UNIONISM AND PRODUCTIVITY IN WEST VIRGINIA COAL MINING: A REPLICATION STUDY

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ABSTRACT: Boal's (1990) article "Unionism and Productivity in West Virginia Coal Mining" studied the effect of the United Mine Workers on coal mines in the early 1920s. Instead of simply inserting a binary variable for unionism, that article allowed unionism to alter all the parameters of the production function. It was shown that unionism lowered productivity at small coal mines, a result described as "economies of scale in labor relations." The 1990 article seemed credible because it measured inputs and outputs in physical terms and exploited a panel design. However, the standard errors were rather large, probably because the sample size was modest (332 observations). This paper replicates the 1990 article with a much larger panel of West Virginia coal mines (5960 observations). The earlier findings do not hold up. Overall, unionism lowered productivity by an average of 8 percent but there is no evidence of a particular negative effect at small mines.

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1. Introduction

Many studies beginning with Pencavel (1977) and Brown and Medoff (1978) have attempted to measure the effects of unionism on productivity by estimating production functions of the form

$$Q = f(L, K, U),$$

where Q denotes output, L denotes labor input, K denotes capital and other inputs, and U denotes unionism (Doucouliagos and Laroche 2003). One such article by Boal (1990) investigated U.S. coal mining in the early 1920s. It showed that the effect of unionism "cannot be reduced to a simple intercept shift" (p. 401), but that unionism lowered productivity at small coal mines, an effect ascribed to "economies of scale in labor relations" (p. 403). The estimates seemed credible because inputs and outputs were measured in physical terms, so they avoided confounding union effects on prices and wages with union effects on production technology, and the unit of observation was the establishment (mine), recommended features of any such study (Doucouliagos and Laroche 2003, pp. 671-672). Moreover, the estimates exploited a "difference-in-differences" panel design in which all mines changed union status though at different points in time. However, the standard errors were rather large, perhaps because the sample size was modest, so the statistical significance of some of the results was borderline.

This paper replicates Boal's (1990) article in hopes of more precise estimates. The same Cobb-Douglas and translog production functions are re-estimated on the original data, with minor improvements to the specification and the estimation method, and the earlier results of a negative union effect at small mines hold up. Then the same production functions are estimated on a much larger panel of coal mines from 1899 to 1925. In the large panel, the earlier results do *not* hold up—there is no longer evidence of a negative union effect on productivity at small mines.

The paper is organized as follows. The next section briefly reviews the history of unionism in West Virginia coal mining, showing why it is conducive to econometric analysis of unionism. The third section replicates Boal's (1990) estimates using his small panel. The fourth section replicates the estimates using a much larger panel. The fifth section concludes.

2. Unionism in West Virginia coal mining

West Virginia experienced waves of unionism in the early twentieth century, as shown in figure 1. Various coal fields were unionized in succession (Boal 1994). The United Mine Workers of America (UMWA) first gained a toehold in the Northern Panhandle field near Wheeling in 1902. The union won most of the Kanawha field near Charleston in 1903. After a long and bitter strike in 1912-1913, the union won the rest of the Kanawha field and the New River field, south of Charleston. In 1919, the union won the Fairmont field in northern West Virginia. During the years immediately following the First World War, the union enjoyed its maximum strength. Coal fields in northern and central West Virginia, producing about 50 percent of total tonnage, were all unionized. However, nonunion fields in the extreme southern part of the state were not.

In the 1920s, the union suffered a series of setbacks (see figure 1). In 1922, the union lost the New River field and most of the Kanawha field. In 1924, it lost the remainder of the Kanawha field and the Fairmont field. By 1927, no mines in West Virginia were operating under union contract and the state remained nonunion until the early 1930s. There were probably many reasons for the union's rapid decline, but two stand out. First, UMWA President John L. Lewis, under pressure from members in states where the UMWA was stronger, refused to allow West Virginia miners to concede a reduction in wages, despite falling coal prices and nonunion coal wages (Mooney 1967, pp. 127-128; Dubofsky and Van Tine 1977, pp. 134-147). Second, the legal position of the union was severely weakened by the U.S. Supreme Court's 1917 *Hitchman* decision, which allowed coal operators to seek broad injunctions against union organizing (Lunt 1979, pp. 37-59).

The rapid change in the UMWA's fortunes in West Virginia in the early twentieth century has attracted much historical research (e.g., Corbin 1981), but here as in Boal (1990) it is exploited for econometric purposes. It is easy to find mines in West Virginia that changed union status during this period, often more than once. Moreover, mines did not change union status simultaneously, as sometimes occurred in other states. So it is possible to measure the effect of the union while controlling for geological and other differences across mines (with mine effects) as well as technical change, government regulations, and other time-varying shocks (with year effects).

