UNIONISM AND PRODUCTIVITY IN WEST VIRGINIA COAL MINING: A LONGER VIEW

William M. Boal*

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ABSTRACT: I measure the effect of the United Mine Workers of America on productivity in West Virginia coal mining in the early twentieth century. I begin by replicating Boal's (1990) estimates, which used a small panel of coal mines from the early 1920s. Using physical measures of inputs and outputs, that study found some evidence of a negative effect of unionism on productivity at small mines, but the statistical significance was less than overwhelming. Then I take a longer view, using a much larger panel beginning in 1897. The earlier finding of a negative effect at small mines is not sustained. However, I find clear evidence of a negative effect of unionism toward the end of the sample, worsening over time. I explore possible explanations, including deteriorating labor relations and a "holdup" effect on unmeasured investment.

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* Address: College of Business and Public Administration, Drake University, Des Moines, IA 50311. Email: william.boal@drake.edu .

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Industrial relations scholars and economists have long recognized that unions may have important nonwage effects on the work environment—effects which, if positive, might compensate in part for unions' efficiency-reducing effects on wages and employment. For example, unions might improve job security, safety, or productivity.

The effects of unions on productivity have attracted special interest. Early scholars such as Slichter, Healy, and Livernash (1960) claimed that unions can increase productivity through a short-run "shock" effect on management. Higher wages encourage management to look for cost savings, especially if product markets are competitive. Later, Freeman and Medoff (1979, 1984) claimed that unions can increase productivity through a "voice" effect—that is, they can provide workers a communication channel with management regarding production processes and working conditions that cannot easily be duplicated in a nonunion environment. Union "voice" increases productivity by reducing labor turnover (Freeman 1980). At the same time scholars have always recognized that unions can have negative effects on productivity. Where labor relations are antagonistic, perhaps because management responds poorly to unions, productivity may suffer. If unions do not trust management to preserve workers' welfare, they are likely to object to any changes in production processes and working conditions, and to impose restrictive work rules, decreasing productivity.

More recently, interest has increased in the long-run effects of unions. In the short run, monopoly unions can raise wages and appropriate the quasi-rents from firms' long-lived tangible and intangible capital. The textbook model of monopoly unionism predicts that firms respond to higher union wages by substituting capital for labor, but the "holdup" model predicts that firms respond by *decreasing* tangible and intangible capital investment to avoid appropriation. The "holdup" effect might thus decrease measured productivity in the long run.[1]

With all these potential effects, there is obviously no single union productivity parameter. It is therefore not surprising that econometric studies attempting to measure the effects of unions on productivity have found widely differing results. Nevertheless, careful measurement of the union effect can suggest which union effects dominate in particular settings.

In this paper, I measure the effect of unionism on productivity in the setting of West Virginia coal mining in the early twentieth century. In this setting, before the Norris-LaGuardia Act and the National Labor Relations Act, unions enjoyed few of the legal protections they enjoy in the U.S. today. Labor relations were disorderly and even violent. At the same time, coal was a vital industry, employing 860,000 workers in the U.S. at its peak in 1923, and the United Mine Workers of America was a huge union, counting 422,000 dues-paying members in the U.S. at its peak in 1921.[2]

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[1] Addison and Hirsch 1989; Kuhn 1998, pp. 1049-1050; Hirsch 2007, pp. 210-215. The "holdup" model is usually attributed to Baldwin (1983) and Grout (1984).
[2] Employment: U.S. Bureau of Mines 1929, Part II, pp. 694-5. Union membership: Boal 2006, table 2, p. 553.

I begin by replicating Boal's (1990) estimates, which use a panel of 78 coal mines from the early 1920s. Output and inputs are measured in physical terms and all 78 mines changed union status, though not simultaneously, so that panel is close to ideal for measuring the effect of unionism on productivity. However, while Boal 1990 finds some evidence of a negative effect of unionism on productivity at small mines, the precision of the estimates is less than overwhelming, perhaps because the sample size was modest. In hopes of more precise estimates, I analyze a similar but much larger and longer panel of coal mines stretching back to the turn of the century. I inquire whether this panel still supports the idea of a union effect related to mine size. Taking a longer view, I also inquire whether the union effect changed over time, as predicted for example by the "holdup" model.

Prior Econometric Literature on Unionism and Productivity

Beginning with Pencavel 1977 and Brown and Medoff 1978, many econometric studies attempt to measure the effects of unionism on productivity through estimation of production functions of the form

$$Q = f(L, K, U), \quad (1)$$

where Q denotes output or output per worker, L denotes labor input, K denotes capital and other inputs, and U denotes some measure of unionism. Studies examine construction, manufacturing, cement, mining, sawmills, schools, hospitals, libraries, banking, and other sectors. Doucouliagos and Laroche (2003) count 77 studies that fit the narrow criteria of their meta-analysis but there are many more. Even reviews of this literature are numerous, including Hirsch and Addison 1986, Addison and Hirsch 1989, Pencavel 1991, Belman 1992, Booth 1995, Kuhn 1998, Belman and Block 2003, Metcalf 2003, and Hirsch 2007. Estimates of the union effect on productivity vary substantially, from positive 47 percent to negative 58 percent in Doucouliagos and Laroche's (2003) meta-analysis.[3] This large variation, reviewers agree, occurs partly because the true union effect depends on the setting, especially the extent of competition in product markets and the quality of labor relations,[4] and partly because data imperfections hamper estimation of the true union effect.

Coal Studies

Econometric studies of unionism and productivity in coal mining, the focus of this paper, are much fewer in number, but show a similar large variation in estimated union effects. Pencavel (1977) estimates a production function on four British coal fields over 13 years preceding the

[3] Doucouliagost and Laroche 2003, p. 659.
[4] Metcalf (2003, pp. 121, 165) and Hirsch (2007, pp. 202, 209) emphasize the effects of competitive product markets. Belman (1992, p. 55), Kuhn (1998, p. 1048), Belman and Block (2003, pp. 51-54), Metcalf (2003, pp. 121, 165), and Freeman (2007, p. 626) emphasize the quality of labor relations.

First World War. Seam width and a quadratic time trend are included, but not field fixed effects. The coefficient of unionism is significantly negative. Pencavel finds that "other things equal, an increase in the fraction unionized from 0.66 to 0.80 (approximately the values for Britain as a whole in 1900 and in 1913 respectively) will reduce the output of coal by some 2.3 per cent." A slightly different specification yields an estimate of 3.1 percent. Extrapolation to compare a completely unionized with a completely nonunionized industry yields a difference of about 22 percent.[5]

Connerton, Freeman, and Medoff (1979) estimate production functions on three cross-sections of U.S. coal mines in 1965, 1970, and 1975. Controlling for state effects and numerous mine characteristics, they find a large relative decline in productivity over time at union mines compared to nonunion mines. The union productivity differential is estimated to be positive 28 percent in1965, negative 4 percent in 1970, and negative 23 percent in 1975. The 1965 and 1975 estimates are significantly different from zero. The authors attribute this relative productivity decline mostly to "worsening labor relations" at union mines, but also to increased government safety regulation targeting larger mines—which were coincidentally more likely to be unionized.[6] Difficulties in matching prevent the use of fixed effects, so this study cannot control for unmeasured differences across mines.

Byrnes, Grosskopf, Fare and Lovell (1988) find positive union effects at surface mines in cross-section samples from two regions of the U.S. in the late 1970s. Using nonparametric mathematical programming methods which are unusual in this literature, the authors find that all union mines are more productive than nonunion mines in both regions. However, "more productive" here means, in the case of mines in the interior region, "operating at a more efficient scale." Using usual parametric econometric methods, unionized mines are found to be more productive than nonunion mines in the western region, but no statistically significant difference is found with respect to unionism in the interior sample. In deriving these results, controls for seam thickness and depth of overburden are used, but controls for unobserved differences across mines are not available because of the cross-sectional structure of the data.[7]

Chezum and Garen (1998) find a negative effect of unionism on productivity, using data on eastern Kentucky underground mines from 1980 to 1984. The point estimate of the union effect is about negative three percent and is significant at the ten percent level, but the authors point out that the estimated effect becomes positive when seam width is excluded as a regressor. The authors conclude that unions have a negative productivity effect that may be obscured in other studies' cross-section data because unions tend to organize the most productive mines, as predicted by their theoretical model (Chezum and Garen 1996). Chezum and Garen's (1998)

[5] Pencavel 1977, p. 144.
[6] Connerton, Freeman, and Medoff 1979, p. 43.
[7] Interestingly, both regional samples include mines which are unionized but not affiliated with the United Mine Workers of America. The econometric point estimates indicate that these mines are substantially more productive than the nonunion mines or the UMWA-affiliated mines (p. 1051).

estimates, however, do not exploit the panel structure of their own data by including fixed effects or by considering serial correlation in computing standard errors.

The Ideal Study

Many studies suffer from data imperfections. What sort of data are needed for credible estimates of the effect of unionism on productivity? There is broad consensus[8] that, first, output should be measured in physical terms. If output instead is measured as sales or value added, then union effects on output might be confounded with union effects on prices. Second, observations from a single industry at a low level of aggregation—say, the firm or the plant—are recommended to "lend credibility to the assumption … of a common technology."[9] Third, panel data, with some units changing union status, but not all simultaneously, are recommended to allow the researcher to control for unmeasured differences across production units. This is particularly important if unions tend to target the most (or least) productive units.[10] Fourth, a long period is needed if union effects take time to emerge. All the coal mining studies described above use data that meet the first criterion and either the second or the third, but none of them (and few studies of other sectors) meet all of the first three criteria.[11] The data on West Virginia coal mining presented below meet *all four* criteria.

Historical Setting: Unionism in West Virginia Coal Mining

History of Unionism

The colorful history of West Virginia coal mining in the early twentieth century is especially conducive to estimating the effects of unionism. West Virginia experienced waves of coal unionism, as shown in figure 1.[12] The first wave began in 1902 in the state's Northern Panhandle, near Wheeling, when several coal operators signed agreements with United Mine Workers of America (UMWA), which had already unionized nearby coal fields in Ohio and Pennsylvania. The next year, the UMWA signed up most of the mines in the large Kanawha coal field in the center of the state near Charleston.

[Figure 1 about here]

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[8] Pencavel 1991, pp. 36-37; Metcalf 1992, pp. 126-128; Booth 1995, pp. 192-196; Kuhn 1998, p. 1047; and Hirsch 2007, p. 202.
[9] Booth 1995, p. 196.
[10] There are nonetheless disadvantages of panel data, as Hirsch (2007, p. 203) notes. First, unions may affect productivity only gradually, so that the union effect may not be observed in a short panel. Second, firms changing union status may not be randomly selected. Third, results from a single industry are difficult to extrapolate to other industries. Fourth, as emphasized by Freeman (1984), errors in measuring union status tend to bias estimates of the union effect toward zero.
[11] Pencavel 1991, p. 37; Metcalf 2003, p. 127-128.
[12] For more detailed chronologies, see Boal 1994a and Fisher and Bezanson 1932, pp. 23-25. For an overview of coal mine labor markets in the early twentieth century, see Fishback 1992.

