WORK INTENSITY AND WORKER SAFETY IN EARLY TWENTIETH-CENTURY COAL MINING

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ABSTRACT: Coal mining was a dangerous industry in the early twentieth century, averaging over three fatalities per thousand workers per year in the United States. Contemporary observers often blamed miners for neglecting safety in their haste to load coal, for which they were paid on piece. Motivated by these observations, this paper estimates the relationship between the speed or intensity of work at the coal face and small-scale mine accidents, the cause of most coal fatalities, using a panel of over 400 coal mines in West Virginia. The elasticity of expected fatalities with respect to work intensity is about one-half. Since coal miners were paid on piece, per ton of coal, this implies a marginal cost of a statistical life to miners of about $400 thousand in 1921 dollars. This likely exceeded the value of a statistical life, so preventing accidents was expensive for miners. However, the union managed to shift the relationship in a favorable direction, reducing fatalities substantially with only small effects on work intensity.

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No one intentionally "produces" industrial accidents. Work injuries are accepted as undesirable "bad" by-products in order to obtain larger outputs of soda pop, bituminous coal, and econometrics textbooks.

—Walter Oi (1973, p. 42)

1. Introduction

In the early twentieth century, the problem of accidents in coal mining was widely debated. Yet the problem was seemingly intractable as high fatality rates persisted with little downward trend (see figure 1).[1] Policy changes such as increasing state inspection and regulation seemed to have little effect on accident rates (Fishback 1986). Legal changes such as raising employer liability, culminating in Workmen's Compensation systems, had little effect either (Fishback 1987) despite high hopes (USCC 1925, Vol 3, pp. 1666-1680).

The coal industry was also notable for its extensive use of piece rates until the late 'thirties (Dix 1988). A recent literature (Bender, Green, and Heywood 2012; Bender and Theodossiou 2014; Artz and Heywood 2015; Freeman and Kleiner 2005, pp. 324-325) has shown that piece rates tend to increase injuries in a wide variety of industries. The presumed mechanism is that piece rates encourage greater speed or intensity of work, which in turn leads to more injuries. Piece rates were essentially universal in early coal mining, so it is not possible to measure the effect of their introduction. However, work intensity (output per worker per day) is observed in both physical and value terms at the establishment (mine) level, so the tradeoff between work intensity and worker safety can in principle be measured directly.

This paper analyzes a panel of several hundred coal mines in West Virginia, a state with relatively high fatality rates per coal worker. Motivated by contemporary observations on accident prevention, it estimates the relationship between the intensity of work at the coal face and small-scale mine accidents, the cause of most coal fatalities. The paper asks three questions. First, do the data show a tradeoff between work intensity and worker safety at the mine level? Second, if the rate of tradeoff can be measured precisely, can it help explain why high fatality rates were such an intractable problem? Third, what role (if any) did the union play in shifting or tilting the work intensity-worker safety frontier or in moving along that frontier?

2. How safety was produced in coal mining

In the early twentieth century in the United States, almost all coal was mined underground by the room-and-pillar method. Most mine workers were "miners" in the narrow sense: workers who cut into the coal face using either pick or mining machine, drilled holes above the undercutting, set off explosives in

[1] By contrast, there was little awareness of lung disease. "There is no positive evidence that bituminous miners are subject to special occupational diseases. In other words, if accidents could be reduced the average bituminous miner would live the normal life span." (USCC 1925, Vol. 3, p. 1655).

these holes to loosen coal from the face, and shoveled the broken coal into mine cars to be hauled out of the mine. These workers worked independently and were paid on piece—per ton of coal loaded—because of the extreme difficulties of supervision underground (Archbald 1922, pp. 39-45; Goodrich 1925). Additional workers drove locomotives or horses to haul the mine cars out, did maintenance work, and picked out impurities as the coal was loaded into railway cars for shipment. These workers were paid per day.

Thousands of coal workers were killed on the job every year in this period. The fatality rate per worker was higher in West Virginia than in the U.S. as a whole, as shown in figure 1. Both series show a dip in the early 'twenties, when a sharp recession was followed by national strikes, but otherwise show little trend. Figure 2 shows that the fatality rate per ton of coal was about the same in West Virginia as in the U.S. as a whole—if one excludes large mine disasters in 1908, 1914, 1915, and 1925—because the greater hazards in West Virginia were offset by higher productivity. Both series show a slight downward trend, reflecting productivity gains over time.

Coal mining was notorious for large-scale disasters that killed many workers simultaneously. From 1897 to 1928 (the period to be analyzed below) 60 such disasters occurred in West Virginia, where "disaster" is defined as five or more miners killed in a single event. Almost all mine disasters were explosions.[2] Coal mine explosions occurred when methane or coal dust was ignited by electrical equipment, miners' lamps, or misplaced explosives intended to loosen the coal from the face.

Thanks to research by the U.S. Bureau of Mines and others, a fair amount was known about how to manage mines to reduce the risk of explosions (Wieck 1942, pp. 79-91; Bloch 1931, pp. 273-275). Accumulation of methane could be prevented by installing and carefully maintaining a thorough and effective ventilation system and by inspecting frequently for gases in the mine. Coal dust could be controlled by wetting down the mine and its flammability could be reduced by sprinkling rock dust. Careful regulation of electricity, use of safety lamps, and use of safer explosives for shooting coal could limit sources of ignition. Two points should be recognized about these preventative measures. First, prevention of explosions was costly. It was accomplished by purchasing special equipment such as fans and safer explosives, and by hiring additional day workers for such tasks like constructing airflow partitions, sprinkling water or rock dust, and testing for gases. Second, measures that reduced the risk of explosions were workplace public goods, creating benefits for all workers in the mine simultaneously. Thus mine management made the key decisions on preventing explosions, the mine owner bore the cost, but all workers in the mine enjoyed the benefits of preventive measures.

Yet explosions accounted for a small minority of mine fatalities, as shown in table 1. Instead, most fatalities occurred in small-scale accidents. The most common cause of coal mine fatalities, in both West Virginia and the United States as a whole, was falls of roof material. Together with falls of coal from the face, roof falls caused about half of fatalities. Such falls typically killed only one or two workers

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[2] Of these 60 West Virginia disasters, two were mine fires, one was a haulage accident, one was a suffocation due to ventilation failure, one was a falling cage in a mine shaft, and all the rest were explosions—see list posted at www.wvminesafety.org/disaster.htm . The overwhelming majority of mine disasters in other states were also explosions—see list posted at www.cdc.gov/niosh/mining/statistics/content/coaldisasters.html .

at a time, but they were tragically frequent. The second most common cause of fatalities was haulage accidents—mine cars and locomotives—which accounted for about 20 percent of fatalities.

Prevention of small-scale accidents was quite different from prevention of explosions. By all accounts, the daily actions of individual miners were critical. In particular, roof falls could be avoided by diligently shoring up the roof material with timbers, by taking down any loose rock in the roof, and by abandoning work areas where the roof seemed weak (West Virginia Department of Mines, hereafter WVDM, 1915, p. 14; Archbald 1922, pp. 49-50; Goodrich 1925, pp. 26-28). Time studies by the West Virginia Coal and Coke Company in 1911 and 1912 showed that the average miner spent about nine percent of his time unloading and setting timbers and taking down dangerous roof material (Goodrich 1925, p. 28). Haulage accidents could be prevented if miners stayed off haulage ways, and walked to their workplaces instead of riding in mine cars. Of course, such safety measures took miners' time away from loading coal and thus reduced output and earnings, since miners were paid on piece. So miners faced a constant tradeoff between safety and earnings. As one observer put it:

> The miner naturally looks to his own self-preservation, but he considers also his wages, and when a tonnage or contract worker puts in an extra timber or takes an extra safety precaution he cuts down his earning power. Therefore he is likely to take perilous chances, and if he often takes them successfully his practice becomes a habit.[3]

Another observer noted:

> When there is loose coal along the face, ready to be loaded there is a temptation for a miner to take a chance and load the coal rather than pull down a slab of loose rock above him. The foreman must watch out for that. If the miner pulls down the rock it will fall on the coal which is ready for loading and he will have extra work afterward cleaning the rock out of it. If he does not, he may get hurt. So he will often take a chance on his life and will shovel away under dangerous roof. When all the coal is loaded and the bottom is clean, then he will pull it down. The coal is in the way, too, for standing a prop that would hold up the slab. He will get no pay for taking down nor for cleaning his coal afterward. With the coal loaded he can attend to the roof more easily and not hurt his earnings, though he himself may get hurt in the meantime.[4]

Observers disagreed on who was "responsible" for small-scale accidents. Some criticized miners' apparent negligence:

> In looking over the accidents reported, it has been found that many are due to the carelessness of the injured and, strange as it may seem, quite a number of those injured are old and experienced men. They seem to take greater risks and continue to do so, notwithstanding the

[3] USCC 1925, Vol 3, p. 1683. See also Archbald (1922, pp. 29, 49-50), Brophy (1964, p. 40), Graebner (1976, pp. 116-117), and Dix (1977, pp. 73, 102).
[4] Archbald (1922, p. 49).