3. Replication of estimates with original small panel

Boal (1990) estimated the effect of unionism on productivity using a small panel of West Virginia coal mines in the early 1920s, exploiting the union's rapid decline in this period to estimate the effect of deunionization. This section replicates those results using the same data but a more current estimation method and a cleaner specification of the production function.

3.1 Data

Boal's (1990) panel followed 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 panel, 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 Fairmont fields, operated on a union basis until the last year of the sample. There were no missing values, so the panel 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 also measured in physical terms: miners (workers at the coal face), other workers (including machine operators, locomotive drivers, etc.), mining machines (used to undercut the coal before blasting), locomotives, and horses and mules. Days of operation were also taken from the *Annual Report*. Information on unionism was taken from many sources to construct a binary variable for unionism (see Boal 1990 appendix). This variable equals one when a mine operated under a formal contract with the United Mine Workers, and equals zero when a mine operated without such a contract. Descriptive statistics of the panel are shown in table 1. Note that 42 percent of the observations were unionized.

[Table 1 about here]

3.2 Replicating the estimates

Table 2 replicates the Cobb-Douglas production function estimates in Boal (1990). As in Boal's (1990) original specification, each input is multiplied by days of operation before taking logs, so the inputs are "miner-days," "other-worker-days," "machine-days," etc. Because zeros were occasionally observed for each input, one was added to "input-days" before taking logs, as in Boal (1990). Days of operation and its square are also included separately. The estimation method here is ordinary least squares, with fixed effects for mines and years, and robust standard errors clustered at the mine level. Boal (1990) actually used a different estimation method due to MaCurdy (1982) that is less popular today. He first-differenced the data and then applied seemingly-unrelated regressions to model serial correlation. Nevertheless, his estimates were quite similar to those reported in table 2.

[Table 2 about here]

Column (i) shows a production function with a simple union binary variable—a specification used by many studies of unionism and productivity. The sum of the input coefficients is about 0.686 (slightly larger than the 0.62 estimated by Boal 19990, p. 398), with a standard error of 0.076, indicating decreasing returns to scale. The estimated coefficient of unionism is small, positive, and smaller than its standard error. There is little evidence here of an effect of unionism on mine productivity on average.

Boal's (1990) article focused on the possibility that unionism might change many of the coefficients of the production function, not just the intercept. Column (ii) accordingly adds interactions of all of the input variables with unionism, giving the specification actually used by Boal. The union variable is now large, negative and statistically significant, but the total effect of unionism on productivity depends on the interactions as well. 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 0.0044 (similar to Boal 1990, p. 398). The sum of the interactions is 0.094 (slightly smaller than the 0.12 estimated by Boal 1990, p. 398), with a standard error of 0.031, indicating that the effect of unionism on productivity was positively related to mine size. Indeed, using this same Cobb-Douglas specification 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” (p. 394). However, that interpretation is somewhat ambiguous: a “large” mine in the specification of column (ii) has large values of “input-days,” but this could mean either many inputs (such as workers) or many days of operation. I eliminate this ambiguity below by tinkering with the specification, in two steps. First I allow unionism to interact with days of operation, and then I separate input levels from days of operation.

3.3 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, for some unknown reason. Column (iii) of table 2 relaxes this restriction to allow these two interactions. It turns out that the coefficients of these two interactions are strongly statistically significant. The union coefficient now becomes enormous, negative and significant, but again the total 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 0.051, confirming that the union effect on productivity is still positively correlated with “mine size” in the sense of large values for “input-days.” Thus, allowing unionism to interact with days of operation, while strongly justified by statistical tests, makes little difference to the key conclusion.

To disentangle union effects related to mine size from union effects related to days of operation, I change the specification to separate input levels from days of operation. Table 3 reports estimates where inputs are *not* multiplied by days of operation before taking logs.[1] Column (i) shows estimates of a Cobb-Douglas production function with a simple union binary variable. As in table 2 column (i), the estimated coefficient of unionism is small, positive, and smaller than its standard error.

[Table 3 about here]

Column (ii) 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 0.055, indicating again that the effect of unionism on productivity was positively related to mine size, even with days of operation held constant. To illustrate this result, following Boal (1990, table 4, p. 399), I computed the effect of unionism at different percentiles of the inputs, while holding days of operation constant at the sample median value. The results are plotted in figure 2, panel (a). With all inputs at their fifth percentiles (that is, very small mines) the union effect is negative 17 percent, but with all inputs at their ninety-fifth percentiles (that is, very big mines) the union effect is positive 18 percent.