There was little change in unionism until 1912, when operators in the Paint Creek section of the Kanawha field tried to deunionize their mines. The resulting strike eventually spread to nearby nonunion fields on Cabin Creek, the New River, and the Winding Gulf. In 1913 the long and bitter strike was finally settled with the intervention of a sympathetic new governor, and all of these fields signed with the union. The union's position then remained stable through the First World War. In 1919, the Winding Gulf operators successfully deunionized their mines, but at the same time, the much larger Fairmont coal field in northern West Virginia first signed with the union. During the years 1919 to 1921, the UMWA enjoyed a peak in strength in West Virginia, with roughly 50 percent of the state's coal output mined under union contract. Coal fields in northern and central West Virginia were entirely unionized. The remaining nonunion coal fields lay in the extreme south of the state, in Logan, McDowell, Mercer, Mingo, and Wyoming counties.

The 1920s brought a reversal of fortune to the UMWA in West Virginia (and elsewhere). In 1922, after a long national strike, the union lost the New River field and most of the Kanawha field. In 1924, after another long national strike, the union lost the remainder of the Kanawha field and the Fairmont field. By 1927, those few mines that had signed a three-year contract with the union in 1924 had either shut down or deunionized. The state's coal mines remained completely nonunion until the 1930s.

While these rapid and frequent changes in unionism facilitate econometric estimation of its effects, it must be remembered that the UMWA in this period functioned in a legal environment very different from today's. Before the Norris-LaGuardia Act of 1931 and the National Labor Relations Act of 1935, the UMWA and other unions in the United States enjoyed almost no legal protection. Miners gained union recognition through strikes, not through certification elections. Unionized mines operated under essentially a "closed shop," while nonunion mines dismissed any employees suspected of being union members—at least after the Paint Creek strike. Nonunion coal operators often required employees to sign so-called "yellow-dog contracts" (pledges not to join the union) as a condition of employment, and thereafter obtained injunctions against union organizing.[13] Labor conflict in the West Virginia coal fields was frequent and often appallingly violent.[14]

Exogeneity of Unionism

[13] It was in West Virginia's Northern Panhandle field that "yellow dog contracts" were first used against the UMWA in 1906 by the Hitchman Coal Company. The company initially welcomed the union into its Benwood mine in Marshall County in 1903, hoping to reduce labor conflict (*Black Diamond*, April 18, 1903, p. 707; April 25, 1903, p. 758). However, the company reversed course in 1906 and resumed operation despite an ongoing strike. It then required its miners to sign contracts pledging not to join the union and used them to obtain a federal court injunction against the UMWA (*Black Diamond*, June 2, 1906, pp. 24, 36; June 16, 1906, p. 24; December 15, 1917, p. 496). The injunction was overturned by an appeals court in 1914. After the legality of these contracts was upheld by the U.S. Supreme Court in 1917, many more nonunion coal companies used them to obtain court injunctions against UMWA organizing activities. See Lunt (1979).

[14] See Mooney 1967; Lee 1969; Lunt 1979; and Corbin 1981 on West Virginia's "mine wars."

In this somewhat unusual historical setting, is estimation of a production function like equation (1) appropriate? Is it plausible to assume that unionism was exogenous in the production function? In other words, was unionism "as good as randomly assigned," [15] conditional on observed production inputs? Or did the UMWA tend to target the most (or least) productive mines, as suggested by Chezum and Garen (1996, 1998)? The historical record shows that whole coal fields usually went union as a group (Boal 1994a). Local associations of coal operators worked together either to negotiate with the union or to resist it (Corbin 1981 pp. 113-114). In coal fields where coal operators were able to control local officials, the union was unable to organize (Corbin 1981, p. 224; Mooney 1967 p. 129; Lee 1969; Lunt 1979). The election of Governor Henry Hatfield, who took office in 1913, was essential to the UMWA's successes in 1913 and 1914.[16] Conversely, the election of Governor Ephraim Morgan, who took office in 1921, may have doomed the UMWA's efforts to organize southern West Virginia.[17] Deunionization in the 1920s was also caused by exogenous forces—for example UMWA President John L. Lewis's rigid wage demands in the face of falling coal prices and nonunion wages.[18] One can never know all the causes of union success and failure, but no historical studies suggest that unionism was correlated with sudden increases or decreases in productivity, or even with permanent differences in productivity across mines (which can be controlled for in panel data). So exogeneity of unionism in coal production functions seems at least plausible.

Unionism and Productivity

In this historical setting, what effect of unionism on productivity should be expected? A positive effect might be expected from figures on labor turnover in the coal fields. According to Freeman (1980), lower turnover at union establishments indicates that the "voice" effect of unionism is operating. Workplace issues are resolved through the communication channel to management provided by the union, rather than through the exit of dissatisfied workers. The U.S. Coal Commission noted that labor turnover was much lower at union mines and fretted about the "waste" caused by high turnover in nonunion coal fields.[19]

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[15] Angrist and Pischke 2009, p. 55.

[16] See Corbin 1981, pp. 97-100; Lee 1969, pp. 43-47; and Lunt 1979, pp. 29-35.

[17] Lunt 1979, pp. 117-119, 124.

[18] See Mooney 1967, p. 127; and Lunt 1979, pp. 162-167 on Lewis's stance. See Fisher and Bezanson 1932, pp. 169-174 on prices and wages.

[19] U.S. Coal Commission 1925, part III, pp. 1263-1269. "A certain amount of labor turnover is undoubtedly healthful to an organization, but there is somewhere, though unestablished, a point of stability that tends to the greatest productiveness. [Industrial] concerns that maintain a turnover less than 50 percent consider that a most satisfactory figure." (U. S. Coal Commission 1925, part III, p. 1264). "Whatever the cause, such high rates of turnover as exist in some of the nonunion districts are certainly unhealthful from the point of view of management. If organization, morale, familiarity with the establishment, and settled community make-up have any value, the waste is undoubtedly high in such districts as Logan, where but 25 per cent of the mine work force is steady throughout the year, and the turnover runs up to 230 per cent per annum." (U.S. Coal Commission, part III, p. 1266). Part of the difference in turnover was surely due to the union wage differential, but the Coal Commission did not adjust its turnover figures for wages as Freeman (1980) did.

A negative effect might be expected from anecdotes on the UMWA's restrictive practices. Coal operators complained that the UMWA's policy was "to make as much work as possible for the greatest number of men." Citing numerous examples, the operators claimed that this policy was enforced "by placing limitations on hours of work, by encouragement of absenteeism, by the restriction of the operators' right to hire and discharge men, by various kinds of opposition to the use of machinery, and by the adoption of artificial and arbitrary wage scales and rules for certain kinds of work."[20] By "artificial and arbitrary wage scales," the operators meant that the union pushed for time rates instead of piece rates, and discouraged new labor-saving technology by insisting on exorbitant piece rates for workers using new machines.[21] In support of their anecdotal evidence, the operators offered data from West Virginia coal mines showing a substantial increase in output per worker per day when those mines changed from union to nonunion operation in the early 1920s. However, the operators' data did not control for mechanization or time effects and the sample size was small.[22] Those limitations are overcome in what follows.

Replication of Estimates with Small Sample

In a 1990 article, Boal estimated the effect of unionism on productivity using a sample of West Virginia coal mines in the early 1920s, thus exploiting the union's rapid decline in this period (see figure 1) to estimate the effect of deunionization. This section replicates those results using the same data but a more modern estimation method and a slightly cleaner production specification. The results are little changed.

Data

Boal's (1990) dataset covered 83 mines over four years (1921, 1923, 1924, and 1925) all of which changed from union to nonunion status. Fifty-five of the mines in the sample, mostly in the New River and Kanawha fields, operated on a union basis only for the first year of the sample. The remaining 28 mines, mostly in the Kanawha and Northern West Virginia fields, operated on a union basis until the last year of the sample. There were no missing values, so the dataset was balanced with 332 total observations.

Data on coal output and inputs were taken from the *Annual Report* of the West Virginia Department of Mines. Coal output was measured in tons. Five inputs were used: miners (workers at the coal face), other workers (including machine operators, locomotive drivers, etc.),

[20] Bituminous Operators 1923, pp. 149, 151.
[21] Bituminous Operators 1923, pp. 195-196. The latter allegation was confirmed by Boal (1994b). See also Slichter 1941, pp. 265-267; and Emmet 1924, pp. 31-33.
[22] Bituminous Operators, 1923, pp. 1-140. Unfortunately, the operators' brief did not name the mines listed in their tables of output, and I was unable to match them to the output of any mines listed in the West Virginia Department of Mines *Annual Report*.

mining machines (used to undercut the coal before blasting), locomotives, and horses and mules. Days of operation were also taken from the *Annual Report*.[23] Information on unionism was taken from many sources to construct a binary variable for unionism (see Boal 1990 appendix). This variable equals one if the mine operated under a formal contract with the United Mine Workers, and equals zero if the mine operated without such a contract.[24] Descriptive statistics of the sample are shown in table 1. Note that 42 percent of the observations are unionized.

[Table 1 about here]

The great strength of this dataset is that it meets the first three criteria recommended by reviewers of this literature: output is measured in physical units (tons), observations are from a single industry at a low level of aggregation (the mine), and the data form a panel with all 83 mines changing union status but not simultaneously. Nevertheless, this dataset also has weaknesses. First, it covers a particular industry in a somewhat unusual historical period, so any results may not generalize. Second, the panel is relatively short, so if the effects of changing union status take time to emerge, they cannot be detected.[25] Third, all of the transitions are in the same direction—from union to nonunion status. Fourth, the number of observations (332) is rather small.[26]

Replicating the Estimates

Table 2 replicates the production function estimates of Boal's (1990) article with variations. Column (i) shows estimates of a Cobb-Douglas production function with a simple union dummy variable. Each input is multiplied by days of operation before taking logs, as in Boal 1990, so the inputs are "miner-days," "other-worker-days," "machine-days," etc. Days of operation and its square are also included separately. The estimation method is ordinary least squares, with fixed effects for mines and years. Standard errors are clustered at the mine level. Of the five production inputs, only the coefficients of miners and other workers are statistically significant at conventional levels. Coefficients of mining machines, locomotives, and horses and mules are not statistically significant and the last two are unexpectedly negative. The estimated coefficient of unionism is about 0.04 and smaller than its standard error. There is little evidence, in an average sense, of an effect of unionism on mine productivity.

[Table 2 about here]

Boal's (1990) article focused on the possibility that unionism might change all the parameters of the production function. Column (ii) accordingly adds interactions of all of the input variables

[23] Hours of work are not available in the *Annual Report*., but in any case, miners and other workers paid on piece were usually allowed to stop work whenever they wanted, according to Archbald 1922, p. 42; and Goodrich 1925, pp. 41-43, 60.
[24] Mines operating under informal agreements were excluded from the sample. Union membership was not available at the mine level.
[25] This weakness is remedied by the larger dataset analyzed below.
[26] Nevertheless, the sample is larger than most analyzed by Doucouliagos and Laroche (2003).

with unionism. The estimation method is again ordinary least squares, with fixed effects and clustered standard errors.[27] The union dummy is now large, negative and significant, but the overall effect of unionism on productivity depends on the interactions. None of the union interactions is individually significant at conventional levels, but a joint test of the null hypothesis that all five are zero gives a p-value of 0.0014. The sum of the interactions is 0.094, with a standard error of 0.030, indicating that the effect of unionism on productivity was positively related to mine size. Indeed, Boal 1990 found a negative effect of unionism at very small mines and a positive effect at very large mines, attributing this result to economies of scale in labor relations.[28] However, this interpretation is somewhat ambiguous: a "large" mine in the specification of column (ii) has a large value of "miner-days," etc., but this could mean either many miners or many days of operation. I eliminate this ambiguity below by tinkering with the specification slightly, in two steps. First I allow unionism to interact with days of operation, and then I redefine the input regressors.