> object lessons that are given them when other men are injured or killed under similar conditions.[5]

Others noted that mine managers were also under pressure to produce as much coal as possible (USCC 1925, Vol. 3, p. 1773; Graebner 1976, p. 96) and criticized mine management's lax supervision of safety:

> Strict discipline, vigorously enforced by the mine officials would reduce the number of accidents from these causes at least one half.[6]

Regardless of "responsibility," two points are clear. First, prevention of small-scale accidents was costly, but in a different way from preventing explosions. Prevention of small-scale accidents was accomplished with the time and effort of miners at the coal face. Second, activities that reduced the risk of small-scale accidents were largely private goods—the primary beneficiaries were the miners who worked more slowly and carefully, but who paid for their greater safety with lower earnings.[7] To my knowledge, no one has yet tried to measure how much miners in this era paid for greater safety.

To what extent did government regulation constrain the safety decisions of miners and mine managers? All government safety regulation of coal mines during this period occurred at the state level. Although the U.S. Bureau of Mines conducted research on mine safety from its inception in 1910, it did not enjoy inspection powers until 1941 nor enforcement powers until 1952 (NRC 1982, p. 53). In any case, the Bureau focused most of its research on the prevention of explosions (USCC 1925 pp. 1670-1673). Whether state regulation was effective is disputed by scholars. Using a state-level panel, Fishback (1986) studied 13 coal mine safety regulations, but found most of them "ineffectual." However, Boal (2009, 2016), analyzing a similar panel with a different econometric specification, found that each regulation on average reduced fatalities by about 5 percent. It should be noted that most safety regulations were aimed at preventing explosions (see Fishback 1986, table 2, p. 284-285). Graebner (1976, pp. 73-77) argued that West Virginia's coal mine safety regulations were the weakest of the major coal mining states, but acknowledged that some "long overdue" improvements were passed in 1907 and 1915.[8] He also argued that enforcement in West Virginia was weaker than in other states (Graebner 1976, pp. 87-94). Changes in legal liability for workplace accidents, culminating in Workmen's Compensation laws, put more responsibility on employers for preventing accidents, but if anything seemed to increase accident rates in coal mining (Fishback 1987; Fishback and Kantor 2000). So it appears that government regulation probably did not constrain miners' safety decisions much.

To what extent did the United Mine Workers union constrain safety decisions? There is little evidence of the union's impact in the formal record. Union contracts in this period said almost nothing about safety (Boal 2009; Graebner 1976, p. 131). Where safety was mentioned in contracts, responsibility was placed on individual miners to maintain safe workplaces, even in states like Illinois where the union was

[5] WVDM (1915, p. 14); same text appears in previous issues. See also Illinois Bureau of Labor Statistics (1883, p. 90).
[6] WVDM (1915, p. 13); same text appears in previous issues. See also Graebner (1976, pp. 112-116).
[7] Fishback (1986, p. 289) also makes this point.
[8] Features of the 1907 law are summarized in WVDM (1907, pp. xii-xvii).

very strong (Bloch 1931, p. 397).[9] Suffern's (1926, pp. 242-245, 255, 264) tabulations show that only a tiny fraction of formal grievance arbitration cases were related to "mine conditions" (most cases were related to pay). According to Graebner (1976, p. 133), "miners were more likely to employ the grievance mechanism to secure the reinstatement of workers dismissed for safety violations than to protest an unsafe condition." Informally, however, the union may have protected workers who refused to work in unsafe places (Mitchell 1908, p. 189; Goodrich 1925, pp. 74-75) and may have encouraged individual workers to take greater care (Goodrich 1925, pp. 86-89; Graebner 1976, pp. 134-135).

3. Modeling the tradeoff between output and safety

The idea of a tradeoff between ordinary output and worker safety goes back at least to seminal papers by Oi (1973, 1974) and by Thaler and Rosen (1976), which proposed that safety and ordinary output be viewed as joint outputs of a firm. Following Thaler and Rosen (1976, pp. 280-281), suppose a firm's joint production frontier can be represented by $F(L,K,x,f)=0$, where L denotes labor input, K denotes other inputs, x denotes ordinary output, and f denotes expected fatalities. The partial derivatives of F with respect to x and f are assumed to have opposite signs: holding inputs constant, more output x can be produced only with more expected fatalities f. Thaler and Rosen did not attempt to estimate the joint production frontier $F(L,K,x,f)=0$ directly. Instead, they developed a model of market equilibrium, assuming that each firm chooses a wage and an expected fatality rate $p=f/L$ and each worker chooses a job based on employer-set wages w and fatality rates p. Competitive equilibrium then creates an upward-sloping locus $w(p)$ of wages and fatality rates in the labor market: dangerous jobs enjoy compensating wage differentials. Thaler and Rosen then estimated the market locus $w(p)$ using data on wages and fatality rates across occupations.

A large literature has followed, estimating compensating differentials in various labor markets. In this literature, the market "value of a statistical life" (VSL) is defined as the change in earnings (across jobs) divided by the change in probability of death for an individual worker. Most studies using recent U.S. data estimate VSL to be much greater than the present discounted value of expected foregone lifetime earnings for a typical worker (Viscusi and Aldy 2003, p. 18). A few studies have estimated compensating differentials using data from the late nineteenth and early twentieth centuries, including Fishback (1992) for coal miners, Kim and Fishback (1993) for railroad workers, and Fishback and Kantor (1992, 1995) for a variety of occupations and industries. These studies mostly find VSLs less than or roughly equal to foregone lifetime earnings.

A smaller literature has tried to estimate Thaler and Rosen's joint production frontier $F(L,K,x,f)=0$ directly, without assuming any labor market equilibrium. Studies in this literature have typically estimated the effect of output (or equivalently productivity since inputs L and K are held constant) on fatalities (or equivalently on the fatality rate since labor input is held constant). Often nonfatal injuries have been studied instead of fatalities, which are infrequent in micro data.

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[9] The United Mine Workers focused more attention on safety after World War II (Derickson 1993) and especially after 1970 (NRC 1982, pp. 74-75; Connerton 1978 pp. 115-117).

This smaller literature features a number of studies of coal mining. Early studies analyzed time series of aggregate annual data. The earliest quantitative study of which I am aware is by Kuczynski (1943, pp. 205-215), who analyzed aggregate annual U.S. data on employment and fatality rates from 1890 to 1939. Using informal methods, Kuczynski found a negative short-run relationship between changes in employment and changes in fatality rates beginning in 1919. He conjectured that the negative relationship was due to increased productivity (or as he termed it, "intensity of work," p. 214) during downturns in employment, but he did not measure productivity directly. Andrews and Christenson (1974) and Wallace (1987) applied more formal methods, estimating time series regressions on aggregate U.S. data from the mid-twentieth century. Andrews and Christenson found negative relationships between nonfatal injury rates and productivity, contrary to the canonical model of Oi (1973, 1974) and Thaler and Rosen (1976), while Wallace found a positive relationship between fatalities and productivity. However, neither study included time trends, so the productivity variable may have captured long-run technical change rather than the short-run production function. In any case, the use of national aggregate data seems less than ideal for estimating what is essentially a firm-level relationship in Thaler and Rosen's formulation. If different mines choose different levels of intensity of work in any given year, with different consequences for accidents, then aggregate data may not provide useful information.