[Figure 2 about here]

Boal (1990) also estimated a so-called "translog" production function, a more flexible functional form which includes squares and interactions of the log-input variables, and again

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1 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 here because one was added to each "input-days" before taking logs in table 2, and one was added to each "input" before taking logs in table 3. This was done, here and in Boal (1990), because the minimum value of most of the inputs was zero, as seen in table 1. Since *log (input-days + 1)* does not exactly equal *log(input + 1) + log(days),* the estimates of the input coefficients in columns (i) and (iii) of table 2 do not exactly equal the estimates in columns (i) and (ii) of table 3.

allowed all “input-days” regressors to interact with unionism. I estimated a similar translog function, with input variables *not* multiplied by days. In other words, my translog function was similar to table 3 column (ii) but with additional 20 second-order terms. The translog coefficient estimates are not reported here because they would take up too much space and because they are difficult to interpret individually. However, the additional coefficients are jointly significant, as in Boal (1990, table 3, p. 399).[2] Again following Boal (1990), I computed the effect of unionism at different percentiles of the inputs, while holding days of operation constant at the sample median. The translog results are plotted in figure 2, panel (b). With all inputs at their fifth percentiles (very small mines) the union effect is negative 31 percent, but with all inputs at their ninety-fifth percentiles (very big mines) the union effect is positive 10 percent.

Figure 2, as a whole, closely resembles figure 1 in Boal (1990, p. 400). The effect of unionism on productivity is negative for small mines, positive for large mines, and close to zero for mines near the median. For the Cobb-Douglas specification, the results are nearly symmetric: the negative effect at small mines is nearly equal but opposite in sign to the positive effect at large mines. For the translog specification, the negative effect at small mines is greater in magnitude than the positive effect at large mines. Here in figure 2, however, the union effects in the translog specification are never significant at five percent, in contrast to Boal (1990, table 4, p. 399). This might be because Boal (1990) used a feasible generalized least-squares estimation method, which can be more efficient, or because he used a less robust method for computing standard errors.

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[2] A joint test of the second-order terms that were not interacted with unionism gave $F(15,82) = 2.87$, $p = 0.001$. A joint test of the second-order terms that *were* interacted with unionism gave $F(15,82) = 2.37$, $p = 0.007$. A joint test of all of the above terms gave $F(30,82) = 8.47$, $p < 0.001$.

In summary, re-estimation of production functions from Boal (1990) with the same panel data, but a different estimation method and a cleaner specification, gives results similar to the earlier article. On average, unionism raised productivity by about 3 percent (according to the specification with the single binary union variable) but this estimate is not statistically significant. The coefficient estimates of the union interactions show that the union productivity effect is positively related to mine size, but the standard errors are somewhat large (see figure 2). So there is an indication that the union productivity effect was positively related to mine size but the evidence is not overwhelming. Definite conclusions are frustrated by imprecision of the estimates. In fact, very few of the coefficient estimates in table 2 or in columns (i) and (ii) of table 3 are statistically significant individually. Perhaps a larger panel might yield more definite conclusions.

4. Replication of estimates with a new large panel

This section reports production function estimates from a new panel, almost 18 times larger than Boal's (1990) panel, 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, taking advantage of the UMWA's waves of expansion in 1903, 1914, and 1919, as well as its decline in the early 1920s (see figure 1).

4.1 Data

The Department of Mines reported that the total 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.* Mine-level data on the five inputs used in Boal's (1990) earlier article 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, 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). (See Appendix A for details.)

[Figure 3 about here]

Unlike the small panel analyzed in the previous section, this large panel is not balanced. Missing values occur 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) 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 large panel covers 523 mines and 27 years, but missing values reduce the total size to 5960 observations.[3] Descriptive statistics given in table 4 show that these mines were slightly smaller than the mines in the small panel used above. They used fewer machines and locomotives, and more horses and mules, as might be expected because the large panel stretches further back in time. Overall, 34 percent of the observations were unionized.

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[3] Despite missing values, this sample is quite large compared to others in this literature. It is larger than all but two samples in the 77 studies analyzed by Doucouliagost and Laroche (2003, table 1, pp. 660-662).

[Table 4 about here]

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 large panel, 227 mines changed union status, many of them more than once: there are 147 transitions from nonunion to union status, and 177 transitions from union to nonunion status.[4] This large panel also includes 107 mines that were always observed as union and 189 mines that were always observed as nonunion. Mines not changing union status are still useful because they help estimate the production function parameters.