A Cleaner Specification

Boal's (1990) specification allowed interactions of unionism with input-days, but not with days of operation itself nor with its square. Column (iii) relaxes the specification to include these two interactions. The union dummy becomes enormous, negative and significant, but again the overall effect of unionism on productivity depends on the interactions as well. Again, none of the union interactions with input-days is individually significant at conventional levels, but the sum of those interactions is 0.161, with a standard error of 0.049, confirming that the union effect on productivity was positively correlated with "mine size." The interactions with days of operation and with its square are strongly significant. However, the relation between the union effect and days of operation is awkward to compute because all the inputs are also multiplied by days of operation.

To disentangle union effects related to input size from union effects related to days of operation, I redefine the regressors. Columns (iv) and (v) report estimates where inputs are *not* multiplied by days of operation before taking logs.[29] Column (iv) shows estimates of a Cobb-Douglas

[27] Boal 1990 used a GLS estimation method that is less popular today: he first-differenced the data and then applied seemingly-unrelated regressions to model serial correlation. Nevertheless, his point estimates and standard errors were quite similar to those reported in table 2. Boal also estimated translog production functions. With union-input interactions, the translog function required 30 more parameters, an approach that might be criticized as "overfitting" today.

[28] In Boal 1990, the positive effect at large mines did not hold up when the production function was specified as translog.

[29] In theory, this modification should affect the estimated coefficient of log(days) but not the estimated input coefficients because log (input-days) = log(input) + log(days). In practice, however, this equation does not hold exactly for these estimates. Because each input (except other workers) occasionally had an observed value of zero, one was added to "input-days" before taking logs for columns (i), (ii), and (iii), and one was added to "input" before taking logs for columns (iv) and (v). Since log (input-days + 1) does not exactly equal log(input + 1) + log(days), the estimates of the input coefficients in column (i) do not exactly equal the estimates column (iv), and the estimates of the input coefficients in column (iii) do not exactly equal the estimates in column (v).

production function with a simple union dummy. As in column (i), the estimated coefficient of unionism is small, positive, and smaller than its standard error.

Column (v) adds interactions of unionism with the input variables (*not* multiplied by days of operation) and with days of operation and its square. The sum of the interactions with the inputs is 0.143, with a standard error of 0.053, again suggesting that the effect of unionism was positively correlated with mine size, holding days of operation constant. This suggestion is weakly supported in the top panel of table 3, where the union effect is computed at different levels of inputs while holding days of operation constant at the sample median value of 176.5 days. With all inputs at their fifth percentiles ("small mines") the union effect is negative 17 percent, but with all inputs at their ninety-fifth percentiles ("big mines") the union effect is positive 18 percent. This pattern is illustrated by figure 2 (which resembles figure 1 in Boal 1990). As can be seen, however, the negative effect at small mines is not quite significantly different from zero at the five percent level.

[Table 3 about here]

[Figure 2 about here]

The relation between the union effect and days of operation can also be computed from the estimates in table 2, column (v). The bottom panel of table 3 shows that the estimated union effect has an inverted U-shape related to days of operation, peaking at about 101 days, near the low end of the sample. Holding inputs constant at their sample median values, the union effect is positive at the sample median (176.5 days) and below, and negative above the sample median, but the union effects are not significant at the 5 percent level except when days of operation are very high.

In summary, re-estimation of Cobb-Douglas production functions from Boal 1990 with a slightly different estimation method and a cleaner specification yields results similar to the earlier study. The coefficient estimates of the union interactions show that the union productivity effect is positively related to mine size. Calculations of the union effect at various sample percentiles suggest that the union had a positive effect on productivity at large mines and a negative effect at small mines, but the standard errors are too large, for the most part, to conclude that unionism's effect on productivity was significantly different from zero. So there is a hint of a union effect on productivity but the results are not very persuasive. Definite conclusions are frustrated by imprecision of the estimates. Perhaps a larger sample might yield more definite conclusions.

New Estimates with a Larger Sample

This section reports production function estimates from a new sample, almost 18 times larger than Boal's (1990) sample, intended to increase the precision of the estimates. More mines were added, including some that did not change union status in the sample period. More years were also added, exploiting the UMWA's waves of expansion in 1903, 1914, and 1919, as well as its decline in the early 1920s (see figure 1). For this larger sample, the earlier conclusion that the union productivity effect was positively related to mine size does not hold up. However, the larger sample permits a longer view of the union effect. It reveals a worsening effect of unionism on productivity toward the end of the sample period.

Data

Additional data were recently collected on West Virginia coal mines. The Department of Mines reported that the number of coal mines in West Virginia expanded from 215 in 1897 to 1702 in 1923, before falling to 866 in 1930, a potentially huge trove of data. Unfortunately, not all of these years and mines could be used. The number of years was constrained by the availability of output and input data from the Department's *Annual Report*. Data on the five inputs used earlier were not published before 1899 or after 1925. The number of mines was constrained by the availability of information on the union. By compiling scraps of information from many sources (see Appendix A) time series of union status were constructed for roughly one-quarter of the coal mines operating in West Virginia during this period (see figure 3).

[Figure 3 about here]

Unlike the small dataset analyzed in the previous section, this dataset is not balanced. Missing values abound for three reasons. First, occasionally a datum was omitted from the *Annual Report*. Second, often a mine could not be confidently matched across successive *Annual Reports*, most likely because the mine did not operate in all periods or because the name of the mine changed due to a change in ownership. Third, very often a mine's union status could not be ascertained for part of its history. As is well known, errors in longitudinal data can cause attenuation bias in estimates (Freeman 1984; Lewis 1986, pp. 60-94; Card 1996) so assignment of union status erred on the side of caution. Observations were dropped if union status could not be determined with certainty or if union status changed in the middle of the year.

In total, this larger sample covers 523 mines and 27 years, but missing values reduce the total size to 5960 observations.[30] Descriptive statistics given in table 4 show that these mines were slightly smaller than the mines in the sample used above. They used fewer machines and locomotives, and more horses and mules, as might be expected because the new sample stretches further back in time. Overall, 34 percent of the observations are unionized.

In panel data, when fixed effects are used to control for unobserved differences across units, the effect of unionism is identified by units changing union status. In this larger sample, 227 mines changed union status, many of them more than once: there are 147 transitions from nonunion to

[30] Despite missing values, this sample is quite large compared to others in this literature. It is larger than all but two analyzed by Doucouliagost and Laroche 2003, table 1, pp. 660-662.

union status, and 177 transitions from union to nonunion status.[31] Mines not changing union status are still useful because they help estimate the production function parameters. This larger sample includes 107 mines that were always observed as union and 189 mines that were always observed as nonunion.

[Table 4 about here]

Estimates

Table 5 shows estimates of a production function specification almost identical to the one estimated in the previous section, but now estimated on this larger sample. The specification in table 5 includes one new variable not used in Boal 1990. Because this larger dataset stretches over a longer period, the first observation of each mine in many cases represents a new mine in the initial development stage. New mines had lower productivity because narrow entries and haulage ways (rather than wide rooms) were being driven to open the mine.[32] At the same time, new mines usually began operation as nonunion. To control for any spurious correlation of initial productivity and initial union status, a binary variable is included indicating the first observation of a mine. Its coefficient estimate is always negative and statistically significant.

[Table 5 about here]

Column (i) in table 5 shows ordinary least-squares estimates of a Cobb-Douglas production function with a simple union dummy variable. Inputs are *not* multiplied by days. Fixed effects for years, but not for mines, are included. The coefficient of the union dummy variable is large and negative, but without fixed effects, column (i) is undoubtedly a misspecification because it does not control for unobserved mine characteristics that might be correlated with unionism.

Column (ii) in table 5 adds mine fixed-effects to this specification, so these estimates are comparable to column (iv) of table 2. All estimated input coefficients are now positive and statistically different from zero at the one percent level—in this respect, the larger sample produces greater precision, as hoped. The sum of the five input coefficients is 1.03, so production is characterized by roughly constant returns to scale. Productivity is lower by about 32 percent for the first observation of each mine, presumably reflecting initial development of a new mine. The coefficient of unionism is about -0.081 and is about four times its standard error, indicating that unionism appears to lower productivity, on average, by about 8 percent.

Column (iii) adds interactions of all of the input variables with unionism and column (iv) further adds interactions of days of operation and its square with unionism. The original estimated input coefficients are virtually unchanged by these additional regressors and remain statistically significant at conventional levels. However, the coefficients of the input interactions are each

[31] Transitions were often mediated by missing observations, for reasons given above.
[32] Piece rates were higher for miners working entries or haulage ways than for miners working rooms (Fisher and Bezanson 1932, p. 37).

quite small and statistically insignificant at conventional levels, and a joint test of the null hypothesis that all five are zero gives a p-value of 0.220 for column (iii) and 0.114 for column (iv). The coefficients of the interactions of days of operation and its square with unionism, included in column (iv), are opposite in sign from those estimated from the small sample (table 1 column (v)) but they are not individually significant.[33]

Is there any evidence of a union productivity effect related to mine size, as found by Boal 1990? The sum of the input interactions is -0.056 with a standard error of 0.028 for column (iii), and -0.076 with a standard error of 0.030 for column (iv), suggesting that, if anything, the effect of unionism on productivity was negatively related to mine size. Calculations in table 6 of the union effect at various sample percentiles yield point estimates that are, if anything, negatively related to mine size and positively related to days of operation—the exact opposite of the earlier results. Boal's (1990) conjecture of economies of scale in labor relations certainly does not hold up in this larger sample.

[Table 6 about here]

Nevertheless, estimates from this larger sample show a negative effect of unionism on productivity on average. The simple specification with only a union dummy (table 5, column (ii)) yields an estimated union effect of about negative 8 percent. The more elaborate specification with full interactions yields an estimated union effect of about negative 5 percent at the sample medians (table 6). Both estimates are highly significant, with p-values less than one percent.

Union Effect Over Time

Did the productivity effect of unionism vary over time? The larger sample can answer this question. Table 5 columns (v) and (vi) shows estimates where the union effect is permitted to vary by year, as the union dummy variable is interacted with the year dummy variables. Unionized mines are observed from 1901 through 1925 (see figure 3) so 25 union-year interactions can be included. Column (v) includes no union effects other than the interactions with years. Column (vi) includes union interactions with all inputs and days of operation. The coefficient estimates in both columns are quite similar to those in columns (ii) through (iv). Again, the input coefficients in both columns are highly significant at the 0.1% level (except horses and mules), while the interactions in column (vi) are not significant at 5 percent.