Later studies avoided these issues by analyzing cross sectional data at the mine level. Connerton, Freeman, and Medoff (1979) analyzed cross-sections of U.S. coal mines in 1965, 1970, and 1975. They regressed productivity on accident rates, unionism, and a variety of controls. Although they had more than 400 mines in each sample, the estimated coefficients of accident rates varied in sign and were not measured precisely. Appleton and Baker (1984) regressed accident rates on productivity and other variables in a cross-section of 213 Kentucky and Virginia coal mines in 1979. They found negative effects of productivity on accident rates, contrary to the canonical model, but with large standard errors. Other studies compared injury rates and productivity across size categories of mines. The National Research Council (1982, pp. 79, 137) (hereafter NRC), Hopkins and Palser (1987), and Grayson (2001) all found a negative relationship between injury rates and productivity. However, Hopkins and Palser (1987) recognized that the relationship was probably not causal: "Again, the explanation lies in the fact that both accident rates and productivity are a function of geological conditions" (p. 33). The NRC was more equivocal, but admitted in a footnote that any "cause-effect tradeoff" would be "better addressed by a longitudinal analysis, where changes in productivity over time for a given mine are correlated to corresponding changes in injury rates and mine characteristics" (p. 98).

A few recent studies have followed the NRC's advice and analyzed longitudinal data. Connerton (1978) analyzed a panel of U.S. coal-mining counties from 1965 to 1971. In contrast to the cross-sectional studies, Connerton found positive effects of productivity on fatalities and on disabling injuries, though only the latter was statistically significant (pp. 152-155). Sider (1983) analyzed a small panel of 26 coal mines in the 'seventies. Regressing productivity on accidents unlike most studies, Sider found that the effect of minor accidents was positive while the effect of serious accidents was large and negative, but neither coefficient was statistically significant, perhaps because the sample was small. Asfaw, Mark, and Pana-Cryan (2013) (hereafter AMP) applied count-data regression to a large panel of 1407 U.S. coal mines from 1992 to 2008. They estimated a negative-binomial model with random effects for mines. The dependent variable was the number of injuries and the key regressor was a value measure of productivity—real revenue per hour worked. The estimated elasticity of injuries with respect to productivity was about negative 0.1 for all definitions of injuries (AMP 2013, tables 3-4, pp. 782-783).

AMP's estimation methods and sample size are similar to those used below in this paper, but several differences should be noted. First, AMP included random effects to control for "unobservable mine heterogeneity" related to "mine-specific geological conditions and management practices" (AMP p. 779) However, random-effects estimators are inconsistent if observed regressors are correlated with unobserved mine effects (Cameron and Trivedi 2013, p. 365). It seems quite likely that productivity is correlated with "mine-specific geological conditions and management practices," so the analysis below will use fixed effects instead. Second, AMP defined total hours worked as an "exposure" variable, effectively constraining the elasticity of injuries with respect to total workers (and hours per worker) to equal one (AMP p. 780). Put simply, AMP assumed in their statistical analysis that injuries are proportional to mine size, *ceteris paribus*. However, AMP elsewhere acknowledged that "larger mines tend to have higher labor productivity … and to employ a higher percentage of their workforce in support operations rather than in more hazardous production operations at the coal face" (AMP p. 784; see also NRC 1982, p. 78). Thus a mine that grows in size might experience both an increase in productivity and a decrease in injuries per worker, but this relationship is not necessarily causal. A falsely negative effect of productivity on injuries might therefore be found if injuries are constrained to be proportional to mine size. The analysis below will not constrain the elasticity of injuries with respect to workers. Third, AMP did not include controls for technical change, despite evident falling injury rates and rising productivity over time (AMP p. 781). The analysis below will include year fixed effects to control for technical change. Fourth, AMP computed standard errors without allowing for serial correlation within mines, so their standard errors were likely too small.[10] The analysis below will compute standard errors clustered at the mine level.

Some studies cited above analyze fatalities and others analyze injuries. Which data are preferable? It is tempting to use injury data, because fatalities are infrequent in micro data and thus require a very large sample to measure anything. However, several authors have recognized that reporting standards for injuries vary over time and across coal mines in recent years (NRC 1982, pp. 77, 86). Reporting standards also seem to differ with respect to union status (NRC 1982, p. 95; Morantz 2013, pp. 90-92). Injury data from the early twentieth century are probably even less reliable. The U.S. Coal Commission (hereafter USCC) refused to include injury data in its massive *Report* because "there is no uniformity among the States in reporting such accidents" (USCC 1925, vol. 3, p. 1659). The USCC noted that passage of state Workmen's Compensation laws encouraged reporting of minor injuries (p. 1775), eliminating uniformity over time as well. Therefore, fatality data seem preferable for analysis, provided a large sample can be obtained.

[10] Cameron and Trivedi (2010, p. 635) advise that "the importance of using cluster-robust standard errors [in panel data] cannot be overemphasized."

Regardless of data issues, injuries matter, of course. They were surely frequent in coal mining and were probably closely correlated with fatalities. Absent useable injury data, the fatality rate should perhaps be interpreted as an index of all job hazards including nonfatal injuries. This same interpretation applies to much of the literature on compensating wage differentials, where injury risk is often excluded from wage regressions due to collinearity with fatality risk (Viscusi and Aldy 2003, pp. 15, 30).

Like the studies cited above, this paper seeks to estimate the relationship between productivity, or "work intensity," and fatalities, but with some differences. Unlike some prior studies, the goal here is not merely to describe the data, but to estimate Thaler and Rosen's (1976) joint production frontier. Moreover, in view of the prevalence of piece rates and the lack of supervision in early twentieth-century coal mining, the expected fatality rate $p=f/L$ is assumed here to be chosen by workers, not by firms as in Thaler and Rosen (1976). The shape of the joint production frontier therefore shows the tradeoff faced by individual coal miners between daily output (and thus earnings) and safety in the early twentieth century.

4. Panel of West Virginia coal mines

The relationship between work intensity and worker safety will be analyzed using a large panel of West Virginia coal mines from 1897 to 1928. This data set was originally assembled to study the effect of the United Mine Workers on coal mining, so only mines whose union status could be ascertained are included. As a result, the panel includes only about a third of coal mines operating in West Virginia, but since West Virginia had a very large number of mines during most of this period, the sample is still reasonably large. For all mines whose union status could be ascertained, additional data were obtained from the *Annual Report* of the West Virginia Department of Mines, including coal output, total workers employed, fraction of coal mined by machine (that is, undercut by machines instead of picks), days of operation, and fatalities. All these variables are available at the mine level in *Annual Reports* for 1897 and for 1899 through 1928 (see Appendix A for details).

The panel is unbalanced for three reasons. First, occasionally a datum was omitted from the *Annual Report*. Second, 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 the name of the mine changed. Third, sometimes a mine's union status could not be determined with certainty in a particular year, or a mine changed union status in the middle of the year. As is well known, errors in longitudinal data can cause attenuation bias in estimates (Freeman 1984; Lewis 1986; Card 1996) so erring on the side of caution, such observations were dropped from the panel.

Descriptive statistics of the panel are shown in table 2. The panel includes 521 mines for a maximum of 31 years, though gaps just described reduce the sample size to 7474 observations. Note that inputs and outputs are measured in physical terms. Note also that days of operation averaged only 205, much less than in other industries but typical of coal mining (Fishback 1992, p. 20). Overall, 30 percent of the observations are unionized.

The fatality data are of central interest. Table 2 shows that most mine-year observations experienced zero fatalities, but the maximum number was enormous.[11] Table 3 shows that this extreme skewness was due to a small number (32) of mine disasters in the data—that is, incidents in which five or more workers were killed simultaneously. Tables 2 and 3 show that small-scale accidents, measured by "non-disaster fatalities," were much more frequent and much less skewed than disaster fatalities, with a maximum of only eight. As noted above, disasters were mostly explosions while small-scale accidents were mostly falls of material. Figure 3 shows that disaster fatalities contribute substantial variability to total fatalities over time, as might be expected.

