productivity effects of shorter hours (Robbins, 1929, pp. 27-28).

By about 1880, most workers in the U.S. were working ten hours a day (Atack and Bateman, 1992). Advocates of shortening the work day still further to eight hours again claimed that shorter hours would not reduce output, and pointed to three voluntary experiments in Europe.

First, the Engis Chemical Works in Belgium reorganized production in 1893 from a two-shift system to a three-shift system, thereby reducing the length of the workday from twelve hours to eight. For engineering reasons, this reorganization was expected to increase daily output by

about 10-20 per cent. In fact, output increased even more, so that in six months, output in an eight-hour shift equaled former output in a twelve-hour shift. The additional increase was attributed to a reduction in worker fatigue and illness (Goldmark, 1912, pp. 147-155).

Second, also in 1893, William Mather's Salford Iron Works in England reduced weekly hours from 53 to 48 by starting later in the morning and reducing meal breaks from two to one. Mather said his records showed "there was actually a larger output in the trial year" than the average for the six previous years but the increase was probably small because the total earnings of piece workers fell very slightly. The improved results were attributed to, among other things, lower absenteeism and fewer employees reporting to work drunk (Mather 1894, pp. 16-19, 27-28).

Third, the Zeiss Optical Works in Germany experimentally reduced its workday in 1900 from nine to eight hours. The hourly earnings of piece workers increased by an average of 16.2 percent, more than offsetting the hours reduction and implying that total output increased with shorter hours (Goldmark 1912, pp. 155-167).

These three experiments challenged the assumption of unitary elasticity of output with respect to hours of work.[1] Nevertheless, it is difficult to know whether the outcomes of these voluntary experiments were representative of the larger population of workplaces and industries.

In the United States, similar workplace-level experiments were not well-documented (Goldmark 1912, pp. 138, 168; Cahill, 1932, pp. 237-239), but advocates of shorter hours pointed to coal mining, where a study by the Industrial Commission (1902) using publicly available data purported to show little negative effect of the eight-hour day on daily output. Of course, one may reasonably question whether estimates for coal mining could apply to other industries. Coal mining was seasonal work due to seasonal demand for home heating, and coal miners worked fewer days per year than workers in other industries (Douglas, 1930, p. 143; Fishback, 1992, p. 84). The majority of workers were paid on piece due to difficulties in supervision underground, and were often permitted to leave early (Archbald, 1922, p. 63; Goodrich, 1925 p. 60; U.S. Bureau of Labor Statistics, 1919).[2] Nevertheless, available data made coal mining attractive for study. Massive amounts of coal data were collected and published by state and federal agencies. Output was reported in physical units, rather than sales or value-added, so output changes could easily be distinguished from price changes. So careful calculations of the output effects of shorter hours in coal mining should at least be credible and internally valid even if external validity might be questioned.

[1] Additional experiments claimed to have little effect on output, but were not well-documented (Webb and Cox, 1891, pp. 254-264; Cahill, 1932, pp. 221-241; and Harris, 1972, pp. 68-69). Harris (1972, pp. 70-73) describes how these experiments prompted advocates for the eight-hour day in Great Britain to retreat from their earlier position that shorter hours would lower productivity and thereby reduce unemployment.

[2] One coal operator reckoned that "The miner is a sort of a free lance; he goes to work when he pleases and he comes out when he pleases. We are not able to control him, and, as far as my experience goes, he works no less hours now [under an eight-hour day] than he did before. I hold that he never worked much more than 8 hours before, for the reason that he went and came as he pleased." (Industrial Commission, 1901, Testimony of George W. Schluederberg, p. 82.) If many coal miners already set their own hours, estimates of the effect of officially shortened hours might be biased toward zero.

The Industrial Commission's study was rarely cited in subsequent decades, but a consensus apparently persisted that the eight-hour day could not have reduced output much (Lester, 1941, pp. 349-350; Owen, 1978, p. 43; White, 1987, pp. 41-45). Considering the economy as a whole, Denison (1962, p. 39) conjectured that a slight reduction in hours from a 48-hour work week would be "fully offset" by a rise in output per man-hour, and that a further reduction from 40 hours per week would be partially offset so that a 1 percent reduction in hours would result in only an 0.6 percent reduction in output. Still, Denison acknowledged that evidence was scarce and more studies would be useful. A few empirical studies have since appeared. Atack, Bateman, and Margo (2003) estimated production functions for manufacturing in 1880 using cross-sectional data and found an elasticity of output (measured as value added) with respect to daily hours of work of just 0.25. Pencavel (2015, 2016, 2018), analyzing time-series data collected by Horace Vernon at a munitions plant in Great Britain during the First World War, found that output appeared "relatively unresponsive to increases in [weekly] hours beyond 55" (2018, p. 84).[3]

The remainder of the paper is organized as follows. The next section re-examines the Industrial Commission study cited by advocates of the eight-hour day. The study's conclusion of zero elasticity of output with respect to daily hours of work is found to be unconvincing. The third section presents a new analysis of the output effects of shorter hours in coal using state panel data from the U.S. Geological Survey. The fourth section presents a new analysis of coal mine panel data from the Illinois Bureau of Labor Statistics. Both new analyses find an elasticity of output with respect to daily hours closer to one than zero. That finding naturally raises the question of whether the eight-hour day boosted employment as some unionists hoped, a question briefly addressed in the fifth section. The sixth section concludes.

2. THE INDUSTRIAL COMMISSION STUDY

Daily hours of work in coal mining were generally nine to ten hours until 1898, when the United Mine Workers won an eight-hour day for bituminous miners in the so-called Central Competitive Field, consisting of Illinois, Indiana, Ohio, and western Pennsylvania. Section 5 of the new contract read in part,

> That on and after April 1, 1898, the eight-hour work day with eight hours' pay, consisting of six days per week, shall be in effect in all of the districts represented [at the joint conference of operators and miners].[4]

The U.S. Industrial Commission, in its *Final Report* (1902, pp. 771-772) analyzed aggregate output data for states in the Central Competitive Field before and after the eight-hour day was

[3] Recent research has focused on the productivity of part-time work (e.g., Goldin, 2014).

[4] *Proceedings of the Joint Conference of Coal Operators and Coal Miners*, 1898. Prior hours of work are listed on pp. 3-4. Section 5 of the new contract appears on p. 27. The contract is also reproduced in Roy (1907, pp. 333-335), Suffern (1926, pp. 447-449), U.S. Geological Survey (1897, p. 338), and twice in Evans (1920, vol. 2, pp. 550-552, 789-791).

won. The Commission recognized that the increasing use of mining machines could confound the results, and therefore focused its discussion on Illinois, where machine mining hardly changed in this period. The Commission's figures for aggregate tons per worker per day for Illinois are reproduced in the first column of table 1 and plotted as Xs in figure 1. From these data, the Commission concluded the following.

> The table shows that in this State [Illinois] the highest output per day for each workman was in 1897, when it reached 3.36 tons. This was a year operated partly under 10 hours and partly under 8 hours. Comparing the two 10-hour years, 1895 and 1896, with the three 8-hour years, 1898, 1899, and 1900, it can be seen that the output for each working day has considerably increased, the 10-hour years showing an average output per day for each employee of 2.53 to 3 tons, while the 8-hour years show an average of 3.11 to 3.21 tons. This must be ascribed solely to the increased energy and promptness of the workmen, since, as already stated, the proportion of coal mined by machinery in that State has remained constant.[5]

The Industrial Commission's reasoning was straightforward. Tons per worker per day averaged 2.82 from 1895 to 1896,[6] and averaged 3.16 from 1898 to 1900, a productivity increase of 12 percent whose only explanation is "increased energy and promptness." But there are two issues with the Commission's analysis.