While the estimated input coefficients columns (v) and (vi) offer nothing new, the estimated coefficients of union-year interactions are quite interesting. To save space and reduce eyestrain, the 50 coefficients are not shown in table 5 but instead are displayed graphically in figures 4 and 5. Figure 4 shows point estimates and 95 percent confidence intervals for the simple specification reported in column (v). The estimated union effect for 1901 is huge and positive,

[33] However a joint test of the interactions of unionism with its square yields a p-value of less than 0.1 percent.

but should be viewed with skepticism because only one unionized mine is observed in 1901 (cf. figure 3).[34] Thereafter, the estimated union effects remain close to zero until about 1914, when they begin to fall below zero. For the last years of the sample, the union effects are about negative 20 percent (in logarithmic terms) and the 95 percent confidence intervals range from negative 10 percent to negative 30 percent. Figure 5 shows analogous estimates for the interactive specification reported in column (vi) (with input levels at the sample medians). The two figures are almost indistinguishable. Both show that the union had little effect on productivity in West Virginia coal mines until about 1914, after which the union had an increasingly negative effect.

[Figure 4 about here]

[Figure 5 about here]

In summary, re-estimation of Cobb-Douglas production functions on a larger sample has attained its goal of increased precision. Certainly the input coefficients are more precisely estimated. The average effect of unionism seems to be negative and statistically significant, whether measured with a single binary variable or with union-input interactions computed at the sample median. However, some of Boal's (1990) results have not proved robust. The union-input interactions, on which Boal 1990 placed much emphasis, now have smaller estimated coefficients that are neither individually nor jointly significant at conventional levels. Also, Boal's (1990) conclusion of a negative union effect at small mines is now reversed: it appears that large mines, not small mines, are worst affected by unionism.

The larger sample does offer one new result not anticipated by Boal's (1990) earlier study—that the effect of unionism on productivity in West Virginia coal mining worsened over time. Yet, after other conclusions from Boal 1990 have proved fragile, one naturally wonders how robust this new result might be.

New Estimates with a Simpler Specification and an Even Larger Sample

The five-input Cobb-Douglas production function used in Boal 1990 and in the estimates above is unusual in the literature and deserves scrutiny. Other studies of unionism and productivity in coal mining use simpler specifications. All use a single type of labor, and in all studies except Pencavel's (1977), labor is the only continuous variable. Capital is represented not by counts of machines or locomotives, but rather by binary variables and fractions representing various technologies.[35] This section reports estimates of a simpler specification for production, more typical of the literature, to see what results from the previous sections hold up. Happily, this

[34] Also, only two unionized mines are observed in 1902.
[35] One might question the appropriateness of simply counting mining machines, because these machines were quite heterogeneous (Dix 1977, 1988).

simpler production specification permits the use of an even larger sample. There is no evidence of a union effect related to mine size in this even larger sample, but there is again evidence of a worsening effect of unionism on productivity toward the end of the sample period.

Data

During the first three decades of the twentieth century, the most important form of technical change in coal mining was the advance of machine mining, whereby cutting machines replaced handheld picks for undercutting coal at the face (Dix 1977, 1988). In West Virginia, the fraction of coal mined by machine rose from 5% in 1897 to 83% in 1928[36]. So the following specification is proposed. The logarithm of output will depend on just two input measures: the log of the total number of workers and the fraction of coal mined by machine. As before, the log of days of operation and its square are also included.

This simpler specification can be estimated on more years of data, because the fraction of coal mined by machine is reported in the *Annual Reports* for more years than are counts of machines, locomotives, and horses and mules. In particular, the new sample can now include data for 1897 and for 1926 to 1928 (see figure 6). In total, this even larger sample covers 533 mines and 31 years, though missing values reduce the total size to 7489 observations.[37] Descriptive statistics for the larger sample are given in table 7. Overall, 30 percent of the observations are unionized. The new sample contains fewer mines observed only as union, more mines changing union status, and more transitions. The number of mines observed only as union has decreased to 45 while the number of mines observed changing status has increased to 296. For these latter mines, 186 transitions from nonunion status to union status are observed, and 267 transitions from union to nonunion status.

[Figure 6 about here]

[Table 7 about here]

Estimates

Table 8 shows estimates of this simpler production function on this even larger sample. As in the last section, a binary variable is included for the first observation of a mine, to control for low productivity when a mine is in initial development.

[Table 8 about here]

Column (i) in table 8 shows ordinary least-squares estimates with a simple union dummy variable. Fixed effects for years, but not for mines, are included. The coefficient of that union dummy variable is large and negative, but without fixed effects, column (i) is undoubtedly a

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[36] West Virginia Department of Mines, *Annual Report*, 1928, p. 9.
[37] Despite missing values, this sample is larger than all but one analyzed by Doucouliagost and Laroche 2003, table 1, pp. 660-662.

misspecification because it does not control for unobserved mine characteristics that might be correlated with unionism.

Column (ii) in table 8 adds mine fixed-effects to this specification. The coefficient of the union dummy variable is still negative, but small and not statistically significant at conventional levels (the p-value is about 10.2% in a two-tailed test).

Union effect over time

Did the productivity effect of unionism vary over time? The last two columns of table 8 show estimates where the union effect is permitted to vary by year, as the union dummy variable is interacted with the year dummy variables. Unionized mines are observed in this sample from 1901 through 1926 (see figure 6) so 26 union-year interactions can be included. Parameter estimates for two specifications are shown. Column (iii) includes no union effects other than the interactions with years. Column (iv) includes union interactions with all inputs and days of operation. The estimated input coefficients of both specifications are quite similar to those in column (ii). Total workers and fraction mined by machine are highly significant at the 0.1% level. The union the interactions in column (iv) are much smaller than their standard errors. A joint test of the interactions gives a p-value of 0.80.

The union effects by year from columns (iii) and (iv) are displayed graphically in figures 7 and 8, respectively. Unionized mines are observed from 1901 through 1926 (see figure 6) so 26 union effects can be estimated. However, the extreme endpoints should be viewed with skepticism due to small numbers of union observations (cf. figure 6).[38] Figures 7 and 8 are almost indistinguishable and are quite similar to figures 4 and 5 above. All four figures show that the union had little effect on productivity in West Virginia coal mines until about 1914, after which the union had an increasingly negative effect.

[Figure 7 about here]

[Figure 8 about here]

Meanwhile, there is no indication of a union effect related to mine size. The estimated coefficients of the union interactions in column (iv) are very small compared to those in table 2, and they are not even remotely significant at conventional levels—either singly or jointly.[39]

Why Did the Union Effect Worsen over Time?

[38] Only one unionized mine is observed in 1901, only two unionized mines are observed in 1902, and only two unionized mines are observed in 1926.

[39] The p-value of a joint test of all four interactions is about 0.80 .

The last two sections both find that the union effect on productivity worsened over time, beginning about 1914. What could explain this result?

Skill Differential

One possibility is that nonunion workers became increasingly skilled relative to union workers over time. However, this explanation seems unlikely. In the early part of the sample, most status transitions were from nonunion to union (see figure 1). A mine might sign with the union after a strike, but the workers in the mine would not change. By contrast, in the 1920s, most transitions were from union to nonunion. To beat the union, mines often hired new nonunion workers—strikebreakers—who had little or no experience in coal mining.[40] So one would expect that deunionization would likely cause a *decrease* in worker skill and mine productivity, contrary to what was found.

Worsening Labor Relations

A second possibility is that labor relations at union mines deteriorated in comparison to nonunion mines during the later years of the sample. Freeman and Medoff (1984) emphasized that the union effect on productivity depends on management's response. They and other writers have acknowledged that poor labor relations can cause a negative union effect on productivity.[41]

Certainly labor relations at union mines in West Virginia were often strained. "Unreasonable" grievances and both authorized and unauthorized strikes were common at union mines.[42] But did labor relations worsen over time at union mines *compared* to nonunion mines? It is important to recognize that during this period, strikes and violence occurred at both union and nonunion mines. In fact, many of the most notorious labor conflicts during this period occurred at nonunion mines: the Hitchman Coal Company's and Red Jacket Coal Company's yellow-dog contracts and anti-union injunctions in 1906 and 1920 respectively, the union miners' march on nonunion Logan County in 1919, the massacre at Matewan in nonunion Mingo County in 1920, the shootings and dynamite in 1920 at the Glen White mine in Raleigh County and at the Willis Branch mine in Fayette County, the long strike in Mingo County from 1920 to 1922, the battle at Blair Mountain in Logan County in 1921 and subsequent declaration of martial law, and the widespread use of armed mine guards and Baldwin-Felts detectives by nonunion coal operators beginning in 1912 to intimidate union sympathizers and organizers.[43]

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[40] Corbin 1981, pp. 198-199. However, strikebreakers were not always used. Sometimes mines became nonunion without a change in personnel (Bituminous Operators 1923, p. 11).
[41] Belman 1992, p. 55; Booth 1995, pp. 185-186; Kuhn 1998, p. 1048; Belman and Block 2003, pp. 51-54; Metcalf 2003, pp. 121, 165; and Freeman 2007, p. 626.
[42] Mooney 1967, pp. 61-69; Bituminous Operators 1923, pp. 171-174.
[43] See Lunt 1979 for a detailed and relatively nonpartisan account of these events emphasizing legal issues. Other excellent but more partisan sources include Corbin (1981) and first-person accounts by Mooney (1967) and Lee (1969).

From 1903 to 1914, the Department of Mines published data on strike activity at the county level: the number of mines reporting strikes and the number of workers "thrown out of work by strikes." These can be compared to county-level estimates of the fraction of tonnage mined under union contract from Boal 1994a. A regression of the fraction of fraction of mines reporting strikes on union-year interactions (with mine and year fixed effects) gives the time-varying estimates graphed in figure 9a. The estimated union effect remains near zero through 1911 and then suddenly exceeds 0.3 in 1912 and 1914. The estimated union effect for 1914 is significantly different from zero at five percent. In a similar regression of the fraction of workers thrown out of work by strikes gives time-varying estimates graphed in figure 9b. Here the estimated union effect remains *negative* through 1913 and then suddenly rises to about 1 in 1914, though it is not significantly different from zero at 5 percent. So the union's effect on strike activity appears to have been zero or negative until about 1914, at which point it became positive. Labor relations at union mines appear to have comparatively worsened at about the same time that productivity comparatively fell. Unfortunately, disaggregated strike data are not available after 1914.