An important limitation of these data is the unit of observation: mine-years. If safety decisions were made by individual coal miners as they worked, as observers believed, it might be more informative to analyze data at the level of the individual coal miner and at higher frequencies—perhaps workweeks or shifts, as is typical in the industrial medicine literature (Dembe et al. 2005; Vegso et al. 2007). Unfortunately, such data are not available for coal mining in this era, to my knowledge. Another limitation is that hours of work per day were not recorded at the mine level, so one cannot be sure that increases in work intensity truly reflect increases in the pace of work rather than increases in the length of the workday.[12] Notwithstanding these data issues, the following analysis will assume that the mine-level data represent the behavior of individual miners and that observed changes in work intensity reflect changes in the pace of work.

5. Estimating the tradeoff

The purpose of this section is to estimate how much individual miners paid, on the margin, for greater safety by working more slowly. In the framework of Thaler and Rosen (1976), this section will estimate the joint production frontier $F(L,K,x,f)=0$, where L denotes labor input, K denotes other inputs, x denotes ordinary output, and f denotes expected fatalities. The analysis below will focus on *non-disaster fatalities* for three reasons. First, the inputs for preventing non-disaster fatalities (that is, coal miners' time) are observed in the available data, whereas the inputs for preventing disasters (that is, ventilating systems, rock dusting, etc.) are not observed. Second, non-disaster fatalities were arguably mostly under direct control of those at risk: individual coal miners (see section 2 above). Third, non-disaster fatalities were numerically more important than disaster fatalities.

Several specification questions must be answered before proceeding. First, how should the production frontier $F(L,K,x,f)=0$ be normalized? Absent convenient instruments, the dependent variable should be the variable with the greatest measurement error. Recall that f in the joint production frontier denotes

[11] The maximum number of lives lost (197) occurred in a huge explosion at Monongah No. 8 mine in Marion County on December 6, 1907. The explosion spread to Monongah No. 6 mine, to which No. 8 was connected underground, causing 163 more deaths. Viewed as a single event, the Monongah No. 6 and 8 explosions were the worst disaster in U.S. coal mining history.

[12] If individual miners controlled the length of their workday, the distinction would be irrelevant. There is evidence that miners did have some control (U.S. Bureau of Labor Statistics 1919; Archbald 1922, p. 63; Goodrich 1925, p. 60; USCC 1925, pp. 1944-1946).

expected non-disaster fatalities, of which observed fatalities are a noisy measure. So the dependent variable should be observed non-disaster fatalities, denoted f′. The equation to be estimated is thus f′ = f(L,K,x) + e, where f(L,K,x) denotes conditional expected fatalities and e denotes a random variable with mean zero.

Second, what stochastic data-generating process should be assumed? Since observed fatalities are a non-negative integer, it is natural to assume a count regression model. For panel data, the usual specifications are Poisson and NB1. Poisson regression is more robust because it is still consistent provided only the conditional mean is correctly specified (Cameron and Trivedi 2013) so it will be used.

Third, how should the conditional mean f(L,K,x) be specified? As the purpose is to model the relationship between expected fatality rates and work intensity, the following initial specification is proposed:

$$f(L,K,x) = \exp[\, \beta_1 \ln(\text{work intensity}) + \beta_2 \ln(\text{number of workers})$$

$$+ \beta_3 \ln(\text{days of operation}) + \text{controls}\,],$$

where "work intensity" is defined as coal output per worker per day. Following convention, the exponential function is used to ensure a positive conditional mean, which implies that the β coefficients are elasticities. The coefficient β_1 is the elasticity of expected fatalities with respect to work intensity, *ceteris paribus*. Because the number of workers and the days of operation appear as regressors, β_1 may also be interpreted as the elasticity of the fatality *rate* (per worker per day) with respect to work intensity. The coefficient of *ln(number of workers)*, β_2, is the elasticity of expected fatalities with respect to mine size. If β_2 is less than one, then the fatality *rate* decreases with mine size, as some studies described above have suggested. The coefficient of *ln(days of operation)*, β_3, is also an elasticity and is surely positive. If β_3 is less than one, the fatality *rate* decreases as a mine operates more continuously, as some contemporary sources suggested.[13] Controls include the fraction of output mined by machine (a measure of K), fixed effects for mines (controlling for geological conditions), and fixed effects for years (controlling for technical change and changes in state regulation).

Poisson estimates of the work intensity-worker safety frontier are shown table 4.[14] Column (1) shows estimates for the initial specification. In that column, the elasticities of expected nondisaster fatalities with respect to mine size and days of operation are plausible in magnitude and fairly precisely estimated. Both are statistically significantly greater than zero but less than one, showing that mines that are larger or that operate more continuously have lower fatality rates, *ceteris paribus*. The fraction of output mined by machine has a positive effect on fatalities, implying that if machine mining replaces pick mining, expected fatalities are estimated to increase by about 6 percent, but the standard error is larger than the estimated coefficient.

[13] The USCC asserted, "The mine that operates only two days a week almost invariably has a bad accident experience" (USCC 1925, Vol. 3, p. 1773), implying an elasticity less than one.

[14] The number of mines and number of observations are fewer than shown in tables 2 and 3 because mines with only one observation or with no fatalities in any observation contribute nothing to the conditional likelihood function and are therefore automatically dropped in estimation.

The most important coefficient here is the elasticity with respect to work intensity (β_1), which is estimated to be positive 0.52 with a 95 percent confidence interval of (0.37, 0.68). Thus a 10 percent increase in output per worker per day is predicted to cause a 5.2 percent increase in expected non-disaster fatalities.

Remaining columns in table 4 demonstrate that estimates of the elasticity with respect to work intensity are fairly robust to changes in the initial specification. Column (2) shows estimates when a square term in *ln(days of operation)* is included. That square term is statistically significant, but the elasticity with respect to work intensity is hardly changed. Column (3) adds more square terms, but their coefficients are small in magnitude and statistically insignificant. Column (4) adds a binary variable for the first observation of each mine, which proved significant in Boal (forthcoming), but its coefficient is insignificant here. In columns (2), (3) and (4), the elasticity with respect to days of operation is allowed to vary, but it lies between zero and one if days of operation are between 20 and 365. Across the four columns, the estimated elasticity with respect to work intensity (β_1) varies between 0.52 and 0.55.[15]

This estimated elasticity with respect to work intensity may be used to compute the cost of safety in terms of lost output as follows. First, note that, holding constant the number of workers and the number of days of operation, β_1 is the elasticity of expected fatalities with respect to coal output:

$$\beta_1 = \frac{d\,f}{d\,x} \times \frac{x}{f} ,$$

where x denotes tons of coal output. The “marginal output cost of a statistical life” (MOCSL) is therefore given by the following formula:

$$MOCSL = \frac{d\,x}{d\,f} = \frac{1}{\beta_1} \times \frac{x}{f} .$$

Next, to get a sense of magnitudes, consider some back-of-the-envelope calculations. The estimated elasticity β_1 is roughly one half, so the estimated MOCSL is about twice the tonnage per fatality (x/f). Total statewide output per non-disaster fatality in West Virginia averaged roughly 200,000 tons during the sample period, with some increase over time. Therefore the marginal output cost of a statistical life was roughly 400,000 tons of coal in this period.

What was the value of this marginal lost output? Multiplying by the price of coal gives the marginal *dollar* cost of a statistical life:

$$MCSL = \frac{1}{\beta_1} \times \frac{x_t}{f_t} \times P_t .$$

Output prices from 1900 to 1916 in West Virginia averaged a little less than $1 per ton, so in current dollars, the marginal dollar cost of a statistical life was a little less than $400,000.

[15] In the specification of column (3), the elasticity varies with the level of work intensity, but the elasticity is less than 0.55 if work intensity is less than 5 tons per worker per day. At the sample median work intensity, the elasticity is 0.548 with standard error 0.079.