The first issue is timing—the Commission's assumption that the transition to the eight-hour day took place in 1897. As noted above, the eight-hour day actually went into effect on April 1, 1898. Moreover, the data presented by the Commission are for fiscal years ending June 30.[7] So in fact all of fiscal 1897, the year of peak productivity, was worked on a 10-hour day. Fiscal 1898 was the true transition year, with only its last three months worked on an eight-hour day. Excluding 1898 instead of 1897, tons per worker per day averaged 3.00 from 1895 to 1897, and averaged 3.16 from 1899 to 1900, a productivity increase of 5 percent—smaller but admittedly still positive and substantial.

The second issue is technical change—or rather, the Commission's assumption of its absence. The graph suggests that productivity may have been rising even before the eight-hour day.[8] To control for technical change, I estimated a simple least-squares regression, explaining output per worker-day with a time trend, a dummy variable for fiscal 1898 (the true transition year) and a second dummy variable for fiscal 1899 and beyond (showing the impact of the eight-hour day). The fitted values of this regression, shown as a solid line in figure 1, indicate an upward trend in productivity broken by a small drop in fiscal 1898 and a bigger drop in fiscal 1899. The

[5] U.S. Industrial Commission, 1902, *Final Report*, pp. 771-772.
[6] It is unclear why the Commission ignored 1894.
[7] The Commission's source for the productivity data was the U.S. Geological Survey, but that agency admits its data are from the *Annual Reports* of the Illinois Bureau of Labor Statistics [IBLS] through 1898 (U.S. Geological Survey, 1901, p. 370). The IBLS published data for fiscal years ending June 30. The long strike that resulted in a shorter workday did not begin until July of 1897—that is, the beginning of fiscal 1898 (IBLS, 1897, p. 161; George, 1898a, p. 186).
[8] Silvestre (2021) describes a continuous stream of small-scale technological advances in U.S. and European coal mining during this period.

coefficient of the second dummy variable is negative 0.72 tons, implying a decrease in productivity with the full implementation of the eight-hour day of about 24 percent. However, the estimated rate of technical progress is extremely, perhaps implausibly rapid, at about 0.25 tons per year (about 8 percent), so that the loss of productivity from the eight-hour day is recovered in about three years.

Hoping to improve the estimate of technical change by lengthening the series, I looked for additional years' data consistent with the Industrial Commission's in the annual reports of the Illinois Bureau of Labor Statistics (hereafter, IBLS). I was unsuccessful, but I did find a single table in the 1905 IBLS report (p. 16, table 4) showing thirteen years of similar data on output and employment. Presuming the numbers in the 1905 table were at least internally consistent, even if they did not match the Industrial Commission's, I divided output by employment and "average days active" (p. 87, table 44) to compute output per worker per day. The results are listed in the second column of table 1 and plotted as Xs in figure 2. I then estimated the same least-squares regression, with a time trend and two dummy variables, and plotted the fitted values in figure 2. Despite substantial differences in some data points (particularly 1896), the general impression is similar to the previous figure. The coefficient of the second dummy variable here is negative 0.32 tons, indicating a productivity drop due to the eight-hour day of about 11 percent. The estimated rate of technical progress is a more plausible 0.06 tons per year (about 2 percent), so that the loss of productivity from the eight-hour day is recovered in about five or six years.

These simple calculations raise doubts about the Industrial Commission's optimistic claim that "output for each working day has considerably increased" in Illinois coal mining as a result of the eight-hour day. Yet they are hardly definitive. First, the sample is very small and the raw data show large unexplained variation in productivity from year to year. As a result, standard errors for the coefficient estimates reported above are large and 95 percent confidence intervals would include zero. Second, aggregation issues muddy the interpretation: the set of mines included in the raw data varied from year to year, and also it is unclear how "average days active" were computed by the IBLS.[9] What is clear, though, is that the Industrial Commission's conclusion that the eight-hour day increased productivity depended on the assumption of no technical change.

3. STATE-LEVEL PANEL ANALYSIS

In the decades following the United Mine Workers' victory in the Central Competitive field, all remaining coal fields in the U.S.—union and nonunion—lowered their hours of work to eight and these changes in hours of work were documented by the U.S. Geological Survey. This suggests the possibility of measuring the effect of shorter hours on productivity using data for an entire industry instead of a single employer or state.

[9] Most likely, "average days" were computed as a simple average across mines, unweighted by employment or output (IBLS, 1899, p. L).

Data. Since the late nineteenth century, the U.S. Geological Survey surveyed all coal mines in the United States and published annual data aggregated to the state level. From these data, a panel was assembled of 25 major coal-producing states, with Pennsylvania anthracite included as a separate "state." Hours of work were first reported for the year 1903, at which time only the Central Competitive Field was working an eight-hour day. Figure 3 shows that most other coal fields adopted an eight-hour day between 1915 to 1920, the same boom period during which many other industries adopted shorter hours (Cahill; 1932, p. 223; Whaples, 1990, 2001). Throughout the 1920s, despite slack coal markets, the industry remained on an eight-hour day.[10] Accordingly, data were collected from 1903 through 1929, but the U.S. Geological Survey did not report data in 1909 for unexplained reasons, leaving 26 useable years.

Confounders. As the U.S. Geological Survey itself recognized, measuring the effect of shorter hours on productivity from state data is challenging because "the mining conditions in the different states vary so markedly, and there are so many other influences, particularly the use of mining machines, which enter into the question" (U.S. Geological Survey 1904, p. 420). Challenging, but perhaps not impossible with panel methods. Permanent differences in mining conditions can be controlled for in panel data using state fixed effects. Changes in machine mining can be controlled for using other data reported by the U.S. Geological Survey.

Other possible confounders include unionism and unobserved technical change. Controlling for unionism might be important because the impetus for shorter hours in coal usually came from successful union organizing. For example, the successful strike of 1897 yielded both an eight-hour day and an explosive growth in union membership in the Central Competitive Field (see figure 4). A large literature suggests that unions may affect productivity, though there is no consensus on the magnitude or even the sign of the effect (Doucouliagos and Laroche, 2003; Hirsch, 2007). To control for unionism, I used estimates of the fraction of coal miners who were members of the United Mine Workers, reported by state and year in Boal (2006) for 16 of the years from 1903 to 1929. To control for unobserved technical change, I followed common practice by including a time trend or year fixed effects.

Descriptive statistics. Summary statistics of the state panel are shown in table 2. Productivity is measured as short tons per worker per day, just as in the Industrial Commission study discussed above. The fraction of mine workers on an eight-hour day is 0.73 on average, but ranges from zero to one in these data. (About two-thirds of remaining workers were on a nine-hour day and one-third on a ten-hour day—see figure 3.) Machine mining, measured as the fraction of tonnage mined by machine, ranges from zero to nearly one, with an average of 0.35. Union density ranges from zero to one, with an average of 0.40.

Estimates. Table 3 shows panel regressions of the log of productivity on the fraction of workers on an eight-hour day. All columns control for the fraction of coal mined by machine, for technical change with either year fixed effects or time trends, and for permanent differences in mining conditions using state fixed effects. Some columns additionally control for unionism.

[10] Rosenbloom and Sundstrom (1994, pp. 163-164), referring to the period before 1903, describe the movement toward shorter hours as a "ratchet effect."

The estimated coefficient of machine mining has the expected positive sign but is not statistically significant. The estimated coefficient of unionism is not statistically significant, either. The estimated coefficient of the time trend indicates an annual rate of technical change of about 2 percent, similar to the reanalysis of the Industrial Commission's study above.

The coefficient of the eight-hour day is always negative and several times larger than its standard error. The hypothesis of no effect is easily rejected at conventional significance levels. For the first four columns, the coefficient of the eight-hour day is at least -0.17. Assuming the average workday was nine and one-third hours for any workers not on an eight-hour day, this implies an elasticity of output with respect to daily hours slightly greater than one. For the last two columns, which include state-specific time trends, the coefficient of eight-hour day is smaller. Yet the hypothesis of no effect of shorter hours on productivity is still easily rejected. The hypothesis of unitary elasticity cannot be rejected at five percent except in the very last column. Weighting the observations by state average employment had almost no effect on the estimates (not shown).