[Figure 9]

Decreasing Unmeasured Investment

A third possibility is that unionized mines enjoyed less measured and unmeasured investment over time, as predicted by the "holdup" model. Operators may have concluded that any increases in productivity would be appropriated by the union, so they may have become less willing to incur the costs of investment.[44]

The production-function estimates reported above already control for measured capital (mining machines and locomotives) so the question is whether *unmeasured* investment may have lagged in union mines. This question is obviously impossible to answer directly. However, the union's effect on the use of mining machines can be estimated using the same mine-level data and may suggest the union's effect on unmeasured investment. A regression of the fraction of coal mined by machine on union-year interactions gives the time-varying estimates graphed in figure 10. Note that this figure is quite similar to figures 4, 5, 7, and 8, except for the extreme endpoints, which should again be viewed with skepticism due to small numbers of union observations (cf. figure 6). The union effect on machine mining is zero or positive through 1913 and negative thereafter. Many of the point estimates toward the end of the sample period are significantly

[44] A Texas coal operator described being "held up." To increase output, the operator wished to install mining machines, and "notified the district president of the United Mine Workers of our desire to install mining machine equipment and as a preliminary wanted to know what kind of [wage] agreement we could get before spending any money on same." After some negotiation, "the result was that the union agreed to a rate of $1.50 per ton for loading" with the proposed new machines. But the operator "had too much faith in the word of the district president and did not require him to sign a document to that effect. The coal company proceeded with its installation and purchase, and due to some local dissatisfaction over the proposed rate for loading, the district president failed to put it into operation. Our only remedy was to agree to a scale of $1.56 per ton, or throw our equipment into the scrap pile." Bituminous Operators 1923, pp. 184-185.

negative at five percent. So the union's effect on measured investment appears to have been negative toward the end of the sample. If the union's effect on *unmeasured* investment were similar, then the "holdup" model might explain the negative union effect on productivity toward the end of the sample.[45]

[Figure 10 about here]

In summary, a skill differential between union and nonunion miners is not a plausible explanation of the worsening union effect on productivity found above. Both the hypothesis of worsening labor relations and the hypothesis of unmeasured investment holdup are at least plausible, but the available evidence is not definitive.

Did the Union Target the Most Productive Mines?

One last issue can be addressed with the data and results at hand. Did the union target the most productive mines, as hypothesized by Kuhn (1988), and by Chezum and Garen (1996, 1998)? On the one hand, if coal mines experienced *transitory* productivity shocks that were correlated with unionism, then the estimates presented above are biased upward. The discussion of the historical setting above argued against that possibility. On the other hand, if mines had *permanent* productivity differences, perhaps determined by geological conditions, and these differences were correlated with unionism, then the estimates presented above are unbiased because mine fixed effects are included. These same estimates can be used to examine the targeting hypothesis.

Union Dummy Coefficient Estimates

One way to examine the hypothesis is to compare the estimated coefficient of the union dummy with and without mine fixed effects. If the most productive mines were more likely to be unionized, one would expect the coefficient of the union dummy to decrease (or become more negative) when mine fixed effects are included.[46] However, a comparison of columns (i) and (ii) in table 5 shows that the coefficient *increased* (that is, became less negative) from -0.20 to -0.08. Again, in columns (i) and (ii) of table 8, coefficient of the union dummy *increased* from -0.16 to -0.03. So permanent productivity differences across mines appear to be negatively correlated, not positively correlated, with unionism.

Average Productivity

A second rather crude way to examine this hypothesis is to compare output per worker per day for three groups of mines: mines that were always observed as union, mines that were observed

[45] See also Boal 1994b and Bituminous Operators 1923.
[46] This is what Chezum and Garen (1998) find. However, they do not exploit the panel structure of their data. Instead of adding fixed effects, they add a variable for coal seam width.

changing union status, and mines that were never observed as union.[47] These computations are reported in the first three columns of table 9 for the "even larger" sample of 7489 observations. Note that average productivity is lowest for the "always unionized" observations and highest for the "never unionized" observations, again contradicting the hypothesis that the UMWA targeted the most productive mines. However, these computations do not control for capital inputs, days of operation, technological change over time (year effects), or unionism itself, so they are unsatisfactory.

[Table 9 about here]

Total Factor Productivity

A third way to examine this hypothesis is to compare the mine fixed effects estimated as part of the regressions reported above. Fixed effects from the Cobb-Douglas specification (table 5 columns (v) and (vi)) are summarized in the next three columns of table 9. Here, total factor productivity at "always union" mines is the same or higher than at "never union" mines. However, total factor productivity is lowest for the "changing status" mines, so there is little evidence that the UMWA targeted the most productive mines. Fixed effects from the simpler specification (table 8 columns (iii) and (iv)) are summarized in the last three columns of table 9. Here, total factor productivity is lowest for the "always unionized" observations and highest for the "never unionized" observations, the same rank ordering as for average productivity.

On balance, the available evidence does not support the hypothesis that the UMWA targeted the most productive mines in this dataset.

Conclusion

In this study, I replicate Boal's (1990) estimates of the effect of unionism on productivity in a panel of West Virginia coal mines in the early 1920s, and then re-estimate the same Cobb-Douglas production function in a larger panel covering many more mines and running from 1899 through 1925. I then estimate a simpler production function on an even larger panel running from 1897 through 1928. All three datasets measure output in physical terms, focus on a single industry at a low level of aggregation, and feature many units changing union status but not all simultaneously.

Evidence of an overall time-invariant effect of unionism is fragile. When the union effect is entered as a single dummy variable, it is not significant in the original small sample, negative and significant in the larger sample, and not significant with the simpler specification in the even larger sample. Evidence of a broader union effect, changing all the parameters of the production function, is also fragile. Union-input interaction effects are jointly significant in the original

[47] All mines analyzed by Boal (1990) were in the same group: "changing status."

small sample, but not significant in the larger sample nor with the simpler specification in the even larger sample. Boal's (1990) claim of a negative union effect at small mines is refuted in the two larger samples.

Boal's (1990) original panel was too short to measure the effect of unionism over time, but my larger panels provide a longer view. In both larger panels, the union effect on productivity remains positive or zero through about 1913. Thereafter, the union effect becomes increasingly negative. I consider several hypotheses to explain this adverse trend. The hypothesis of deteriorating labor relations is supported by evidence that strike activity increased at union mines, compared to nonunion mines, about 1914. The investment holdup hypothesis is supported by an estimated relationship between unionism and machine mining which grows increasingly negative over time. Perhaps both hypotheses play a role.

Appendix A: Data sources

Output and inputs

Coal output, miners, other workers, total employment, machines, locomotives, horses and mules, days of operation, and coal mined by machine were taken from the *Annual Report* of the West Virginia Department of Mines. These data are reported on a fiscal year basis (ending June 30) through 1924, and on a calendar year basis thereafter. Miners, other workers, machines, locomotives, and horses and mules are reported by the Department from 1899 through 1925. Coal output and coal mined by machine are reported at the mine level in 1897, and from 1899 through 1928. Coal is reported in long tons through 1923 and in net tons thereafter; I converted all data to net tons.

Union Status

The union status of 533 mines was determined for as many years as possible by collecting references to West Virginia mines in the sources listed below. The most fruitful sources were *Coal Age, Coal Trade Bulletin,* and the *United Mine Workers Journal.* Very often a mine's union status could not be ascertained for part of its history. As is well known, errors in longitudinal data can cause attenuation bias in estimates (Freeman 1984; Lewis 1986 pp. 60-94; Card 1996) so data collection erred on the side of caution. Observations were dropped if union status could not be determined with certainty or if union status changed in the middle of the year.

- Bituminous Operators' Special Committee (1923), "The United Mine Workers in West Virginia," submitted to the U.S. Coal Commission, September 10, 1923.
- *Black Diamond* , Chicago, various issues.
- *Coal Age* , New York, various issues.
- *Coal Trade Bulletin* , Pittsburgh, various issues.
- Corbin, David Alan (1981), *Life, Work, and Rebellion in the Coal Fields: The Southern West Virginia Miners, 1880-1922*, Urbana: University of Illinois Press.
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- *United Mine Workers Journal*, Indianapolis and Washington: various issues.
- United Mine Workers of America, *Proceedings of the Convention*, various issues.
- United States Senate Committee on Education and Labor, 67th Congress, First Session, Hearings pursuant to S. Res. 80 "...to investigate the recent acts of violence in the coal fields of West Virginia...," Washington, 1921.
- United States Senate Committee on Interstate Commerce, 70th Congress, First Session, Hearings pursuant to S. Res. 105 "...to investigate conditions in the coal fields of Pennsylvania, West Virginia, and Ohio," Washington, 1928.
- United States Senate Subcommittee of the Committee on Mines and Mining, 72nd Congress, First Session, Hearings on S. 2935 "...a bill...to create a Bituminous Coal Commission...," Washington, 1932.
- West Virginia State Federation of Labor, *Proceedings of the Convention and Official Year Book*, various issues.

I developed this panel starting with Boal's (1990) dataset on mines in the early 1920s. I expanded the set of mines to include mines which did not change union status. I then collected data for earlier and later years as available. Hence attrition occurred both backward and forward in time. The dataset and a list of mine names are available by request.

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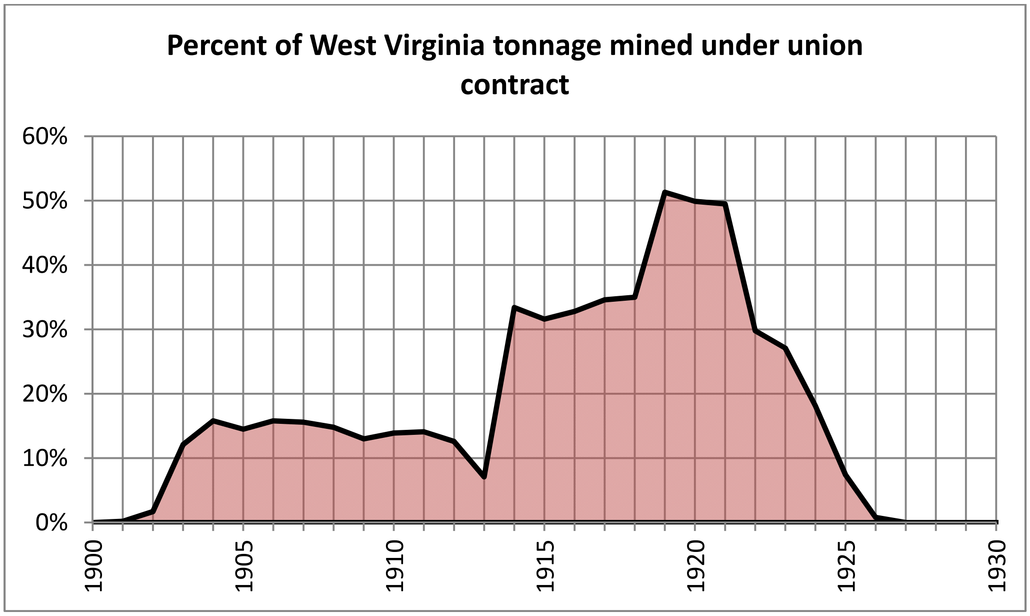
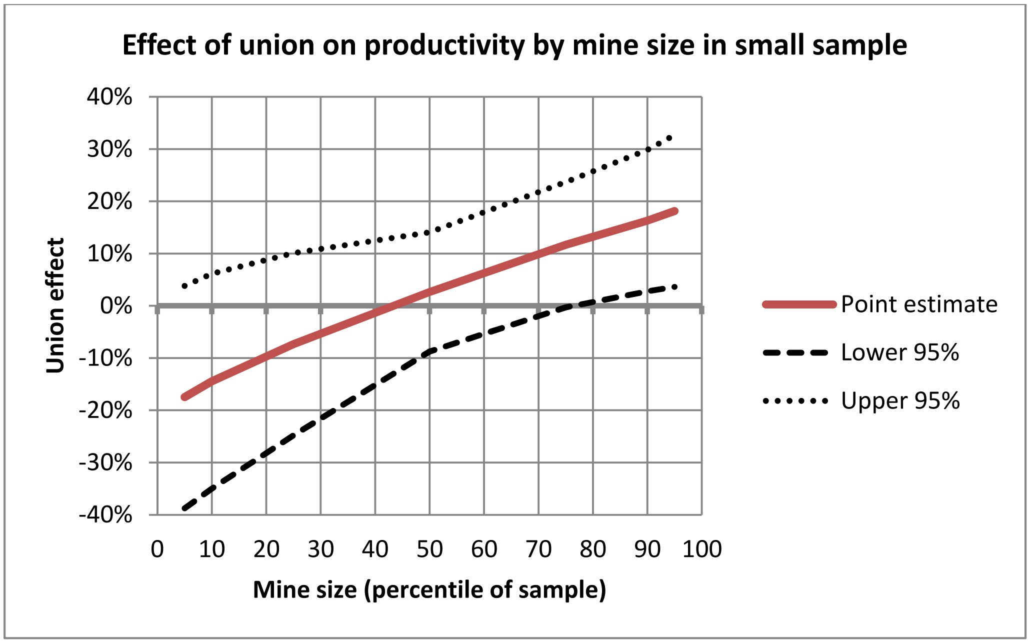
Figure 1.