Who paid for this lost output? Miners, because they were paid on piece, and coal operators necessarily split the cost. The average wage paid pick miners in West Virginia was just below $0.50 per ton from 1900 to 1916, so miners and operators split the dollar cost of lost output roughly evenly during this period.[16] (In the late 'teens and 'twenties, wages and especially prices were more volatile so this conclusion no longer holds.)

Now let us make a more precise calculation for a particular year using the above formula for MCSL. In 1921, tonnage per non-disaster fatality was about 261 thousand for the entire state. The average wage paid pick miners in West Virigina was $0.95 per ton, so insert this value for P_t. Finally, insert 0.5526, the estimate of β_1 from table 4 column (2). The marginal dollar cost of a statistical life to miners comes to about $450 thousand. Now, according to Fishback (1992, table 6-7, p. 93) median annual earnings of full time tonnage workers in West Virginia in 1921 were about $1400,[17] so for any reasonable estimate of working lifespan, MCSL is several times higher than the lifetime earnings of a coal miner. To compute the marginal cost of a statistical life to coal operators, insert the selling price of coal minus the pick miner's wage per ton for P_t. The average selling price of coal in 1921 was $4.65 (much higher than earlier or later years) so the marginal dollar cost of a statistical life to coal operators in that year was nearly $2 million.

Figure 4 shows estimated marginal dollar costs of a statistical life computed for each year from 1897 to 1930. Computations use the estimated elasticity 0.5526 for β_1, each year's total output and non-disaster fatalities, and each year's average pick miners' wage and output price. To correct for inflation during this period, which was particularly rapid from 1915 to 1920, all estimates are converted to 1921 dollars using the CPI.[18] Figure 4 shows that the MCSL for operators was high and volatile in the late 'teens and early 'twenties, but the MCSL for miners remained relatively stable.

How does the miners' MCSL compare with VSL estimated from wages and job risk? A median estimate for VSL in the U.S. in the late twentieth century is about $7 million in 2000 dollars (Viscusi and Aldy 2003, p. 18), which is roughly $700 thousand in 1921 dollars. However, there are reasons to believe that workers' VSL was much lower in the early twentieth century. First, safety is a normal good (Viscusi and Aldy 2003, Costa and Kahn 2004) and coal miners' incomes in the early twentieth century were much lower than typical U.S. workers' incomes in the late twentieth century. Second, direct estimates of the VSL for the early twentieth century were also much lower. Fishback (1992, p. 110) estimated a VSL of roughly $150 thousand in 1967 dollars for coal miners from 1912 to 1923 using data on small-scale accidents, which is equivalent to about $80 thousand in 1921 dollars. Kim and Fishback (1993, p. 812) estimated a VSL of roughly $30-$36 thousand in 1967 dollars for railroad workers from 1893 to 1909,

[16] I have ignored other costs the operator might have saved from lower output, such as the costs of hauling and cleaning coal, but also additional costs the operator might have incurred to promote safety, such as more supervisory personnel.

[17] The West Virginia Department of Mines (1922, p. 13) estimate of pick miners average earnings in 1921 was only $1166, but this may have included miners not working a full year.

[18] The Bureau of Labor Statistics CPI-U was used beginning in 1913 (U.S. Bureau of Labor Statistics 2016, table 24, p. 69) and Albert Rees's cost of living index for earlier years (U.S. Department of Commerce, Vol. 1, series E186, p. 212).

which is equivalent to $16 to $19 thousand in 1921 dollars. Costa and Kahn (2004) extrapolated a VSL of $600 thousand in 1990 dollars for all workers in 1920, which is equivalent to $82 thousand in 1921 dollars. These estimates of VSL are much all smaller than the MCSL to miners computed above.

How robust is this finding? MCSL is inversely related to elasticity of expected fatalities with respect to work intensity (β_1). Consequently, any downward bias in the estimate of β_1 (caused for example by measurement error on work intensity) would cause upward bias in MCSL. One therefore wonders how sensitive MCSL is to higher but still plausible values of β_1. The upper end of the 95% confidence interval for β_1 is about 0.71 (see column 1, 2, or 4 in table 4). Using this value for β_1, MCSL in 1921 comes to about $350 thousand. Even using a value of unity for β_1, MCSL still comes to about $250 thousand. So the conclusion that MCSL was much greater than VSL seems insensitive to moderately higher estimates of the elasticity of expected fatalities with respect to work intensity.

In sum, coal miners prevented non-disaster fatalities by working more slowly and carefully, which reduced their earnings. However, the Poisson regression estimates shown in figure 4 show that a reduction in work intensity caused a less-than-proportional reduction in fatalities—the elasticity was just over one-half. Since coal miners were paid on piece, reducing the risk of non-disaster fatalities by, say, 10 percent required accepting a reduction in earnings of almost 20 percent. For coal miners in West Virginia during the sample period, the marginal cost of a statistical life was thus quite large, probably several times larger than the value of a statistical life. Preventing fatalities was expensive for coal miners.

6. Impact of unionism on the tradeoff

Boal (2009, 2016) estimated that unionism reduced fatalities in coal mining during this period by a remarkably large amount—about 20 to 40 percent, depending on specification. The estimated union effect hardly changed when controls were introduced for state regulations. However, Boal (2009, 2016) studied all fatalities, including disasters, and did not include work intensity as a regressor.

Could unionism have lowered non-disaster fatalities simply by reducing the intensity of work? Boal (forthcoming) found that unionism lowered output in West Virginia coal mining about 5 to 10 percent after 1913. Table (5) columns (1) and (2) replicate Boal's simple production-function estimates with a change in the dependent variable. For convenience, the dependent variable here is work intensity (output per worker per day) instead of total output as in Boal (forthcoming). In both columns (1) and (2), the estimated coefficients unrelated to unionism are sensible. The elasticity of work intensity with respect to number of workers is about negative 0.1, implying decreasing returns to mine size. The elasticity of work intensity with respect to days of operation varies, due to the square term, but is negative if days of operation are greater than 35, implying decreasing returns to days of operation. Several explanations for decreasing returns to days suggest themselves. Coal workers might have become fatigued from more continuous work (Pencavel 2015) or they might have chosen to work more slowly when opportunities for work were plentiful. The fraction of coal output mined by machine has a positive effect on work intensity, as might be expected if mining machines were productive. The first observation of each mine has much lower work intensity, which according to Boal (forthcoming) reflects the lower output of coal mines during initial development.

Now consider the coefficients related to unionism. Column (1) includes a single union dummy variable for the entire sample period. Its estimated coefficient is negative but small in magnitude (less than three percent[19]) and not statistically significant. Column (2) adds a second union dummy for the period after 1913, when a major strike occurred in West Virginia coal. Together, the estimates in column (2) suggest that unionism may have *increased* work intensity by about 6 percent until 1913 (though the estimate is not statistically significant) but certainly *decreased* work intensity by about 5 percent after 1913. However, multiplying this 5 percent times the estimated elasticity of fatalities with respect to work intensity presented above in table 4 gives only negative 2 or 3 percent. By itself, the reduction in work intensity caused by the union after 1913 could cause only a small reduction in fatalities, not the 20 to 40 percent reduction found by Boal (2009, 2016). It appears that unionism could not have lowered non-disaster fatalities simply by reducing the intensity of work—that is, by a *movement along* the work intensity-worker safety frontier estimated in table 4.

Could unionism have simultaneously *shifted* or *tilted* the frontier? This possibility is investigated in columns (3), (4), and (5) of table 5. Column (3) simply adds a union binary variable to the fatalities equation. Its coefficient shows that unionism shifted the joint production function by a substantial 26 percent for the whole period, and is statistically significant. Column (4) investigates whether unionism also tilted the function by adding an interaction between unionism and work intensity. Its coefficient suggests that unionism may have lowered slightly the elasticity of expected fatalities with respect to work intensity, but is not statistically significant. So the union apparently did not tilt the work intensity-worker safety frontier much. Finally, column (5) investigates whether unionism shifted the frontier a second time by adding a second union dummy for the period after 1913. *Both* union coefficients are now statistically significant. Together they show that, holding work intensity constant, unionism reduced fatalities by an enormous 58 percent until 1913 and by a still-substantial 22 percent after 1913. It is clear that the union did shift the work intensity-worker safety frontier, and that the union shift varied over time.