In summary, the state-level panel estimates indicate that output per worker per day moved roughly in proportion to the length of the workday. The hypothesis that shorter hours had no effect on productivity is easily rejected at conventional levels of significance.

4. ILLINOIS MINE-LEVEL PANEL ANALYSIS

The previous state-level analysis relied on aggregate data. A skeptic might wonder whether the analysis measured the effect of shorter hours on the same mines or the effect of shorter hours on the composition of mines. Similar results using mine-level panel data would be reassuring. Now many states published mine-level data on production and employment, but none reported hours of work. So how can the effect of shorter hours be measured at the mine level?

Data. The strategy adopted here is to select a large state where the timing of the transition to shorter hours can be known with relative certainty. A natural choice is Illinois, the same state favored by the Industrial Commission study. Illinois was the second largest coal-producing state at this time, after Pennsylvania. Before 1898, the typical workday in Illinois coal was apparently ten hours.[11] Union density was probably higher in Illinois than in the rest of the Central Competitive Field.[12] Unionized mines in Illinois, as part of the Central Competitive Field, should have adopted the eight-hour day beginning April 1, 1898, and several sources reckon that compliance with the eight-hour day was widespread in Illinois except perhaps at very small mines.[13]

[11] Proceedings of Joint Conference (1898, p. 4); Illinois Bureau of Labor Statistics (1899, p. XL); Industrial Commission (1901, pp. 109-110).
[12] As of 1902, the earliest year reported by Boal (2006), Illinois's union density was 81.7%, higher than Indiana (70.5%) or Ohio (63.7%), and much higher than Pennsylvania bituminous (21.0%) or Pennsylvania anthracite (23.9%).
[13] U.S. Industrial Commission (1901, pp. 108, 180, 185); Roy (1907, p. 340); Illinois Bureau of Labor Statistics (1897, p. 182; 1898, p. 131; 1899, pp. iii); U.S. Geological Survey (1903, p. 375).

Using *Annual Reports* of the Illinois Bureau of Labor Statistics (IBLS), data were collected on individual coal mines for the year 1898 and for seven years before and after—that is, for 15 years from 1891 through 1905. Mines in all counties that sent at least one operator to the 1898 Chicago joint conference setting the eight-hour day were included.[14] Small mines--defined as observations with fewer than 10 employees or operating fewer than 20 days--were excluded.[15]

Confounders. The same confounders discussed above in the state-level analysis are likely present here: machine mining, unobserved technical change, and unionism. Machine mining is reported every year, so as in the state-level analysis, the fraction of tonnage mined by machine can be introduced as a control variable. Unobserved technical change can be controlled for using a time trend.

Controlling for unionism is more difficult because no source reports the union status of individual Illinois coal mines. Nationally, the successful strike in 1897 led to explosive growth of membership in the United Mine Workers (see figure 6) so unionism and shorter hours were closely correlated in this period. However, there is reason to believe that the union enjoyed a loyal following in at least parts of Illinois well before the 1897 strike, having led prior statewide strikes in 1891 and 1894. So unionism can perhaps be held constant by focusing on mines where the union was surely strong both before and after the reduction in hours. (The same mines were presumably most likely to comply with the eight-hour day after 1898.) In what follows, results will be presented for the full sample and two subsamples of Illinois coal mines that were very likely unionized throughout this period.

Subsample (A): "Shipping" mines. These mines were located on railroads and were typically much larger than so-called "local mines" which served the local market only. Such large mines were more likely to be unionized (IBLS 1898, p. 131).

Subsample (B): Mines whose operators were present at the Chicago joint conference setting the eight-hour day. It turns out that (B) is nearly a subset of (A) because all but one operator present at the joint conference were shipping mines.

Because all mines changed to an eight-hour day simultaneously, there is no control group, and identification requires the absence of simultaneous change in other variables affecting productivity. One possible variable is miners' pay. The same agreement that resulted in shorter hours also gave miners an increase in the wage and, in Illinois, a change in the basis of payment. In this era, workers at the coal face were paid a piece-rate wage, per ton of coal loaded into coal cars. However, most mines used screens to separate large lumps from small pieces and coal dust (which fetched a lower price) and paid workers only for the large lumps. The system of paying only for screened coal was a constant irritation to miners and a law banning the practice was passed in Illinois in 1897, but the law was immediately declared unconstitutional. Screens were finally banned in the same union contract that implemented the eight-hour day.[16] It is difficult to say for certain how the wage increase and the change in the basis of payment would have affected productivity, but if the supply of effort were increasing in the wage, one would perhaps

[14] A total of 111 Illinois coal operators are listed in Proceedings of Joint Conference (1898, pp. 32-34). Some operated multiple coal mines in various counties.
[15] For the years 1902 to 1905, data on "local mines" were not collected to reduce data collection costs.
[16] IBLS, 1897, P. 165; IBLS 1898, p. 55; U.S. Industrial Commission, 1901, Vol. 12, p. 104, 108, and 184; George, 1898b, p. 452.

expect an increase in output per worker per day. If so, then estimates of the effect of the eight-hour day on productivity might be biased in a positive direction.

Descriptive statistics. Descriptive statistics for the full sample are shown in table 4. There are 4,528 mine-year observations on 814 mines observed from 1891 to 1905.[17] The fraction of coal mined by machine ranges from zero to one with a mean of just 0.16. Mean days of operation are 202 and mean employment is 111.2, but there is considerable variation in both variables, as might be expected in a micro sample. If days of operation and employment have independent effects on productivity, as in Atack, Bateman, and Margo (2003) or Boal (2017), it may be important to control for them. Shipping mines constitute 93 percent of the sample and mines whose operators were present at the 1898 conference constitute 38 percent of the sample.

Estimates. Table 5 shows the results of regressing the log of output per worker per day on a binary variable for the eight-hour day, with controls for machine mining, unobserved technical change, and in some columns, days of operation and employment. In this panel estimation, fixed effects are included for mines and standard errors are clustered on mines.

Before discussing the estimates shown in this table, consider an exploratory regression of log output per worker per day on machine mining, fixed effects for mines, and fixed effects for years. The coefficients of those year fixed effects are plotted as Xs in figure 5. Despite considerable variation from year to year, these coefficients show an overall pattern quite similar to the aggregate data discussed above in the context of the Industrial Commission study (figures 1 and 2). Output per worker per day increased irregularly until 1898, the transition year, decreased sharply in 1899, the first full fiscal year of the eight-hour day, and then eventually resumed its upward climb. The 95 percent confidence intervals displayed in the graph demonstrate that the productivity drop from 1898 to 1899 was statistically significant. Incidentally, there is no evidence in these data of a brief "adjustment period" to shorter hours followed by a rebound in productivity, as suggested by George (1898b, p. 457, fn) and Hicks (1935, p. 108). Instead, the fixed effects for 1900 and 1901 in figure 5 are slightly *lower* than 1899 (a similar pattern was seen in figures 1 and 2).

To enable measurement of the effect of the eight-hour day, the year fixed effects were replaced by a time trend, a binary variable for (fiscal) year 1898, and a binary variable for 1899 and beyond. The fitted values of that specification are graphed as a solid line in figure 5. This line increases through 1897, the last (fiscal) year before the eight-hour day. It drops a little in (fiscal) 1898, the transition year when the eight-hour day was adopted for the last three months. Then the line drops sharply in (fiscal) 1899, the first full year of the eight-hour day, before resuming its upward climb.

The estimates underlying the solid line in figure 5 are displayed in column (1) of table 5. Consider first the coefficients of the controls before returning to the effect of the eight-hour day. The effect of machine mining in column (1) is positive 14 percent and easily significant by conventional criteria. The coefficient of the time trend shows that the average rate of technical change (holding machine mining constant) is estimated to be about 1.6 percent, similar to the state-level rate, and it is easily significant by conventional criteria. The coefficient of the binary variable for the transition year of 1898 is negative but not statistically significant.