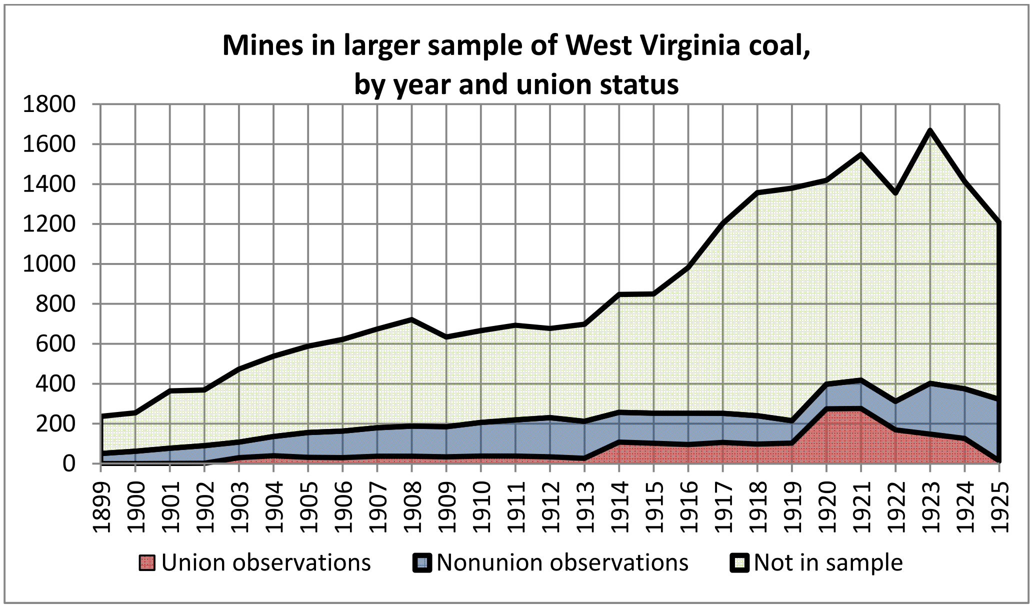
SOURCE: Boal (1994a).

Figure 2.



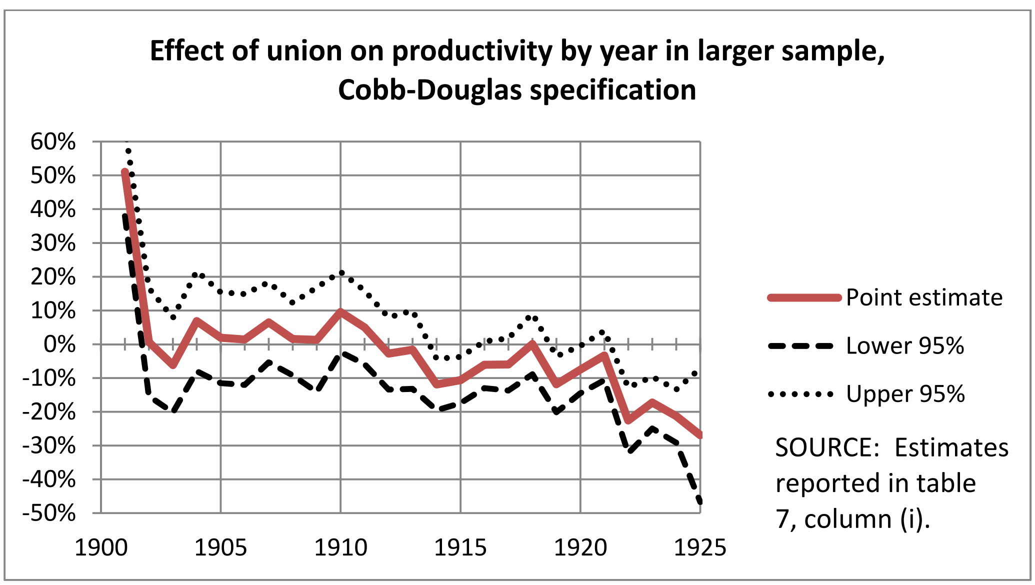
SOURCE: Computed from estimates in table 2 column (v).

Figure 3.



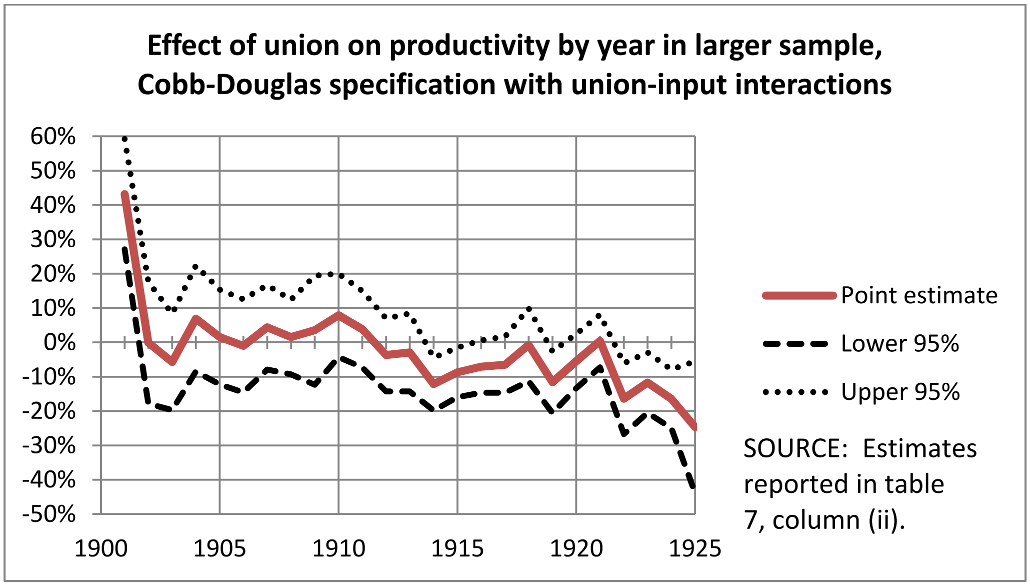
SOURCES: Union and nonunion observations: author's tabulations. Total observations: West Virginia Department of Mines, *Annual Report*.

Figure 4.



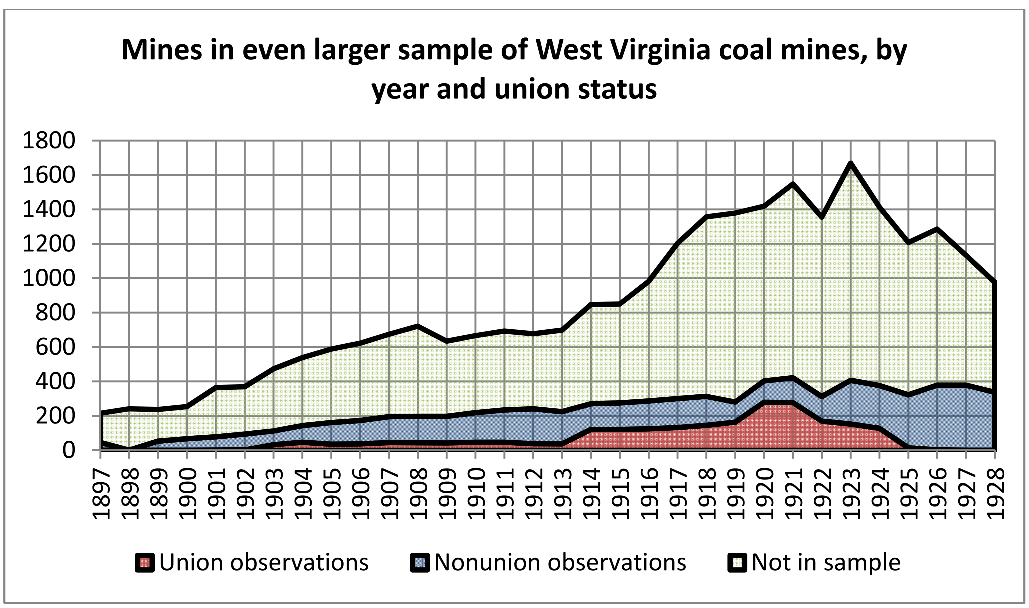
SOURCE: Estimates reported in table 5 column (v).

Figure 5.



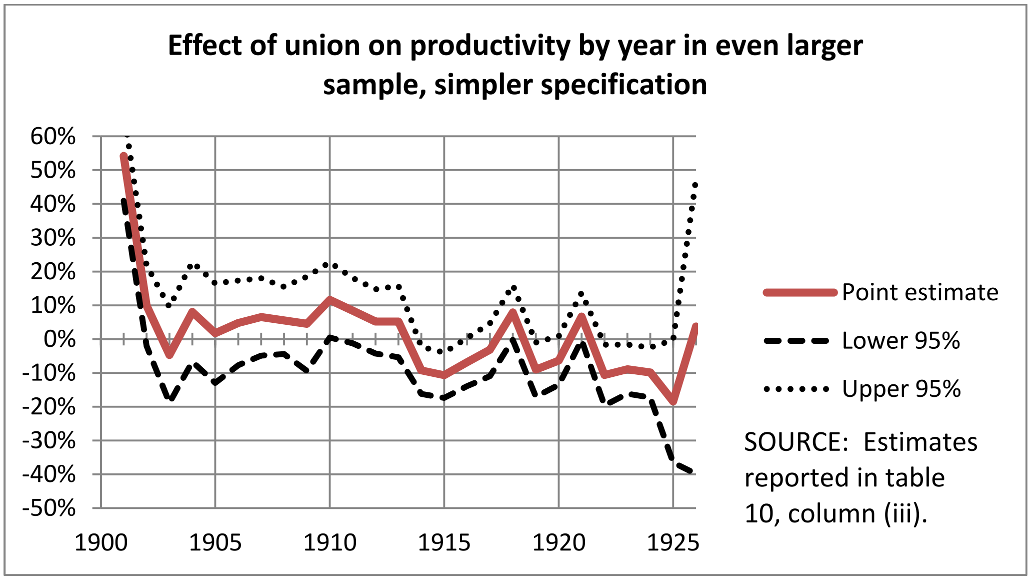
SOURCE: Estimates reported in table 5 column (vi).