Table 6 summarizes these results by decomposing the union effect on fatalities into a *shift* of the work intensity-worker safety frontier, and a *movement along* that same frontier, using the estimates in table 5. The first column computes the decomposition assuming a constant union effect for all years, using the estimates in table 5 columns (1) and (3). The total union effect is a substantial 28 percent reduction in fatalities, but it is almost entirely due to the shift in the joint production function. The last two columns compute the decomposition allowing the union effect to change after 1913, using the estimates in table 5 columns (2) and (5). The total union effect until 1913 is an enormous 54 percent reduction in fatalities, again almost entirely due to the shift in the frontier. The total effect after 1913 is a smaller, but still substantial 25 percent effect, again almost entirely due to the shift in the frontier.

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[19] All percent differences mentioned in this section are simple differences in logarithms.

In sum, the negative union effect on all fatalities found by Boal (2009, 2016) also holds for non-disaster fatalities alone. This favorable union effect was due almost entirely to a *shift* in the work intensity-worker safety frontier, rather than a reduction in work intensity or a tilt in the frontier. Mines under union operation enjoyed a substantially lower rate of non-disaster fatalities, but at the margin faced the same elasticity of expected fatalities with respect to work intensity. Finally, union effects on fatalities were especially favorable in the early part of the sample, the same period in which the union had a no negative effect on productivity.

7. Conclusion

The three questions posed at the beginning of this paper can now be answered. The first question was whether the data show a tradeoff between work intensity and worker safety, and the answer is clearly *yes*: a 10 percent increase in output per worker per day would have caused about a 5 percent increase in expected non-disaster fatalities.

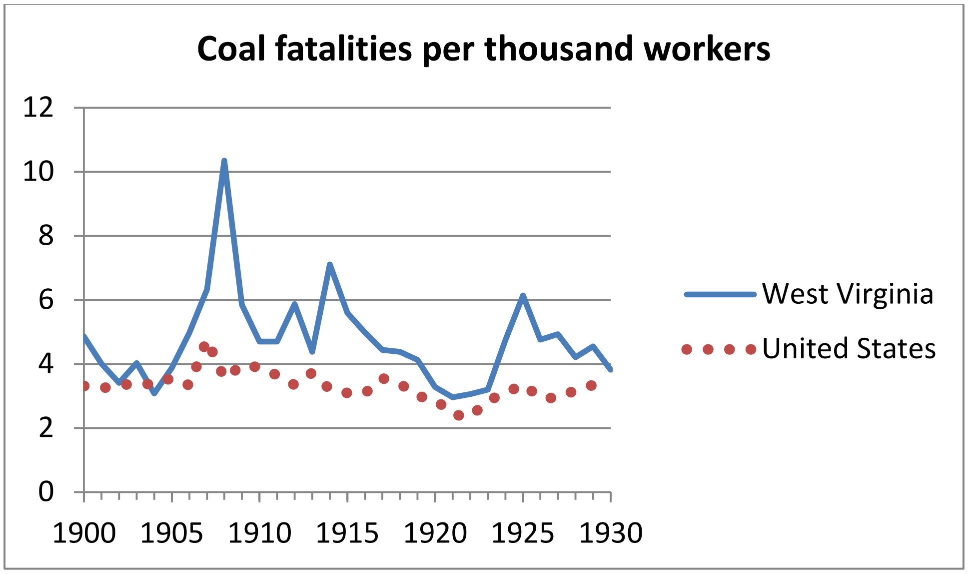
This result helps answer the second question: Why were high fatality rates such an intractable problem? As many observers recognized, coal miners purchased safety at the cost of lower earnings because they were paid on piece, per ton of coal. This paper shows that the marginal dollar cost of a statistical life to miners was high, many times their lifetime earnings. Given this high marginal cost of safety, it seems likely that coal miners—even “old and experienced men”—were reluctant to pay for additional safety by working slower.

The third question about the role of the union has a happier answer. The union clearly shifted the work intensity-worker safety frontier in a favorable direction, especially in the early period. Fatalities were reduced about 54 percent through 1913, and thereafter by about 25 percent. However, it appears that the union did not tilt the frontier, and it reduced work intensity only a little. Essentially all of the union effect on fatalities was due to a shift in the frontier, not a movement along it.

What explains the dramatic negative effect of unionism on fatality rates? The analysis above ruled out a reduction in work intensity, but did not produce an alternate explanation. Lower turnover in union mines, which was well-documented (USCC 1925, p. 1266), might be an explanation. Another explanation was proposed by United Mine Workers President John Mitchell, who said that “where men are organized and are able to act in concert they will refuse to work in a dangerous place and will not permit one of their number to be discharged or discriminated against who refuses to work in an unsafe place.”[20] In any case, unionized miners managed to increase safety substantially with little reduction in work intensity—a remarkable increase in economic efficiency.

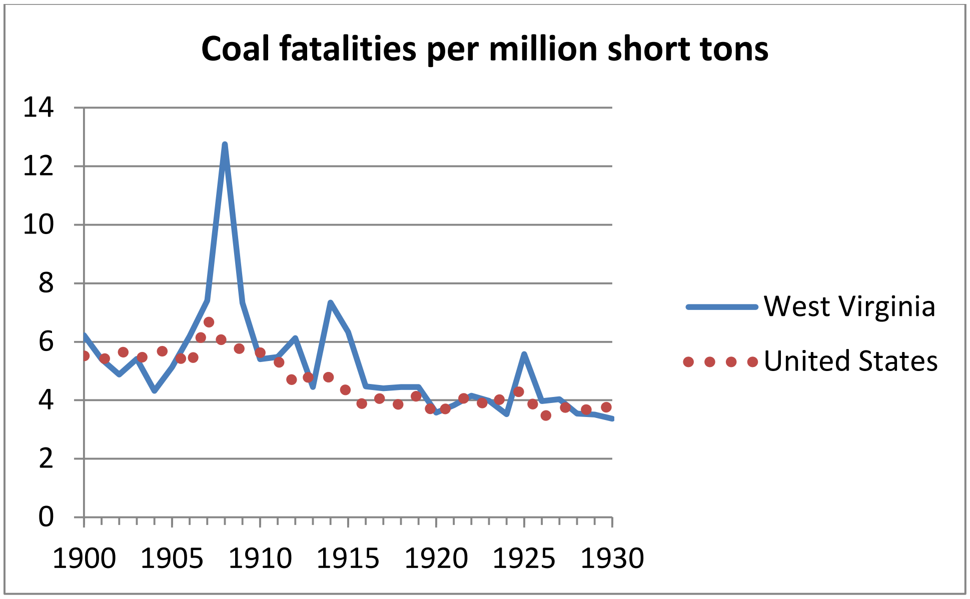
[20] Mitchell (1908, p. 189). Mitchell further argued that “where men are organized they are able to secure legislation, and they cannot do it unless they are organized. And what is equally important, where the men are organized and where they act together the laws are better enforced and there are better mine inspectors than in the states where the men are unorganized.” Since any statewide effects are controlled with time dummies, changes in laws cannot explain the results in table 5.