[17] Of these, 286 mines are observed both before and after 1898, the transition year to the eight-hour day.

The estimated effect of the eight-hour day on productivity is shown in the top row of the table. For column (1), the effect is -0.17, easily statistically significant at conventional levels. Since the rate of unobserved technical change is about 1.6 percent, the loss of productivity from the eight-hour day would be made up in about 11 years.

Near the bottom of the table, the productivity effect is divided by the log change in hours, giving an elasticity of output with respect to daily hours of 0.74. A direct interpretation of this elasticity is that the estimated reduction in productivity, though substantial, was less than proportional to the reduction in hours of work. Now an output elasticity is necessarily the ratio of marginal product to average product. So another interpretation is that output per hour in the last two hours of work (marginal product), while certainly positive, was less than output per hour in the first eight hours (average product).

Column (2) again uses the full sample but allows for non-constant returns to scale at the mine level by adding controls for days of operation and employment. Days of operation have a statistically significant negative effect on productivity, which might reflect diminishing returns to days or possibly measurement error since days also appear in the denominator of the dependent variable. Employment has a small positive effect that is not significant. The coefficient of the eight-hour day is -0.14, implying an output elasticity of 0.62, slightly smaller than in column (1) and statistically significantly different from one.

Columns (3) and (4) estimate the same two specifications on subsample (A), shipping mines. The estimated coefficients of the eight-hour day are slightly larger than the estimates for the full sample—as might be expected if compliance with the eight-hour day were greater among shipping mines—and the standard errors are similar.

Columns (5) and (6) estimate the same specifications on subsample (B), mines whose operators were present at the Chicago joint conference. The estimated coefficients of the eight-hour day are similar to those in columns (1) through (4) and again statistically significant, despite the much smaller sample.

In summary, the mine-level panel estimates indicate that daily output per worker fell substantially but not quite proportionately as daily hours were shortened from ten to eight. The hypothesis that adoption of the eight-hour day had no effect on productivity is easily rejected at conventional levels of significance. In fact, the estimated output elasticities are all closer to one than to zero, but the hypothesis of unitary elasticity can also be rejected when days of operation and employment are entered as controls.

5. EMPLOYMENT AND DAYS OF OPERATION

In contrast to other advocates of an eight-hour day, leaders of the United Mine Workers (UMW) fully expected that shorter hours would reduce daily output per worker, and in fact believed shorter hours would encourage mines to employ more workers and operate more days per year. As early as 1889, miners' union President John McBride predicted that an eight-hour day "would necessitate the operation of idle mines or an increased number of working days, and either of these would absorb the surplus labor surrounding our mines" (Evans, 1920, vol. 1, p. 483). Similarly, in 1892, UMW District 6 President J.P. Jones predicted that "by reducing hours, room

will be made and thousands of our idle brothers will be absorbed and given the much-desired opportunity of earning a sustenance" (Evans, 1920, vol. 2, p. 167). One year after the eight-hour day was adopted in the Central Competitive Field, UMW President John Mitchell testified that the shorter workday had "given employment to many men who, prior to its inauguration, were unable to secure work" (Industrial Commission, 1901, p. 47). By contrast, the Industrial Commission, relying on its estimate that shorter hours did not reduce daily output, itself believed that "the shorter working day has not increased the amount of employment of miners, and that the increase which has actually occurred in the number of days worked is to be ascribed solely to the improved industrial conditions of the country, and not to the reduction of hours" (Industrial Commission, 1902, p. 772). Can these claims be tested with either data set at hand?

Confounders. The Industrial Commission was certainly correct that year-to-year fluctuations in coal demand had a first-order effect on coal mining employment and days of operation. For that reason, a simple before-and-after design like the Illinois mine panel cannot credibly estimate the effect of the eight-hour day on employment or days of operation. Nevertheless, a difference-in-differences design like the state panel might work. Year fixed effects might control for fluctuations in demand, assuming a nationally integrated coal market.

Estimates. Table 6 shows panel regressions of the log of employment or days of operation on the fraction of workers on an eight-hour day. All columns control for the fraction of coal mined by machine, and for permanent differences in mining conditions using state fixed effects. Year fixed effects control for national factors including technical change and demand conditions. Two columns additionally control for unionism. It turns out that the coefficients of machine mining and unionism are never statistically significant.

In the first two columns, where the dependent variable is the log of employment, the coefficient of the eight-hour day is positive and statistically significant. In fact, the coefficient magnitudes are implausibly large. The point estimates suggest that the eight-hour day increased employment by about 35 percent, twice the estimated magnitude of the effect on productivity shown in table 3 above. But the standard errors are also large, so that 95 percent confidence intervals would range from about 6 percent to 64 percent. In the last two columns, where the dependent variable is the log of days of operation, the point estimates are again positive and now more plausible in magnitude—about 6 or 7 percent—but they are not statistically significant.

In summary, state-level panel estimates suggest that miners' union leaders were right—the eight-hour day increased employment—though the effect is not estimated with any precision. Point estimates suggest that the eight-hour day also increased days of operation, but one cannot reject the hypothesis of no effect on days.

6. CONCLUSIONS

Advocates for shortening the workday in the late nineteenth and early twentieth centuries sometimes claimed that doing so would employ more workers, but more often claimed that

workers could produce as much in eight hours as they could in ten hours so there would be no loss of daily productivity. In support of this claim, advocates cited individual plants in Europe that voluntarily experimented with shorter hours in the nineteenth century and a study by the Industrial Commission (1902) of U.S. coal mining, where unionized miners enjoyed an eight-hour day earlier than most other workers. The Industrial Commission study found no decrease in output per worker per day after hours were shortened, but overlooked the confounding effect of ongoing technical change (other than machine mining) and did not provide any measure of statistical precision. Reanalysis suggests that the eight-hour day might in fact have reduced daily productivity, but the tiny sample size discourages firm conclusions.

In this paper, new estimates from two large panel data sets are reported that show a substantial, statistically significant negative effect of the eight-hour day on productivity. The change to eight hours in the state-level panel caused a nearly proportionate fall in output per worker per day. The change from ten hours to eight hours in the mine-level panel also caused a fall in output per worker per day, though not quite proportional to the fall in hours of work. In both samples, the estimated local elasticity of output with respect to the length of the workday is closer to one than zero. In addition, there is some evidence from the state-level panel that shorter daily hours increased employment, a goal of the miners' union.

These new estimates explicitly control for machine mining, but also for unionism and more importantly for ongoing unobserved technical change. Other possible sources of bias—wage increases and piece workers leaving early—could not be controlled for with the available data. If they were present, then these new estimates are most likely biased toward zero and the conclusions just given are strengthened.

These results suggest that employers may not have been as thick-headed in opposing shorter hours as some have suggested. According to Pigou (1920, p. 417), employers frequently "fail to realize that shorter hours would promote efficiency among their workpeople, and so would redound to their own interest." Similarly, Hicks (1935, p. 107) speculated that "probably it had never entered the heads of most employers that it was at all conceivable that hours could be shortened and output maintained." Yet as we have seen, output was *not* maintained in coal mining. Productivity actually fell almost in proportion with hours. Interestingly, coal operators were not won over to shorter hours with experience, as Pigou and Hicks might have predicted. After a year of operation under the eight-hour day, coal operator George Schluederberg testified in 1899 that "as far as the operator is concerned it was a mistake" (Industrial Commission, 1901, p. 82). Likewise, S.M. Dalzell, President of the Illinois Coal Operators Association said, "I think the larger part of the operators believed [the eight-hour day] was a mistake. ... I doubted the wisdom of it at the time [it was agreed to] and I do yet. ... [A coal miner] cannot do in eight hours more than four-fifths the work ... that he could in ten." (Industrial Commission, 1901, p. 108-109).