Figure 6.



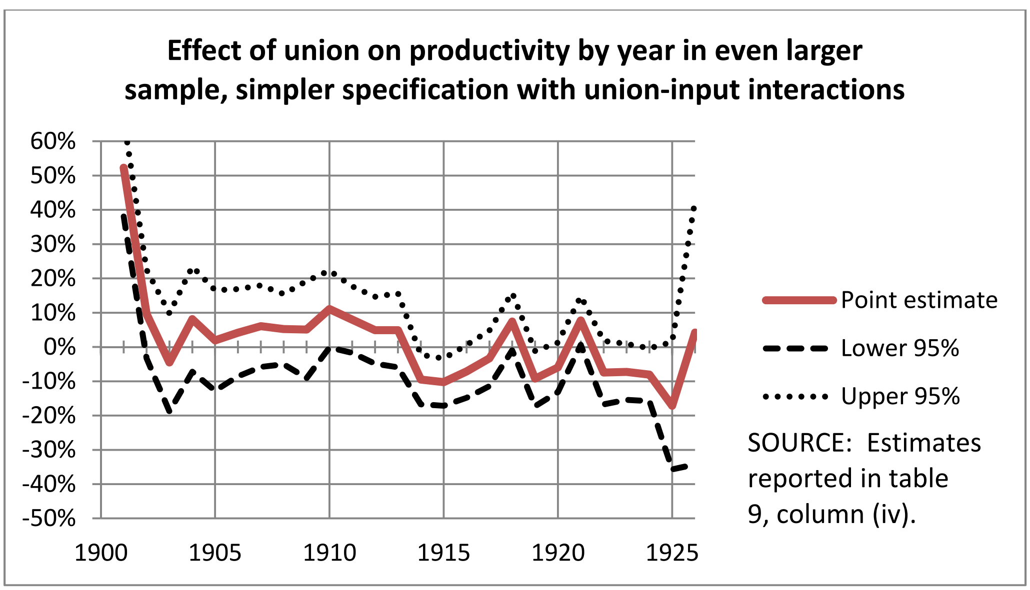
SOURCES: Union and nonunion observations: author's tabulations. Total observations: West Virginia Department of Mines, *Annual Report*.

Figure 7.



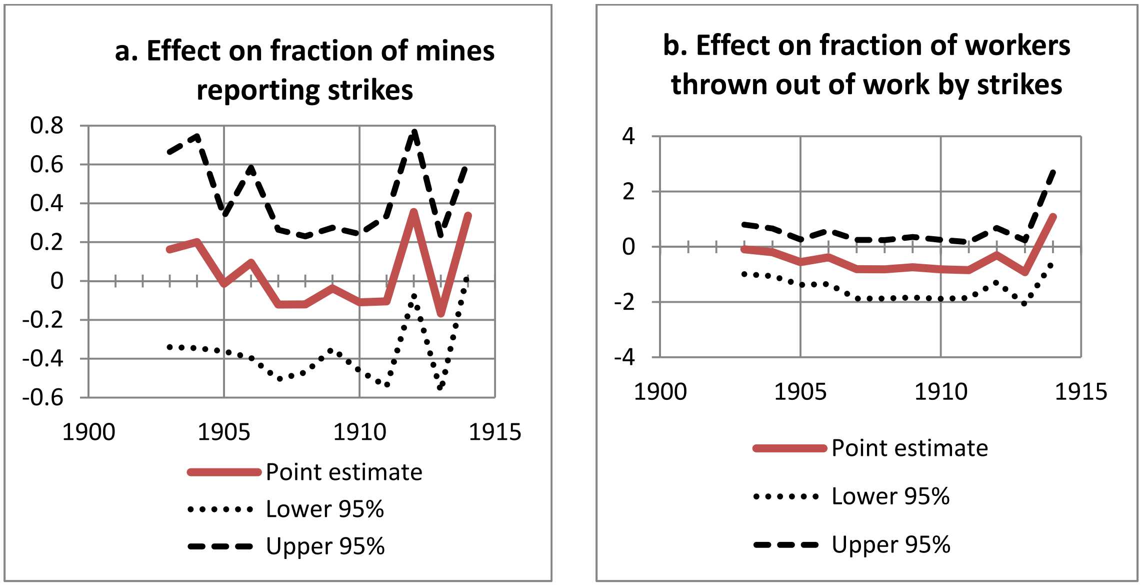
SOURCE: Estimates reported in table 9 column (iii).

Figure 8.



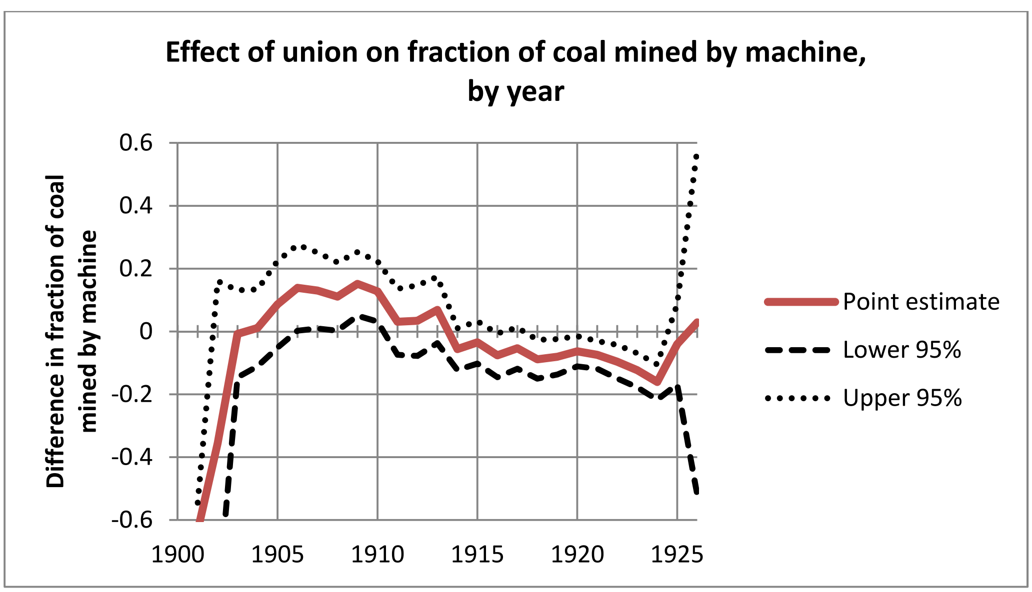
SOURCE: Estimates reported in table 9 column (iv).

Figure 9. Effect of union on strike activity



SOURCE: Author's estimates using county-level data. Unionism from Boal (1994a). Mines reporting strikes and workers thrown out of work by strikes from West Virginia Department of Mines.

Figure 10.



SOURCE: Author's estimates using "even larger" sample of 533 mines and 7489 observations.

Table 1: Descriptive statistics of small sample of West Virginia coal mines

	Mean	Std Dev	Min	Max
Coal output (net tons)	135196.7	116997.3	1191	614476
Miners	85.8	63.4	0	500
Other workers	81.7	65.3	4	365
Total workers	167.5	122.9	10	622
Mining machines	6.4	5.3	0	39
Mine locomotives	7.2	6.3	0	40
Horses and mules	9.4	11.1	0	58
Days of operation	173.7	66.6	4	311
Unionism	0.419	0.494	0	1

SOURCE: Unionism--author's tabulations. Other variables--
West Virginia Department of Mines, *Annual Report* , various issues.

Number of mine x year observations = 332.
Data are balanced: 83 mines over 4 years: 1920, 1923, 1924, 1925.
All mines changed union status exactly once, from union to nonunion.

Table 2: Estimates of Cobb-Douglas production function for small sample of West Virginia coal mines

	(i)	(ii)	(iii)	(iv)	(v)
Log (miners x days of operation)	0.2723 ***	0.2003 *	0.2981 ***	0.3176 ***	0.3292 ***
	(0.0729)	(0.0778)	(0.0602)	(0.0729)	(0.0613)
Log (other workers x days)	0.3850 ***	0.4150 ***	0.3244 ***	0.3548 ***	0.3267 ***
	(0.0831)	(0.0869)	(0.0749)	(0.0827)	(0.0731)
Log (mining machines x days)	0.0086	0.0515	0.0304	0.0308	0.0390
	(0.0210)	(0.0493)	(0.0481)	(0.0436)	(0.0638)
Log (mine locomotives x days)	0.0207	0.0222	0.0200	0.0953	0.0559
	(0.0157)	(0.0191)	(0.0183)	(0.0630)	(0.0555)
Log (horses and mules x days)	-0.0009	-0.0012	-0.00004	0.0379	0.01726
	(0.0071)	(0.0069)	(0.0064)	(0.0246)	(0.0223)
Log (days of operation)	-0.1889	0.0266	-0.6717 *	0.6402	0.2333
	(0.5172)	(0.4328)	(0.3360)	(0.4544)	(0.2638)
Square of log days	0.0348	0.0103	0.0898 **	0.0194	0.0645 *
	(0.0533)	(0.0444)	(0.0334)	(0.0484)	(0.0293)
Unionism (binary variable)	0.0383	-0.9346 ***	-7.8356 ***	0.0280	-7.1043 ***
	(0.0569)	(0.2435)	(1.2239)	(0.0569)	(1.2360)
Interactions with unionism:					
U x log (miners x days of operation)		0.1550	0.1518		0.1291
		(0.0976)	(0.0877)		(0.0926)
U x log (other workers x days)		-0.0178	0.0607		0.0547
		(0.1014)	(0.0932)		(0.0959)
U x log (mining machines x days)		-0.0387	-0.0341		-0.0397
		(0.0450)	(0.0429)		(0.0518)
U x log (mine locomotives x days)		-0.0033	-0.0111		0.0061
		(0.0281)	(0.0226)		(0.0602)
U x log (horses and mules x days)		-0.0016	-0.0063		-0.0075
		(0.0089)	(0.0090)		(0.0296)
U x log (days of operation)			2.9422 ***		2.8267 ***
			(0.5124)		(0.5186)
U x square of log days			-0.3367 ***		-0.3062 ***
			(0.0581)		(0.0585)

Number of mine x year observations = 332.
Data are balanced: 83 mines over 4 years: 1920, 1923, 1924, 1925.
Block standard errors (in parentheses), robust to both heteroskedasticity and serial correlation.
* indicates estimate is significantly different from zero at 5%.
** indicates estimate is significantly different from zero at 1%.
*** indicates estimate is signficantly different from zero at 0.1%.
All estimates computed using fixed effects for mines and years.
In columns (iv) and (v), input variables are NOT interacted with days of operation (see text).