4.2 Estimates

Table 3 columns (iii) and (iv) show estimates of a Cobb-Douglas production function specification almost identical to that in columns (i) and (ii), but now estimated on this large panel. Columns (iii) and (iv) include one new variable not used in Boal (1990) or in columns (i) and (ii). Because this large panel stretches over a longer period, the first observation of each mine in many cases represents a new mine in initial development. New mines had lower productivity because narrow entries and haulage ways (rather than wide rooms) were being driven to open the mine.[5] 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.

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[4] Transitions were often mediated by missing observations, for reasons given above.

[5] Piece rates were correspondingly higher for miners working entries or haulage ways than for miners working rooms (Fisher and Bezanson 1932, p. 37).

Compare column (iii) in table 3 with column (i), the specifications with a simple binary variable for unionism. In column (iii), all estimated input coefficients have much smaller standard errors and are now statistically different from zero at the one percent level—in this respect, the large panel delivers greater precision, as hoped. Some other differences are apparent. The sum of the five input coefficients in column (iii) is now 1.031 (with standard error 0.027) so production is now characterized by approximately 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 now about *negative* 0.081 and is about four times its standard error, indicating that unionism appears to lower productivity by an average of 8 percent.[6]

Compare column (iv) in table 3 with column (ii), the specifications where all regressors are interacted with unionism. Again, all estimated input coefficients now have much smaller standard errors. The coefficients of the input interactions are mostly small and individually statistically insignificant, but a joint test of the null hypothesis that all seven are zero gives a p-value of less than 0.001.

Is there any evidence of a union productivity effect related to mine size in column (iv)? The sum of the union-input interactions now is *negative* 0.076 with a standard error of 0.030, indicating that, if anything, the effect of unionism on productivity was *negatively* related to mine size. I again computed the effect of unionism at different percentiles of the inputs, while holding days of operation constant at the sample median value. The results are plotted in figure 4, panel

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[6] There is some evidence the union effect varied over time. When I interacted the union variable with the year fixed effects, the resulting coefficients were slightly positive or close to zero through 1913, after which they became increasingly negative.

(a). The effect of unionism is estimated more precisely here than with the small panel (compare figure 2), but the union effect is closer to zero and slightly negatively related to mine size.

[Figure 4 about here]

I also estimated a translog function on the large panel, with all regressors interacted with unionism. To save space, the translog coefficient estimates are not reported here, but the additional coefficients are jointly significant.[7] Again I computed the effect of unionism at different percentiles of the inputs, while holding days of operation constant at the sample median. The results are plotted in figure 4, panel (b). That figure shows some evidence of a *positive* union effect on productivity at small mines—exactly the opposite of Boal's (1990, table 4, p. 399) conclusion—but the effect is not statistically significant. The union effect at the twenty-fifth percentile and above is almost exactly zero, and fairly precisely estimated. The two panels of figure 4 resemble each other in their slight downward slope, but they bear no resemblance to figure 2 nor to Boal's figure 1 (1990, p. 400). Boal's (1990) conjecture of "economies of scale in labor relations" certainly does not hold up in this large panel.

[Figure 5 about here]

In summary, re-estimation of production functions on a large panel has attained its goal of increased precision. Input coefficients and point predictions are both more precise. However, the conclusions from the small sample are now reversed. In the large sample, unionism *lowered* productivity by an average of 8 percent (according to the specification with the single binary union variable), but there is little evidence of a union productivity effect related to mine size. If anything, the union effect seems *negatively* related to mine size.

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[7] A joint test of the second-order terms that were not interacted with unionism gave $F(15,522) = 14.25$, $p < 0.001$. A joint test of the second-order terms that *were* interacted with unionism gave $F(15,522) = 1.50$, $p = 0.100$. A joint test of all of the above terms gave $F(30,522) = 8.89$, $p < 0.001$.

5. Conclusions

In this study, I replicate Boal's (1990) estimates of the effect of unionism on productivity using his same panel of West Virginia coal mines in the early 1920s, and then re-estimate the same production functions in a large panel covering many more mines and running from 1899 through 1925. Both panels measure output in physical terms, focus on a single industry at a low level of aggregation, and feature many establishments (mines) changing union status but not all simultaneously, so they would seem to promise credible estimates.

Re-estimation of Boal's (1990) production functions using his original panel data set, with minor improvements to the specification and estimation method, yields quite similar conclusions. A negative effect of unionism on productivity at small mines is found again, along with a possible positive effect at large mines, though neither effect is statistically significant.

Estimation of the same production functions using the large panel produces more precise estimates, as hoped, but quite different conclusions. The estimated effect of unionism on productivity is actually *positive* at small mines. If anything, the union effect is *negatively* related to mine size. There is no evidence in the large panel of "economies of scale in labor relations." In view of the large standard errors for the small-panel estimates, perhaps Boal's (1990) results were driven by sampling variation.