It must be acknowledged that these results *do not* imply that the eight-hour day was economically inefficient. As advocates for shorter hours emphasized, long work hours imposed health and welfare costs on workers and their families, costs that are not addressed in this study. It also must be acknowledged that these results may not apply to other industries. Bituminous

coal mining was a large industry but it was unusual in many respects. Studies of additional industries are needed to provide the comprehensive assessment of shorter hours that Denison (1962) wanted to see.

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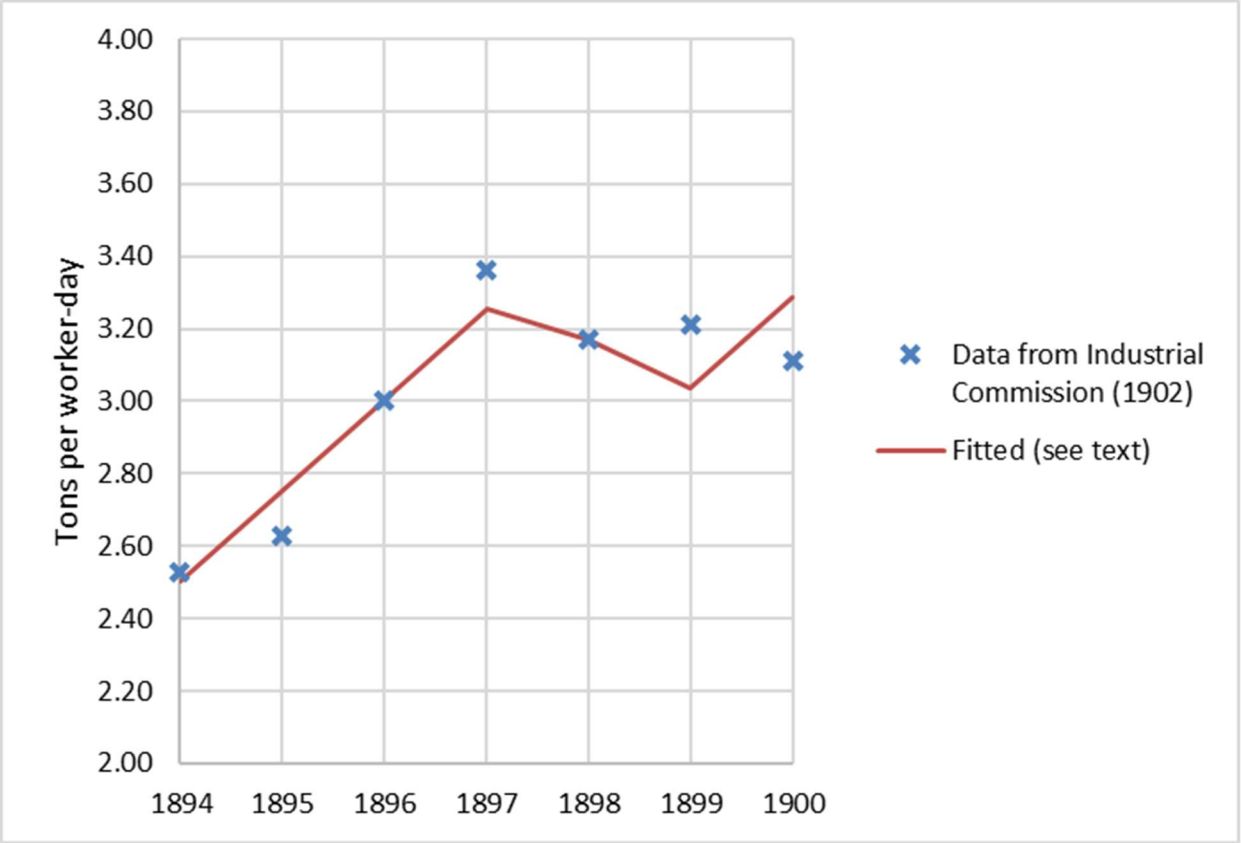
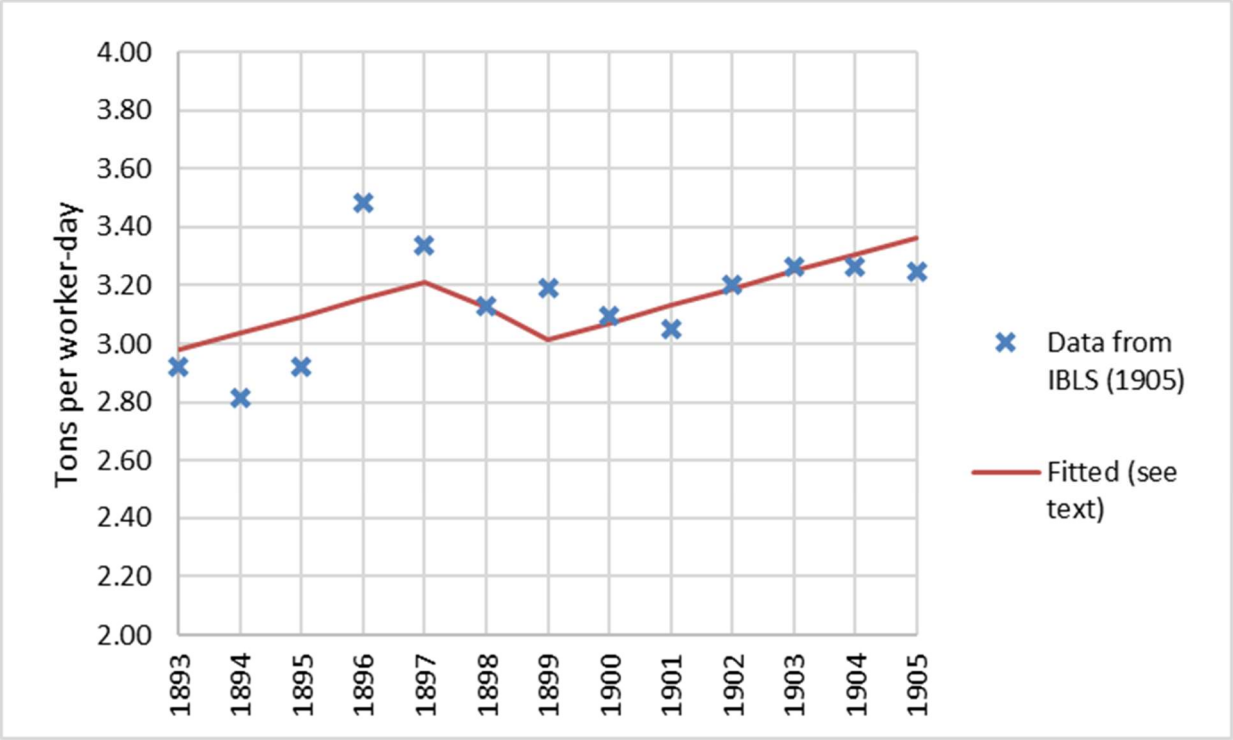
Figure 1: Productivity in Illinois coal mining (Industrial Commission)