Figure 1:



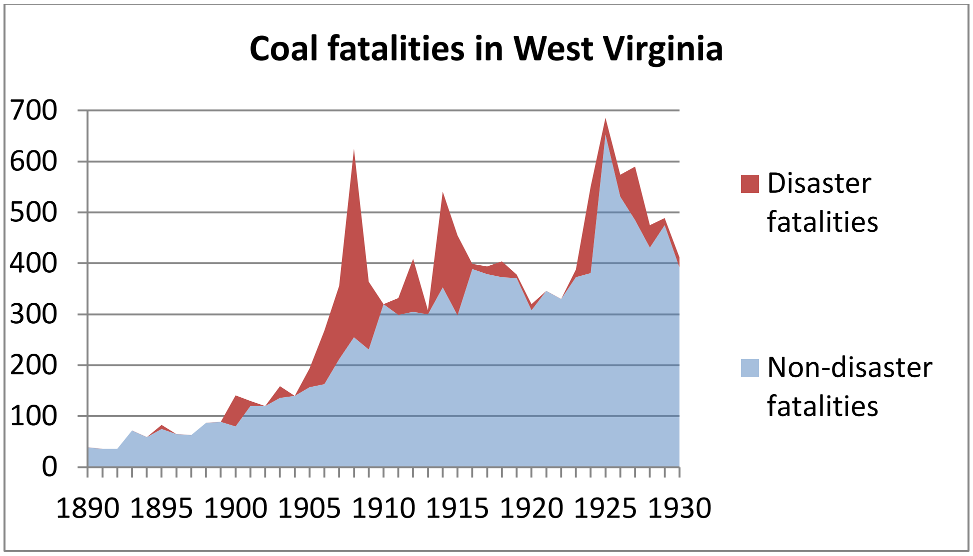
SOURCES: West Virginia—West Virginia Office of Miners' Health, Safety and Training, http://www.wvminesafety.org/historicprod.htm, accessed June 8, 2014. United States—Mine Safety and Health Administration, http://arlweb.msha.gov/stats/centurystats/coalstats.asp, accessed March 8, 2016. West Virginia data are for fiscal years ending June 30 through 1924, and calendar years thereafter; data for 1925 cover 18 months.

Figure 2:



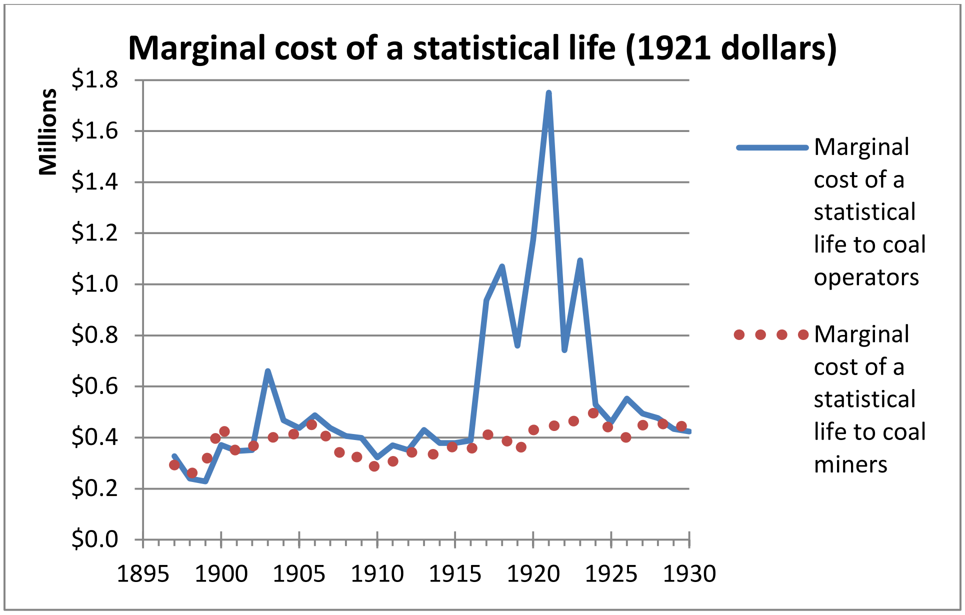
SOURCES: West Virginia—West Virginia Office of Miners' Health, Safety and Training, http://www.wvminesafety.org/historicprod.htm. United States—Mine Safety and Health Administration, http://arlweb.msha.gov/stats/centurystats/coalstats.asp. West Virginia data are for fiscal years ending June 30 through 1924, and calendar years thereafter; data for 1925 cover 18 months.

Figure 3:



SOURCES: Fatalities from disasters—http://www.wvminesafety.org/disaster.htm . All fatalities—http://www.wvminesafety.org/historicprod.htm . Data are for fiscal years ending June 30 through 1924, and calendar years thereafter; data for 1925 cover 18 months.

Figure 4:



SOURCES: Author's calculations (see text).

Table 1: Coal mining fatalities by cause

	West Virginia 1923-27		United States 1917-26		
	Number killed	Percent of fatalities	Number killed	Percent of fatalites	Killed in disasters[a]
UNDERGROUND ACCIDENTS					
Falls of roof (coal, rock, etc.)	1151	46.3%	9987	42.6%	5
Falls of face or pillar coal	88	3.5%	1234	5.3%	0
Mine cars and locomotives	513	20.6%	4027	17.2%	0
Explosions of gas or coal dust	388	15.6%	2951	12.6%	2081
Explosives	57	2.3%	1230	5.2%	98
Suffocation from mine gases	1	0.0%	114	0.5%	5
Electricity	111	4.5%	800	3.4%	0
Animals	4	0.2%	61	0.3%	0
Mining machines	62	2.5%	252	1.1%	0
Mine fires (burned, suffocated, etc.)	5	0.2%	87	0.4%	61
Other causes	13	0.5%	592	2.5%	6
Subtotal	2393	96.2%	21335	90.9%	2256
SHAFT ACCIDENTS	23	0.9%	441	1.9%	5
SURFACE ACCIDENTS	171	6.9%	1690	7.2%	13
GRAND TOTAL	2487	100.0%	23466	100.0%	2274

SOURCES: West Virginia--Adams (1928, table 32, p. 60). United States--Adams (1928, table 22, p. 32).

[a] A disaster is defined as an incident in which five or more workers were killed simultaneously.

[b] Note: West Virginia had fewer shaft mines than other states.

Table 2: Descriptive statistics of West Virginia panel

	Mean	Standard deviation	Skew-ness	Minimum	First quartile	Median	Third quartile	Maximum
Number of workers	148.5	111.7	1.642	1	65	119	203	1340
Days of operation	205.3	65.7	-0.620	4	165	215	255	365
Work intensity (tons per worker per day)	4.808	2.422	7.258	0.211	3.461	4.478	5.738	65.590
Fraction of output mined by machine	0.639	0.390	-0.664	0.000	0.268	0.799	1.000	1.000
Mine under union operation (binary)	0.303	0.460	0.855	0	0	0	1	1
Total fatalities	0.742	4.778	30.106	0	0	0	1	197
Disaster fatalities[a]	0.194	4.666	32.072	0	0	0	0	197
Non-disaster fatalities	0.548	0.933	2.231	0	0	0	1	8

Number of mines = 521. Number of observations = 7,474. Years 1897, 1899-1928. Data for 1898 not availab

[a] A disaster is defined as an incident in which five or more workers were killed simultaneously.

SOURCES: Unionism--author's compilations. Disaster fatalities--http://www.wvminesafety.org/disaster.htm .
Other variables--West Virginia Department of Mines, *Annual Report* , various issues.

Table 3: Frequency of fatalities in West Virginia panel

	All fatalities		Disaster fatalities[a]		Non-disaster fatalities	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
0	4869	65.1%	7442	99.6%	4887	65.4%
1	1613	21.6%	0	0.0%	1617	21.6%
2	614	8.2%	0	0.0%	619	8.3%
3	221	3.0%	0	0.0%	224	3.0%
4	86	1.2%	0	0.0%	88	1.2%
5	29	0.4%	3	0.0%	27	0.4%
6	5	0.1%	2	0.0%	5	0.1%
7	8	0.1%	2	0.0%	5	0.1%
8	3	0.0%	0	0.0%	2	0.0%
9	1	0.0%	0	0.0%	0	0.0%
≥ 10	25	0.3%	25	0.3%	0	0.0%
Total	7474	100.0%	7474	100.0%	7474	100.0%

Number of mines = 521. Number of observations = 7,474.
Years 1897, 1899-1928. Data for 1898 are not available.

[a] A disaster is defined as an incident in which five or more workers were killed simultaneously.

SOURCES: All fatalities--West Virginia Department of Mines, *Annual Report* , various issues.
Disaster fatalities--http://www.wvminesafety.org/disaster.htm .