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Appendix A: Data sources for large panel

The large panel data set was assembled to measure the influence of the United Mine Workers on various aspects of West Virginia coal mining in the early twentieth century. The union status of as many West Virginia mines for as many years as possible was determined by collecting references to mines in various sources: union and operator documents, periodicals, Congressional hearings, books, etc. For this study, a mine was defined as unionized in a particular year if sources indicated that it was covered by a signed contract with the UMWA. Mines operating under informal agreements, contracts with company unions, or contracts with the Fuel Administration during the First World War were counted as nonunion. Thus the measure of unionism is coverage, not membership.

In any given year, the union status could be determined for only about one-quarter of West Virginia mines. Sometimes the union status of a particular mine could be determined for some years and not others. Observations were dropped from the analysis if union status could not be determined with certainty or if union status changed in the middle of the year.

For those mines whose union status could be identified, other data were then collected from the *Annual Report* of the West Virginia Department of Mines. Coal output, miners, other workers, mining machines, locomotives, horses and mules, and days of operation are given by the *Annual Report* at the mine level from 1899 through 1925. The data are reported for fiscal years ending June 30 through 1924, and for calendar years in 1925. Coal output is reported by the *Annual Report* in long tons (2240 lbs.) through 1923 and in net tons (2000 lbs.) thereafter, so I converted the earlier years to net tons.

Construction of a long panel was hindered by the fact that the *Annual Report* used no permanent identifiers for mines in this period. Sometimes a mine could not be confidently matched across successive Annual Reports, most likely because the mine did not operate in all periods but perhaps because its name changed. The data set, sources for union status, and a list of mine names are available by request.

Table 1. Descriptive statistics of small panel of West Virginia coal mines

Variable	Mean	Std Dev	Min	Median	Max
Coal output (net tons)	135196.7	116997.3	1191	102548.8	614476
Miners	85.8	63.4	0	70.0	500
Other workers	81.7	65.3	4	63.0	365
Total workers	167.5	122.9	10	138.5	622
Mining machines	6.4	5.3	0	5.0	39
Mine locomotives	7.2	6.3	0	5.0	40
Horses and mules	9.4	11.1	0	6.0	58
Days of operation	173.7	66.6	4	176.5	311
Unionism	0.419	0.494	0	0.0	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 production function with original specification

	(i)		(ii)		(iii)	
Log (miners × days of operation)	0.2723	***	0.2003	*	0.2981	***
	(0.0746)		(0.0802)		(0.0623)	
Log (other workers × days)	0.3850	***	0.4150	***	0.3244	***
	(0.0850)		(0.0896)		(0.0775)	
Log (mining machines × days)	0.0086		0.0515		0.0304	
	(0.0215)		(0.0508)		(0.0498)	
Log (mine locomotives × days)	0.0207		0.0222		0.0200	
	(0.0160)		(0.0197)		(0.0190)	
Log (horses and mules × days)	-0.0009		-0.0012		0.0000	
	(0.0072)		(0.0071)		(0.0066)	
Log (days of operation)	-0.1889		0.0266		-0.6717	
	(0.5292)		(0.4463)		(0.3477)	
Log (days of operation), squared	0.0348		0.0103		0.0898	**
	(0.0545)		(0.0458)		(0.0345)	
Mine unionized (binary variable)	0.0383		-0.9346	***	-7.8356	***
	(0.0582)		(0.2512)		(1.2663)	
<u>*Interactions with unionism:*</u>		-				
U × log (miners days of operation)			0.1550		0.1518	
			(0.1007)		(0.0907)	
U × log (other workers × days)			-0.0178		0.0607	
			(0.1045)		(0.0965)	
U × log (mining machines × days)			-0.0387		-0.0341	
			(0.0464)		(0.0444)	
U × log (mine locomotives × days)			-0.0033		-0.0111	
			(0.0290)		(0.0234)	
U × log (horses and mules × days)			-0.0016		-0.0063	
			(0.0091)		(0.0093)	

U × log (days of operation)	2.9422 (0.5302)	***
U × log (days of operation), squared	-0.3367 (0.0601)	***

Small panel with 83 mines and 332 observations. Mine and year effects included. Cluster-robust standard errors in parentheses. * indicates estimate is significantly different from zero at 5%. ** indicates estimate is significantly different from zero at 1%. *** indicates estimate is significantly different from zero at 0.1%.