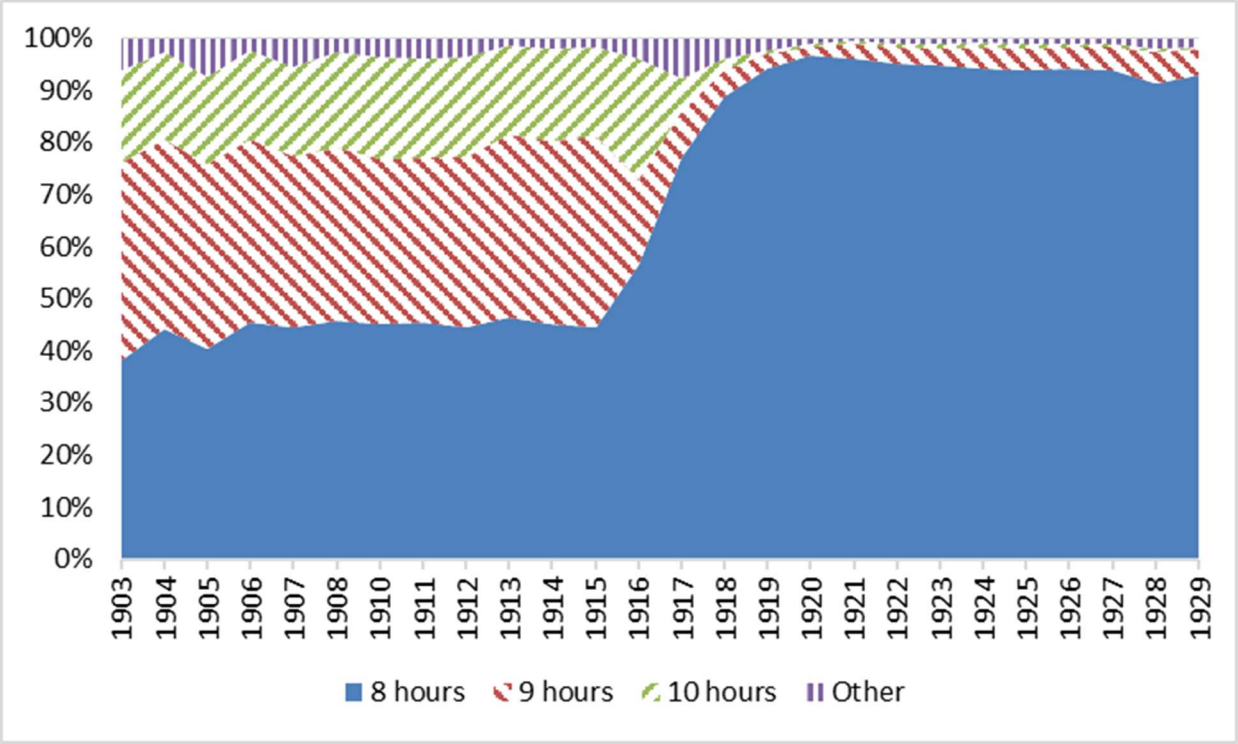
SOURCE: U.S. Industrial Commission, Final Report, 1902, p. 771.

Figure 2: Productivity in Illinois coal mining (Illinois Bureau of Labor Statistics)



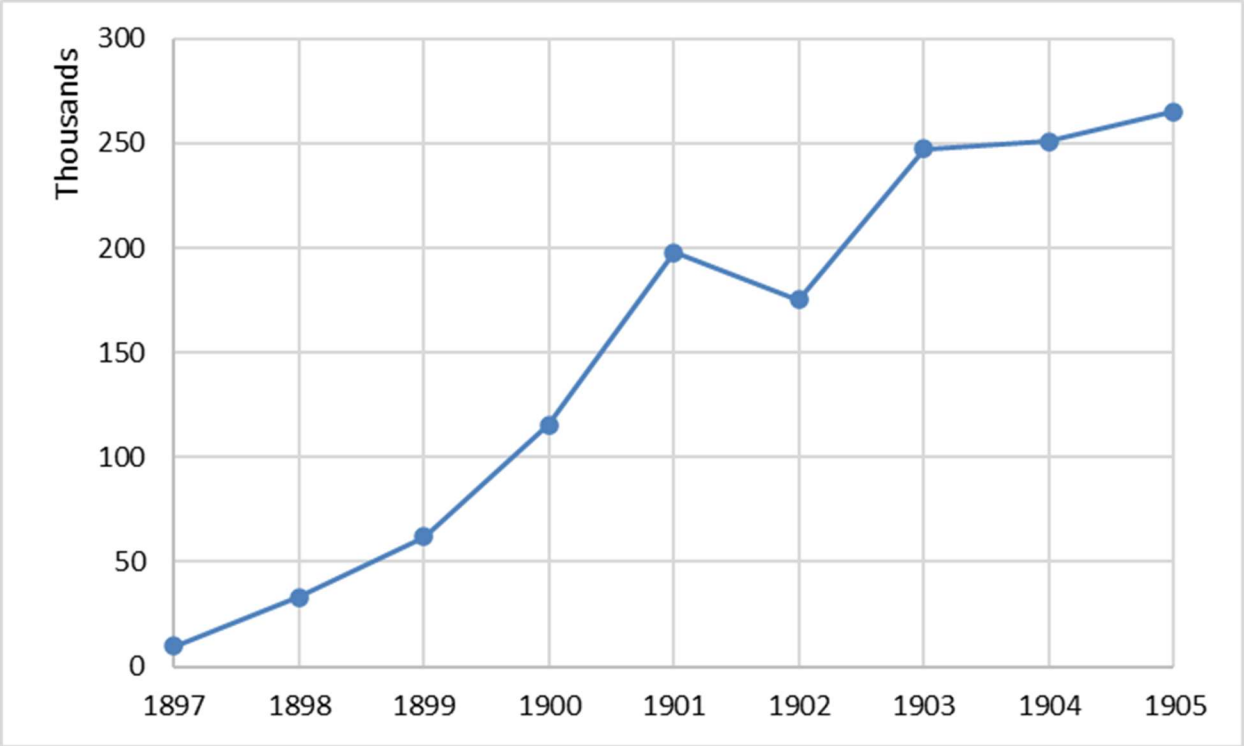
SOURCE: Computed from Illinois Bureau of Labor Statistics, Annual Report, 1905, p. 16, table 4 and p. 87, table 44.

Figure 3: Hours of work in U.S. coal mining: percent of workers on days of various lengths



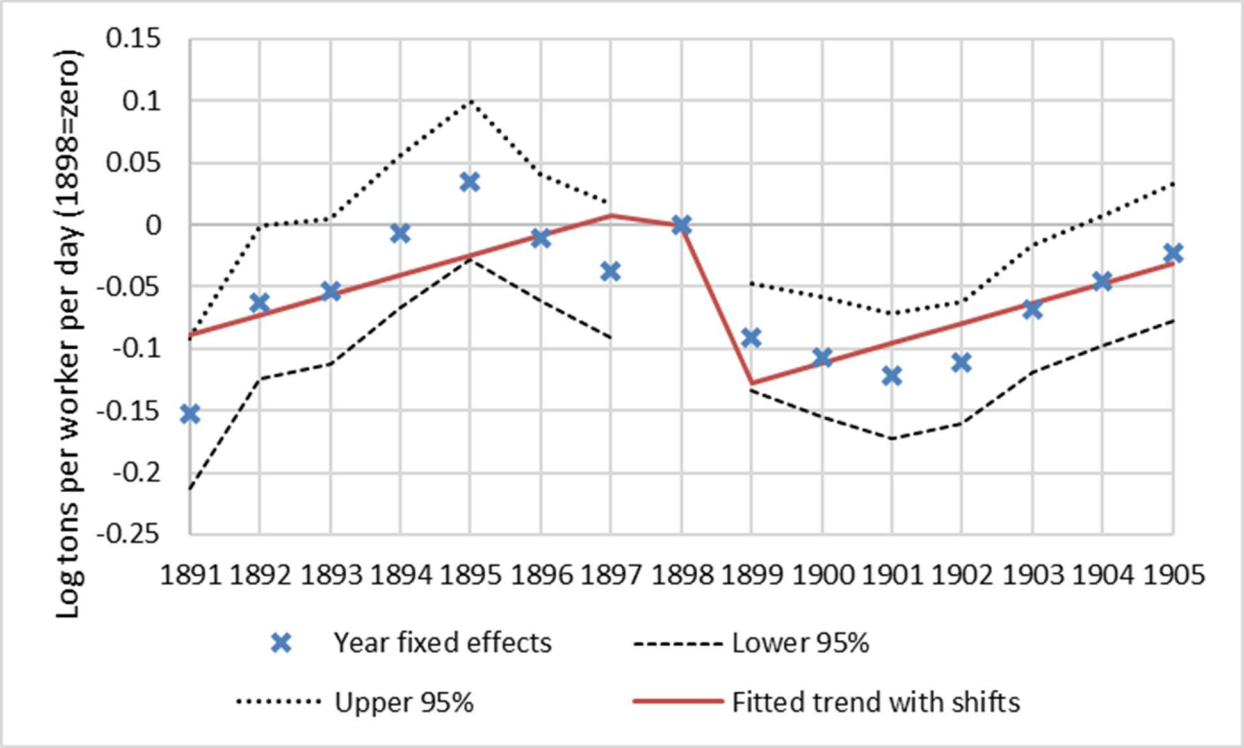
SOURCE: U.S. Geological Survey, *Mineral Resources of the United States*, various issues.