Table 3: Effect of unionism on log output at various quantiles for small sample of West Virginia coal mines

	Estimate	Std error	P-value
Days of operation held constant at median (176.5)			
Inputs at their 5th percentiles	-0.1748	(0.1086)	[.108]
Inputs at their 10th percentiles	-0.1444	(0.1049)	[.169]
Inputs at their 25th percentiles	-0.0735	(0.0890)	[.409]
Inputs at their medians	0.0266	(0.0582)	[.648]
Inputs at their 75th percentiles	0.1169	(0.0612)	[.056]
Inputs at their 90th percentiles	0.1630	(0.0691)	[.018]
Inputs at their 95th percentiles	0.1815	(0.0741)	[.014]
Inputs held constant at their medians			
Days of operation at 5th percentile (67)	0.0701	(0.0781)	[.369]
Days of operation at 10th percentile (87)	0.1150	(0.0679)	[.090]
Days of operation at 25th percentile (126)	0.1069	(0.0561)	[.057]
Days of operation at median (176.5)	0.0266	(0.0582)	[.648]
Days of operation at 75th percentile (227)	-0.0788	(0.0754)	[.296]
Days of operation at 90th percentile (265)	-0.1628	(0.0925)	[.078]
Days of operation at 95th percentile (282)	-0.2007	(0.1006)	[.046]

Number of mine x year observations = 332.
Data are balanced: 83 mines over 4 years: 1920, 1923, 1924, 1925.
Block standard errors (in parentheses), robust to both heteroskedasticity and serial correlation.
Computed from estimates reported in column (v) of table 2.

Table 4: Descriptive statistics of larger sample of West Virginia coal mines

	Mean	Std Dev	Min	Max
Coal output (net tons)	133793.4	117734.4	319	1383285
Miners	72.9	56.9	0	912
Other workers	72.3	59.7	0	543
Total workers	145.2	107.8	1	1340
Mining machines	4.4	4.6	0	78
Mine locomotives	3.7	4.0	0	40
Horses and mules	11.5	11.6	0	99
Days of operation	202.0	64.5	4	365
Unionism	0.336	0.472	0	1

SOURCE: Unionism--author's tabulations. Other variables--
West Virginia Department of Mines, *Annual Report* , various issues.

Number of mine x year observations = 5960.
Data are unbalanced: 523 mines over 27 years (1899-1925).
Number of mines always observed as union = 107.
Number of mines always observed as nonunion = 189.
Number of mines which changed status = 227.
Number of transitions from nonunion to union = 147.
Number of transitions from union to nonunion = 177.

Table 5: Estimates of Cobb-Douglas production function for larger sample of West Virginia coal mines

	(i)		(ii)		(iii)		(iv)		(v)		(vi)	
Log (miners)	0.5422	***	0.4844	***	0.4774	***	0.4820	***	0.4906	***	0.4858	***
	(0.0273)		(0.0352)		(0.0415)		(0.0419)		(0.0353)		(0.0430)	
Log (other workers)	0.4065	***	0.3364	***	0.3319	***	0.3350	***	0.3329	***	0.3354	***
	(0.0239)		(0.0293)		(0.0343)		(0.0342)		(0.0294)		(0.0342)	
Log (mining machines)	0.0749	***	0.0552	***	0.0611	***	0.0598	***	0.0521	***	0.0566	***
	(0.0148)		(0.0151)		(0.0163)		(0.0161)		(0.0149)		(0.0160)	
Log (mine locomotives)	0.0369		0.1244	**	0.1413	**	0.1398	**	0.1199	***	0.1271	***
	(0.0190)		(0.0172)		(0.0195)		(0.0195)		(0.0169)		(0.0204)	
Log (horses and mules)	0.0209	*	0.0309	**	0.0372	**	0.03879	**	0.0333	**	0.0390	**
	(0.0094)		(0.0113)		(0.0121)		(0.0122)		(0.0109)		(0.0120)	
Log (days of operation)	1.9168	***	1.7129	***	1.7164	***	1.9511	***	1.6556	***	1.9207	***
	(0.2127)		(0.1951)		(0.1942)		(0.4794)		(0.1950)		(0.4825)	
Square of log days	-0.1276	***	-0.1013	***	-0.1018	***	-0.1309	**	-0.0969	***	-0.1274	**
	(0.0222)		(0.0203)		(0.0203)		(0.0483)		(0.0202)		(0.0487)	
First observation of this mine	-0.2172	***	-0.3163	***	-0.31738	***	-0.32132	***	-0.3272	***	-0.32699	***
(binary variable)	(0.0275)		(0.0273)		(0.0274)		0.02795		(0.0281)		(0.0285)	
Unionism (binary variable)	-0.1965	***	-0.0809	***	-0.1062		1.0274					
	(0.0245)		(0.0203)		(0.1019)		(1.2689)					
Interactions with unionism:												
U x log (miners)					0.0220		0.0052				0.0081	
					(0.0438)		(0.0438)				(0.0509)	
U x log (other workers)					0.0237		0.0096				0.00004	
					(0.0422)		(0.0417)				(0.0440)	
U x log (mining machines)					-0.0330		-0.0237				-0.0196	
					(0.0266)		(0.0267)				(0.0266)	
U x log (mine locomotives)					-0.0497	*	-0.0478				-0.0177	
					(0.0253)		(0.0247)				(0.0258)	
U x log (horses and mules)					-0.0187		-0.0189				-0.0181	
					(0.0174)		(0.0171)				(0.0174)	
U x log (days of operation)							-0.5921				-0.5503	
							(0.5127)				(0.5202)	
U x square of log days							0.0755				0.0675	
							(0.0518)				(0.0529)	
U x year effects	no		no		no		no		yes		yes	

Number of mine x year observations = 5960.
Data are unbalanced: 523 mines over 27 years (1899-1925).
Remaining columns estimated using fixed effects for mines and years.
Block standard errors (in parentheses), robust to both heteroskedasticity and serial correlation.
* indicates estimate is significantly different from zero at 5%.
** indicates estimate is significantly different from zero at 1%.
*** indicates estimate is signficantly different from zero at 0.1%.
All estimates computed using fixed effects years. Fixed effects for mines in all columns except (i).

Table 6: Effect of unionism on log output at various quantiles for larger sample of West Virginia coal mines

	Estimate	Std error	P-value
Days of operation held constant at median (210)			
Inputs at their 5th percentiles	0.0566	(0.0542)	[.297]
Inputs at their 10th percentiles	0.0622	(0.0566)	[.272]
Inputs at their 25th percentiles	-0.0158	(0.0279)	[.572]
Inputs at their medians	-0.0538	(0.0203)	[.008]
Inputs at their 75th percentiles	-0.0986	(0.0234)	[.000]
Inputs at their 90th percentiles	-0.1349	(0.0322)	[.000]
Inputs at their 95th percentiles	-0.1548	(0.0378)	[.000]
Inputs held constant at their medians			
Days of operation at 5th percentile (81)	-0.1899	(0.0413)	[.000]
Days of operation at 10th percentile (111)	-0.1600	(0.0317)	[.000]
Days of operation at 25th percentile (161)	-0.1055	(0.0238)	[.000]
Days of operation at median (210)	-0.0538	(0.0203)	[.008]
Days of operation at 75th percentile (250)	-0.0140	(0.0231)	[.544]
Days of operation at 90th percentile (281)	0.0152	(0.0284)	[.593]
Days of operation at 95th percentile (298)	0.0306	(0.0320)	[.339]

Number of mine x year observations = 5960.
Data are unbalanced: 523 mines over 27 years (1899-1925).
Block standard errors (in parentheses), robust to both heteroskedasticity and serial correlation.
Computed from estimates reported in column (iv) of table 5.

Table 7: Descriptive statistics of even larger sample of West Virginia coal mines

	Mean	Std Dev	Min	Max
Coal output (net tons)	145396.8	135931.1	137.5	1383285
Total workers	148.4	111.7	1	1340
Fraction of coal mined by machine	0.638	0.390	0	1
Days of operation	205.3	65.8	1	365
Unionism	0.304	0.460	0	1

SOURCE: Unionism--author's tabulations. Other variables--
West Virginia Department of Mines, *Annual Report* , various issues.

Number of mine x year observations = 7489.
Data are unbalanced: 533 mines over 31 years (1897, 1899-1928).
Number of mines always observed as union = 45.
Number of mines always observed as nonunion = 192
Number of mines which changed status = 296.
Number of transitions from nonunion to union = 186.
Number of transitions from union to nonunion = 267.

Table 8: Estimates of simpler production function for even larger sample of West Virginia coal mines

	(i)	(ii)	(iii)	(iv)
Log (total workers)	0.9845 ***	0.8970 ***	0.8989 ***	0.9017 ***
	(0.0136)	(0.0190)	(0.0189)	(0.0199)
Fraction of coal mined by machine	0.1092 ***	0.1370 ***	0.1286 ***	0.1343 ***
	(0.0251)	(0.0271)	(0.0271)	(0.0313)
Log (days of operation)	1.8822 ***	1.3072 ***	1.2841 ***	1.2194 *
	(0.0693)	(0.3130)	(0.3106)	(0.5553)
Square of log days	-0.1199 ***	-0.0556	-0.0537	-0.0485
	(0.0079)	(0.0334)	(0.0330)	(0.0576)
First observation of this mine (binary variable)	-0.26979 ***	-0.36194 ***	-0.3661 ***	-0.3659 ***
	(0.0314)	(0.0283)	(0.0287)	(0.0288)
Unionism (binary variable)	-0.1573 ***	-0.0292		
	(0.0224)	(0.0178)		
<u>*Interactions with unionism:*</u>				
U x log (total workers)				-0.0061
				(0.0189)
U x fraction of coal mined by machine				-0.0180
				(0.0387)
U x log (days of operation)				0.0784
				(0.5722)
U x square of log days				-0.0036
				(0.0594)
U x year effects	no	no	yes	yes

Number of mine x year observations = 7489.
Data are unbalanced: 533 mines over 31 years (1897, 1899-1928).
Block standard errors (in parentheses), robust to both heteroskedasticity and serial correlation.
* indicates estimate is significantly different from zero at 5%.
** indicates estimate is significantly different from zero at 1%.
*** indicates estimate is signficantly different from zero at 0.1%.
Column (i) estimated by ordinary least squares using fixed effects for years only.
Remaining columns estimated using fixed effects for mines and years.

Table 9: Comparative productivity of coal mines by union status

	Average productivity			Total factor productivity, Cobb-Douglas specification			Total factor productivity, simpler specification		
		Tons of coal output per worker per day			Estimated fixed effects (deviation)			Estimated fixed effects (deviation)	
	Number of obs.	Raw	% dev.	Number of mines	5(v)	5(vi)	Number of mines	8(iii)	8(iv)
Mines always observed as union	312	4.02	-16.3%	107	4.1%	2.9%	45	-16.6%	-16.4%
Mines changing status in sample	4495	4.77	-0.7%	227	-3.7%	-3.8%	296	-1.2%	-1.2%
Subtotal: mines ever unionized	4807	4.72	-1.7%	334	-1.2%	-1.7%	341	-3.2%	-3.2%
Mines never observed as union	2682	4.95	3.0%	189	2.2%	2.9%	192	5.7%	5.7%
Total: All mines in sample	7489	4.80	0.0%	523	0.0%	0.0%	533	0.0%	0.0%

SOURCE: Estimated fixed effects are from specifications reported in table 5, columns (v) and (vi), and from specifications reported in table 8, columns (iii) and (iv).