Table 3. Estimates of production function, inputs not multiplied by days

	(i)		(ii)		(iii)		(iv)	
Panel data set	Small		Small		Large		Large	
Number of mines	83		83		523		523	
Number of observations	332		332		5960		5960	
Log (miners)	0.3176	***	0.3292	***	0.4844	***	0.4820	***
	(0.0746)		(0.0634)		(0.0354)		(0.0421)	
Log (other workers)	0.3548	***	0.3267	***	0.3364	***	0.3350	***
	(0.0847)		(0.0756)		(0.0294)		(0.0343)	
Log (mining machines)	0.0308		0.0390		0.0552	***	0.0598	***
	(0.0446)		(0.0660)		(0.0151)		(0.0162)	
Log (mine locomotives)	0.0953		0.0559		0.1244	**	0.1398	**
	(0.0645)		(0.0574)		(0.0172)		(0.0195)	
Log (horses and mules)	0.0379		0.01726		0.0309	**	0.0388	**
	(0.0251)		(0.0230)		(0.0113)		(0.0122)	
Log (days of operation)	0.6402		0.2333		1.7129	***	1.9511	***
	(0.4649)		(0.2730)		(0.1959)		(0.4815)	
Log (days of operation), squared	0.0194		0.0645	*	-0.1013	***	-0.1309	**
	(0.0495)		(0.0303)		(0.0204)		(0.0485)	
First observation of each mine (binary variable)					-0.3163	***	-0.3213	***
					(0.0274)		(0.0281)	
Mine unionized (binary variable)	0.0280		-7.1043	***	-0.0809	***	1.0274	
	(0.0583)		(1.2788)		(0.0204)		(1.2746)	
Interactions with unionism:		-		-		-		
U × log (miners)			0.1291				0.0052	
			(0.0958)				(0.0440)	
U × log (other workers)			0.0547				0.0096	
			(0.0992)				(0.0419)	
U × log (mining machines)			-0.0397				-0.0237	
			(0.0535)				(0.0269)	

U × log (mine locomotives)	0.0061 (0.0623)		-0.0478 (0.0248)
U × log (horses and mules)	-0.0075 (0.0307)		-0.0189 (0.0172)
U × log (days of operation)	2.8267 (0.5366)	***	-0.5921 (0.5150)
U × log (days of operation), squared	-0.3062 (0.0605)	***	0.0755 (0.0520)

Mine and year effects included. Cluster-robust standard errors in parentheses. * indicates estimate is significantly different from zero at 5%. ** indicates estimate is significantly different from zero at 1%. *** indicates estimate is significantly different from zero at 0.1%.

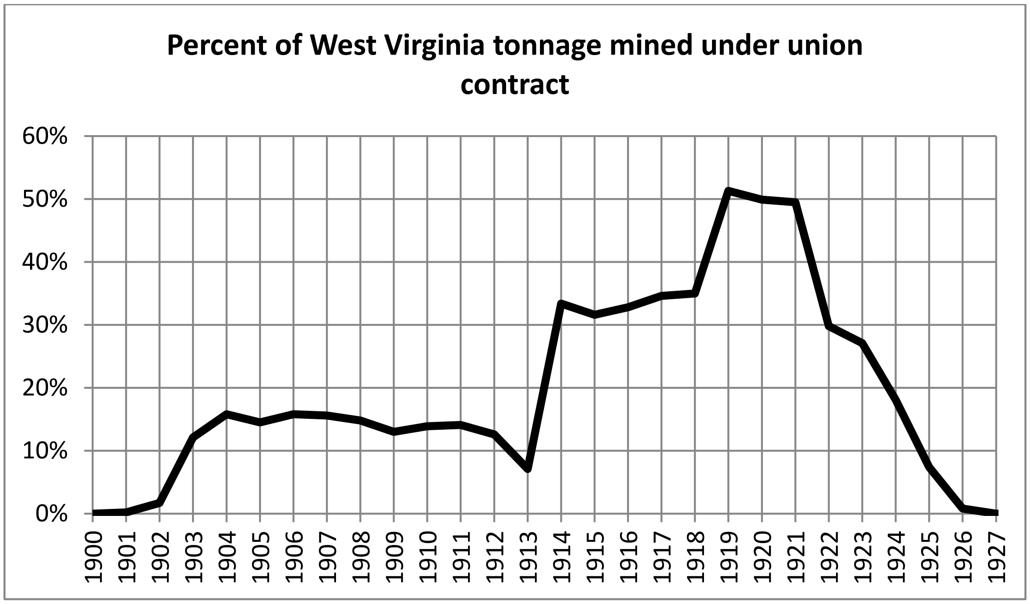
Table 4. Descriptive statistics of large panel of West Virginia coal mines