Figure 4: Membership in the United Mine Workers, 1897-1905



SOURCE: Wolman (1936), pp. 172, 192. Figures in Suffern (1926), p. 450, are similar. (Neither source provides state-level estimates.)

Figure 5: Productivity in Illinois coal mines (mine-level regressions)



SOURCE: "Fitted trend with shifts" is from table 5, column (1). "Year fixed effects" is from a similar regression with trend replaced by fixed effects. Confidence intervals are computed with clustering on mines.

Table 1: Productivity in Illinois coal mining (aggregate data)

Fiscal Year	Tons per worker per day	
	Industrial Commission (1902)	Illinois Bureau of Labor Statistics (1905)
1893		2.92
1894	2.53	2.82
1895	2.63	2.92
1896	3.00	3.48
1897	3.36	3.34
1898	3.17	3.13
1899	3.21	3.19
1900	3.11	3.10
1901		3.05
1902		3.20
1903		3.27
1904		3.26
1905		3.25

SOURCES: Industrial Commission, *Final Report*, 1902, p. 771; Illinois Bureau of Labor Statistics, *Annual Report*, 1905, p. 16, table 4 and p. 87, table 44. Illinois coal mines switched from a ten-hour day to an eight-hour day in the last three months of fiscal 1898.

Table 2: Descriptive statistics of state panel

Variable	Obs.	Mean	Standard deviation	Min.	Max.
Productivity = tons per worker per day	649	3.447	1.095	1.598	7.943
Fraction of workers on 8-hour day	649	0.732	0.363	0.000	1.000
Fraction of coal mined by machine	649	0.354	0.279	0.000	0.994
Union membership as a fraction of total employment	400	0.404	0.336	0.000	1.027
Year	649	1916.3	7.8	1903	1929

NOTES: 25 states: Alabama, Arkansas, Colorado, Iowa, Illinois, Indiana, Kansas, Kentucky, Maryland, Michigan, Missouri, Montana, North Dakota, New Mexico, Ohio, Oklahoma, Pennsylvania anthracite, Pennsylvania bituminous, Tennessee, Texas, Utah, Virginia, Washington, West Virginia, Wyoming.
All observed from 1903 to 1929, excluding 1909 for lack of data.
Panel is slightly unbalanced: Pennsylvania anthracite field excluded for 2016, a transition year.
Tons are short tons of 2000 pounds.
SOURCES: Union membership from Boal (2006). All other data from U.S. Geological Survey, various issues.

Table 3: Effect of eight-hour day on productivity in state panel

Regressor	(1)	(2)	(3)	(4)	(5)	(6)
Fraction of workers on 8-hour day	-0.1757	-0.1763	-0.1761	-0.1926	-0.1117	-0.0869
	(0.0365)	(0.0389)	(0.0409)	(0.0411)	(0.0299)	(0.0340)
Fraction of coal mined by machine	0.0234	0.0662	0.0319	0.0904	0.1517	0.1988
	(0.1684)	(0.1657)	(0.1745)	(0.1688)	(0.1109)	(0.1488)
Union membership as a fraction		0.0336		0.1117		-0.0533
of total employment		(0.0566)		(0.0752)		(0.0454)
Time trend (1900=zero)	0.0211	0.0197				
	(0.0038)	(0.0036)				
State fixed effects?	yes	yes	yes	yes	yes	yes
Year fixed effects?	no	no	yes	yes	no	no
State-specific time trends?	no	no	no	no	yes	yes
Elasticity of output w.r.t. hours	1.1399	1.1440	1.1426	1.2497	0.7245	0.5638
	(0.2369)	(0.2524)	(0.2650)	(0.2666)	(0.1940)	(0.2206)
Number of states	25	25	25	25	25	25
Number of (state x year) obs.	649	400	649	400	649	400

NOTES: Dependent variable is log of short tons per worker per day.
Standard errors clustered on states are shown in parentheses.
Elasticity estimate divides coefficient of eight-hour day by log change in hours, that is, by (ln(8) - ln(9 1/3)), where 9 1/3 is the average length of the workday for workers not on an eight-hour day.

Table 4: Descriptive statistics of Illinois mine panel

Variable	Obs.	Mean	Standard deviation	Min.	Max.
Productivity = tons per worker per day	4,528	3.360	1.720	0.176	31.626
Fraction of coal mined by machine	4,528	0.145	0.338	0.000	1.065
Days of operation	4,528	202.0	55.4	20	365
Employment	4,528	111.2	116.8	10.0	790
Year	4,528	1898.2	4.4	1891	1905
Shipping mine (binary)	4,528	0.929	0.257	0	1
Represented at 1898 conference (binary)	4,528	0.382	0.486	0	1

NOTES: 814 mines observed over 15 years.
Panel is unbalanced. Median number of observations per mine is 4.
Tons are short tons of 2000 pounds.
Observations with fewer than 10 employees or operating fewer than 20 days excluded
SOURCE: Illinois Bureau of Labor Statistics (various issues).

Table 5: Effect of eight-hour day on productivity in Illinois mine panel

Regressor	(1)	(2)	(3)	(4)	(5)	(6)
Binary variable for 8-hour day	-0.1661	-0.1385	-0.1921	-0.1612	-0.1868	-0.1221
(equals 1 beginning 1899)	(0.0261)	(0.0269)	(0.0256)	(0.0270)	(0.0331)	(0.0373)
Fraction of coal mined by machine	0.1370	0.1510	0.1335	0.1470	0.1406	0.1605
	(0.0459)	(0.0460)	(0.0458)	(0.0458)	(0.0630)	(0.0636)
Time trend (1898=zero)	0.0159	0.0130	0.0183	0.0146	0.0131	0.0073
	(0.0029)	(0.0030)	(0.0028)	(0.0030)	(0.0034)	(0.0040)
Binary variable for 1898	-0.0229	-0.0273	-0.0423	-0.0476	-0.0474	-0.0734
(transition year)	(0.0241)	(0.0242)	(0.0238)	(0.0239)	(0.0331)	(0.0344)
Log days of operation		-0.1086		-0.1188		-0.2191
		(0.0339)		(0.0339)		(0.0596)
Log number of workers		0.0072		0.0170		-0.0006
		(0.0246)		(0.0244)		(0.0395)
Mine fixed effects?	yes	yes	yes	yes	yes	yes
Elasticity of output w.r.t. hours	0.7446	0.6208	0.8609	0.7222	0.8373	0.5473
	(0.1170)	(0.1205)	(0.1149)	(0.1208)	(0.1485)	(0.1673)
Number of mines	814	814	666	666	148	148
Number of (mine x year) obs.	4,528	4,528	4,205	4,205	1,730	1,730

NOTES: Dependent variable is log of tons per worker per day.
Standard errors clustered on mines are shown in parentheses.
Sample includes mines in all counties where at least one mine was represented at the 1898 conference that established the eight hour day.
Observations with fewer than 10 employees or operating fewer than 20 days are excluded.
Columns (3) and (4) include only shipping mines.
Columns (5) and (6) include only mines directly represented at 1898 conference.
Elasticity estimate divides coefficient of eight-hour day by log change in hours, that is, by (ln(8) - ln(10)).

Table 6: Effect of eight-hour day on employment and days of operation in state panel

	(1)	(2)	(3)	(4)
Dependent variable (in logs)	Employ-ment	Employ-ment	Days	Days
Regressor				
Fraction of workers on 8-hour day	0.3526	0.3447	0.0572	0.0748
	(0.1444)	(0.1475)	(0.0392)	(0.0456)
Fraction of coal mined by machine	0.3811	0.3967	0.0700	0.0254
	(0.4009)	(0.4193)	(0.0858)	(0.1057)
Union membership as a fraction of total employment		-0.0611		-0.0629
		(0.1586)		(0.0538)
Number of states	25	25	25	25
Number of (state x year) obs.	649	400	649	400

NOTES: All regressions include state and year fixed effects.
Standard errors clustered on states are shown in parentheses.

DATA APPENDIX

State-level panel data

Scope of sample. The U.S. Geological Survey (USGS), and beginning in 1924 the U.S. Bureau of Mines, published aggregate state-level coal data on a calendar-year basis in a chapter of an enormous annual report, *Mineral Resources of the United States*. The data were tabulated from a comprehensive survey of coal operators, supplemented by information from state mining agencies and railroads. Later editions of *Mineral Resources* include detailed discussions of data collection and reliability. See for example USGS (1921, pp. 447-449 and 484-485).

States with few mines were reported in combination with other states, presumably to preserve confidentiality. Unfortunately, the small-state grouping varied from year to year, so these small states were excluded from the analysis. The following states were reported consistently and were used in the analysis: Alabama, Arizona, Colorado, Illinois, Indiana, Iowa, Kansas, Kentucky, Maryland, Michigan, Missouri, Montana, North Dakota, New Mexico, Ohio, Oklahoma, Pennsylvania, Tennessee, Texas, Utah, Virginia, Washington, West Virginia, and Wyoming.

The Pennsylvania anthracite field in the eastern part of the state was reported separately from the bituminous fields in central and western Pennsylvania, so Pennsylvania anthracite and Pennsylvania bituminous were each entered as distinct "states."

Data. The dependent variable for the analysis was coal output per worker per day, which was computed from state-level figures on coal output (in short tons of 2000 pounds), employment, and average days of operation. The USGS cautioned that the employment numbers reflect the number of workers typically on the payroll, not the average number at work each day (USGS, 1921, p. 485). A discussion of how the average days worked were computed is given in USGS (1922, pp. 493-494). The fraction of coal mined by machine was computed by dividing machine-mined coal by total coal output.

The key regressor was the fraction of workers on an eight-hour day. The number of workers on an eight-hour day in each state was first reported by the USGS in 1903, so that year determined the beginning of the state-level sample. By the 1920s, almost all mines were working an eight-hour day, so data were collected only through 1929. The fraction of anthracite workers on an eight-hour day was not reported, but was determined from historical sources to equal zero through 1915, and equal one starting in 1917. The transition year of 1916, when the operators agreed to the eight-hour day effective May 9, was excluded for anthracite field only.

No data were reported for 1909 on days of operation or the length of the workday. The USGS said simply, "The statistics covering the number of days worked or the number of hours to the working days have not been compiled," without further explanation (USGS, 1909, p. 38). So the full sample, from 1903 to 1929 omitting 1909, included 26 years.

Union density estimates were taken from table 3 in Boal (2006, pp. 544-545). These estimates were computed by Boal from per-capita tax receipts as reported in convention proceedings of the UMWA, which convened annually until 1911, every other year until 1923, and every third year until 1929, for a total of 17 available years. Boal converted membership to union density by dividing by employment as reported by USGS in the closest year. In one case (Iowa 1919) the resulting density value was slightly greater than one.

Illinois-mine-level panel data

Scope of sample. The Illinois Bureau of Labor Statistics (IBLS) reported mine-level data in its annual *Coal Report*. For 1898 and earlier, the report was titled *Coal in Illinois.* For 1894 and earlier, in even years, the report was included in the *Biennial Report* of the IBLS. The data cover fiscal years ending June 30.

For this study, mine-level data were collected for about half of the coal-producing counties listed in the report. Counties were included if at least one mine in the county was represented at the January 1898 conference where the union and operators agreed to an eight-hour day. In the published proceedings of the conference, representatives of the operators and their companies are listed on pages 29-34. Operators from Illinois were more numerous that those of any other state, and 111 of them are listed on pages 32-34. The name of the representative, the company, and an address are given. Using this information, these operators were matched to 145 mines, in 26 counties, in the 1898 IBLS report. Data for all mines in these 26 counties were collected for this study. The 26 counties were Bond, Bureau, Christian, Clinton, Fulton, Grundy, Jackson, Kankakee, LaSalle, Logan, Macoupin, Madison, Marion, Marshall, Menard, Montgomery, Peoria, Perry, Randolph, Sangamon, Shelby, St. Clair, Tazewell, Vermilion, Williamson, and Woodford.

The IBLS reports data on mines of all sizes, both shipping mines located on railroads and local mines serving only the surrounding community. Local mines were numerous but small and therefore less likely to be unionized and less likely to observe an eight-hour day after 1898. So observations with fewer than 10 workers and fewer than 20 days of operation were excluded. After selecting counties as described above and excluding small mines, the sample in 1898 compares to the universe of Illinois coal mines as follows.

	Illinois (IBLS 1898, p. 19)	Sample in 1898
Coal-producing counties	52	26
Mines	881	294
Total coal output	18,599,299 tons	16,499,327 tons
Total coal employment	35,026	30,276

The table shows that the sample covers only about a third of Illinois mines in operation in 1898, but nearly 90 percent of coal output and 86 percent of coal employment.

Because the focus of this study is the eight-hour day implemented in 1898, data were collected for seven years before and seven years after the change—that is, from 1891 to 1905. This was a period of rapid growth in coal mining, so the number of mines typically increased from one year to the next.

After the data were collected, observations were linked across years. No permanent number or name was assigned to mines by the IBLS, so observations had to be linked by hand on the basis of operator or mine name (allowing for spelling error), location, depth, and seam width. Occasionally, mine inspectors reported changes of ownership, which information was also used for linking. The resulting panel includes 814 mines observed for a maximum of 15 years. The panel is unbalanced. The median number of observations per mine is 4, and the quartiles are 1 and 9. Only about 8.6 percent of mines are observed in all 15 years.

Data. The mine-level data reported by the IBLS were remarkably detailed but inconsistently presented over the years. Some items were reported every year. Total coal output--the sum of coal output of all sizes, including coal used by the mine itself--was reported in all years in short tons of 2000 pounds. Similarly, days of operation were reported in all years. However, the number of workers and the fraction of coal mined by machine were not consistently reported. For this study, the number of workers was computed as follows.

Years	Definition of number of workers
1891-1895	Sum of average number of miners and average number of others.
1896	Sum of employees underground in winter, employees above ground in winter, employees underground in summer, and employees above ground in summer, all divided by two.
1897-1905	Average number of all employees.

The fraction of coal mined by machine was computed as follows.

Years	Definition of fraction of coal mined by machine
1891-1901	Coal mined by machine divided by total coal output.
1902-1905	One minus (coal mined by hand divided by total coal output).

The IBLS distinguished shipping mines from local mines in reports from 1891-1896, and from 1902 to 1905. For this study, a mine was defined as "shipping" if it was described as such in any year. (From 1902 to 1905, data on "local" mines were not collected at all, to economize on data collection costs.)

A few data edits were necessary. Errors in the IBLS source tables were often uncovered when mine data did not sum to county totals. A cross-check was usually sufficient to find and correct most errors. Data for Fulton county in 1896 were so scrambled in the source (IBLS, 1896, pp. 92-94) that unfortunately only three observations in that county and year were usable. Data for three coal operators, each operating several mines, were reported inconsistently--aggregated in some years, disaggregated in others. These were Pana Coal Co. in Christian county, Devlin Coal Co. in Marshall county, and Jefford Brothers in Peoria county. Data for these three companies were aggregated for all years for consistency.