Variable	Mean	Std Dev	Min	Median	Max
Coal output (net tons)	135850.5	119296.1	324.8	101615.9	1383285
Miners	72.9	56.9	0	60.0	912
Other workers	72.3	59.7	0	54.0	543
Total workers	145.2	107.8	1	116.0	1340
Mining machines	4.4	4.6	0	4.0	78
Mine locomotives	3.7	4.0	0	2.0	40
Horses and mules	11.5	11.6	0	8.0	99
Days of operation	202.0	64.5	4	210.0	365
Unionism	0.336	0.472	0	0.0	1

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

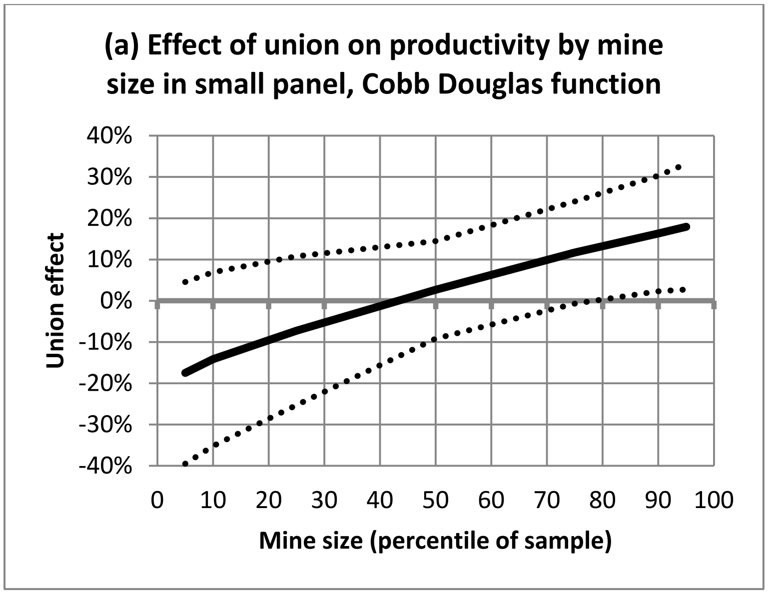
Number of mine x year observations = 5960. Data are unbalanced: 523 mines over 27 years: 1899-1925.

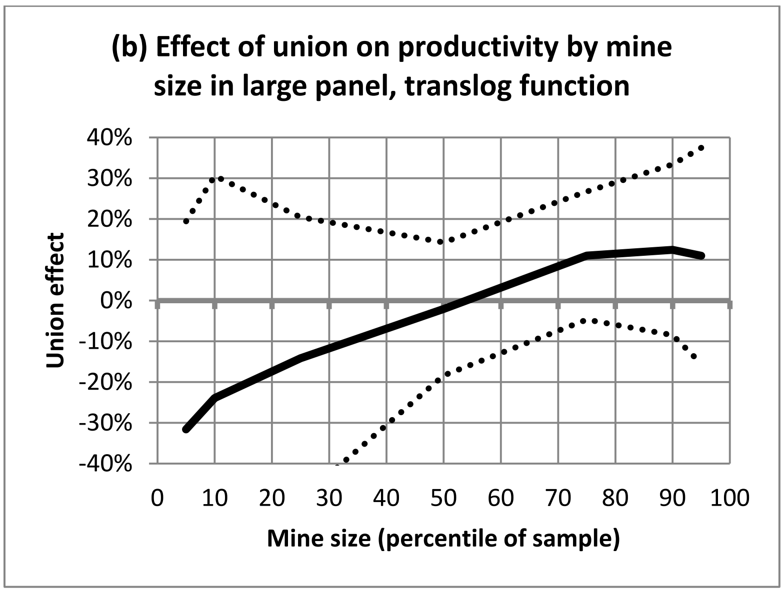
Figure 1.



SOURCE: Boal (1994).

Figure 2.

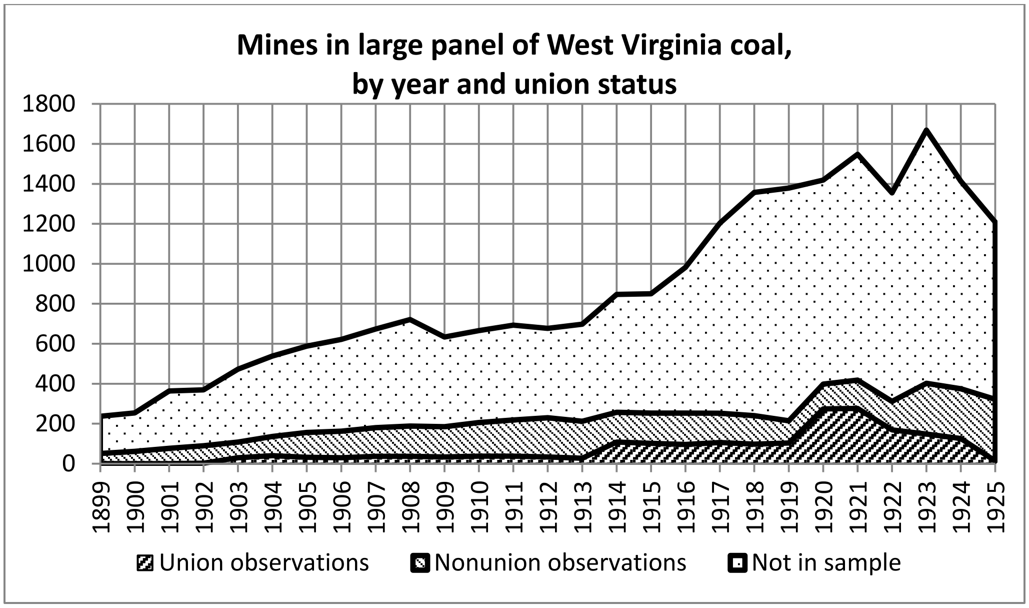




Union effect is measured as difference in logarithms. Dotted lines delimit 95% confidence intervals.

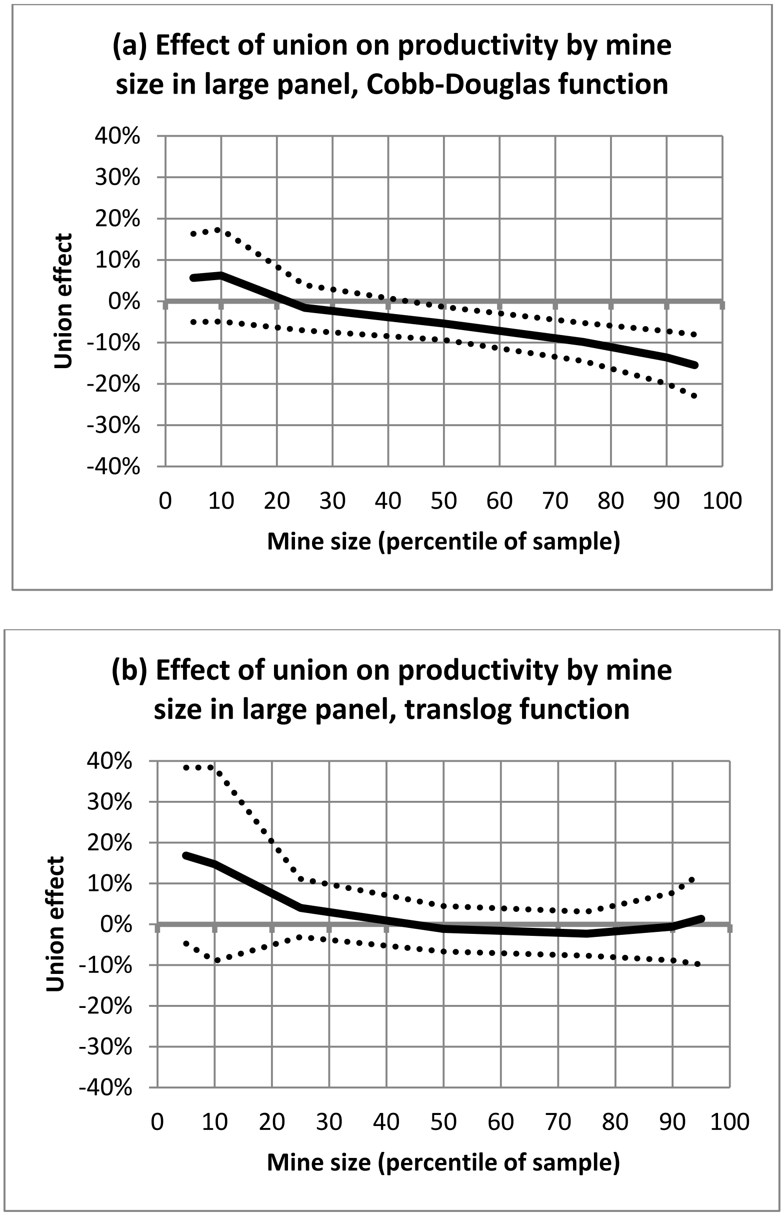
SOURCE: Panel (a) computed from estimates reported in table 3 column (ii). Panel (b) computed from translog estimates described in text.

Figure 3.



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

Figure 4.



Union effect is measured as difference in logarithms. Dotted lines delimit 95% confidence intervals.

SOURCE: Panel (a) computed from estimates reported in table 3 column (iv). Panel (b) computed from translog estimates described in text.