Table 4: Poisson FE regressions of non-disaster fatalities

Regressor	(1)		(2)		(3)		(4)	
Log work intensity (= tons per worker per day)	0.5228	***	0.5526	***	0.5218	*	0.5444	***
	(0.0804)		(0.0792)		(0.2249)		(0.0803)	
Log number of workers	0.7023	***	0.7041	***	1.1457	**	0.6990	***
	(0.0564)		(0.0563)		(0.3765)		(0.0558)	
Log days of operation	0.6486	***	-0.9698		-1.0267		-0.9586	
	(0.0957)		(0.5650)		(0.5726)		(0.5644)	
Fraction of output mined by machine	0.0564		0.0582		0.0438		0.0603	
	(0.1019)		(0.1011)		(0.1024)		(0.1012)	
Log days of operation, squared			0.1647	**	0.1699	**	0.1629	**
			(0.0582)		(0.0590)		(0.0582)	
Log number of workers, squared					-0.0440			
					(0.0363)			
Log work intensity, squared					0.0088			
					(0.0707)			
First observation of each mine (binary variable)							-0.0671	
							(0.1340)	
Mine fixed effects?	Yes		Yes		Yes		Yes	
Year fixed effects?	Yes		Yes		Yes		Yes	
Number of mines	443		443		443		443	
Number of (mine x year) observations	6870		6870		6870		6870	
Log pseudolikelihood	-5258.9		-5255.6		-5254.7		-5255.4	

Cluster-robust standard errors in (parentheses).
Years 1897, 1899-1928. Data for 1898 are not available.
Dependent variable excludes fatalities from "disasters," defined as incidents in which 5 or more workers were killed (from http://www.wvminesafety.org/disaster.htm). Almost all disasters were explosions.
Coefficients computed by maximizing conditional likelihood function,
so mines for which total fatalities in all years equal zero are dropped.
* 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%.

Table 5: Impact of unionism on the tradeoff

Regressor	(1)		(2)		(3)		(4)		(5)	
Dependent variable	Log work intensity		Log work intensity		Non-disaster fatalites		Non-disaster fatalites		Non-disaster fatalites	
Estimation method	OLS		OLS		Poisson		Poisson		Poisson	
Log work intensity (= tons per worker per day)	(dep var)		(dep var)		0.5514	***	0.5686	***	0.5556	***
					(0.0781)		(0.0827)		(0.0781)	
Log number of workers	-0.0963	***	-0.0971	***	0.7094	***	0.7100		0.7089	***
	(0.0179)		(0.0178)		(0.0562)		(0.5652)		(0.0559)	
Log days of operation	0.6832	***	0.6702	***	-0.9864		-1.0225		-0.9353	
	(0.1523)		(0.1516)		(0.5672)		(0.5652)		(0.5740)	
Log days of operation, squared	-0.0962	***	-0.0949	***	0.1652	**	0.1685	**	0.1609	**
	(0.0160)		(0.0159)		(0.0584)		(0.0583)		(0.0591)	
Fraction of output mined by machine	0.1316	***	0.1235	***	0.0361		0.0364		0.0579	
	(0.0267)		(0.0268)		(0.0991)		(0.0994)		(0.0985)	
First observation of each mine (binary variable)	-0.4400	***	-0.4442	***						
	(0.0315)		(0.0316)							
Mine under union operation (binary variable)	-0.0274		0.0598		-0.2645	***	-0.1091		-0.5717	***
	(0.0175)		(0.0325)		(0.0668)		(0.2143)		(0.1317)	
Union x log work intensity							-0.1073			
							(0.1342)			
Union x (year > 1913) (binary variable)			-0.1123	**					0.3488	*
			(0.0354)						(0.1356)	
Mine fixed effects?	Yes		Yes		Yes		Yes		Yes	
Year fixed effects?	Yes		Yes		Yes		Yes		Yes	
Sum of union coefficients			-0.0521	**					-0.2229	**
			(0.0188)						(0.0700)	
Number of mines	521		521		443		443		443	
Number of (mine x year) observations	7474		7474		6870		6870		6870	
Log pseudolikelihood					-5246.9		-5246.6		-5243.8	

Cluster-robust standard errors in (parentheses).
Years 1897, 1899-1928. Data for 1898 are not available.
* 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%.

Table 6: Decomposition of union effect on expected non-disaster fatalities

	All years	Break after 1913	
		1897-1913	1914-1928
Union-induced shift in joint production function	-26.5%	-57.2%	-22.3%
Union-induced movement along joint production function	-1.5%	3.3%	-2.9%
Total union effect	-28.0%	-53.8%	-25.2%

SOURCE: "All years"--estimates in table 5 columns (1) and (3).
"Break after 1913"--estimates in table 5 columns (2) and (5).

References

Adams, W. W. (1928). *Coal mine fatalities in the United States 1927*. Washington DC: Government Printing Office.

Andrews, W. H., & Christenson, C. L. (1974). Some economic factors affecting safety in underground bituminous coal mines. *Southern Economic Journal, 40*(3), 364-376.

Appleton, W. C., & Baker, J. G. (1984). The effect of unionization on safety in bituminous deep mines. *Journal of Labor Research, 5*(2), 139-148.

Archbald, H. (1922). *The four hour day in coal*. New York: H.W. Wilson Company.

Artz, B., & Heywood, J. S. (2015). Performance pay and workplace injury: panel evidence. *Economica, 82*(S1), 1241-1260. doi:10.1111/ecca.12153.

Asfaw, A., Mark, C., & Pana-Cryan, R. (2013). Profitability and occupational injuries in U.S. underground coal mines. *Accident Analysis and Prevention, 50*(1), 778-786.

Bender, K., & Theodossiou, I. (2014). The unintended consequences of the rat race: the detrimental effects of performance pay on health. *Oxford Economic Papers, 66*(3), 824-847.

Bender, K. A., Green, C. P., & Heywood, J. S. (2012). Piece rates and workplace injury: does survey evidence support Adam Smith? *Journal of Population Economics, 25*, 569-590. doi:10.1007/s00148-011-0393-5

Bennett, J. D., & Passmore, D. L. (1985). Unions and coal mine safety: comment. *Journal of Labor Research, 6*(2), 211-216.

Bloch, L. (1931). *Labor agreements in coal mines: a case study of the administration of agreements between miners' and operators' organizations in the bituminous coal mines of Illinois*. New York: Russell Sage Foundation.

Boal, W. M. (2009). The effect of unionism on accidents in U.S. coal mining, 1897-1929. *Industrial Relations, 48*(1), 97-120.

Boal, W. M. (2016). *The effect of unionism on accidents in U.S. coal mining, 1897-1929: errata*. Retrieved from wmboal.com/research

Brophy, J. (1964). *A miner's life* (J. O. P. Hall Ed.). Madison: University of Wisconsin Press.

Cameron, A. C., & Trivedi, P. K. (2010). *Microeconometrics using Stata* (Revised ed.). College Station, Texas: Stata Press.

Cameron, A. C., & Trivedi, P. K. (2013). *Regression analysis of count data* (2nd ed.). Cambridge: Cambridge University Press.

Card, D. (1996). The effect of unions on the structure of wages: a longitudinal analysis. *Econometrica, 64*(4), 957-979.

Connerton, M. M. (1978). *Accident control through regulation: the 1969 Coal Mine Health and Safety Act experience.* (PhD), Harvard University, Cambridge, Massachusetts.

Connerton, M. M., Freeman, R. B., & Medoff, J. L. (1979). *Productivity and industrial relations: the case of U.S. bituminous coal*.

Costa, D., & Kahn, M. E. (2004). Changes in the value of life, 1940-1980. *Journal of Risk and Uncertainty, 29*(2), 159-180.

Dembe, A. E., Erickson, J. B., Delbos, R. G., & Banks, S. M. (2005). The impact of overtime and long work hours on occupational injuries and illnesses: new evidence from the United States. *Occupational and Environmental Medicine, 62*(9), 588-597.

Derickson, A. (1993). Participative regulation of hazardous working conditions: safety committees of the United Mine Workers of America, 1941-1969. *Labor Studies Journal, 18*(2), 25-38.

Dix, K. (1977). *Work relations in the coal industry: the hand-loading era, 1880-1930*. Morgantown: West Virginia University Press.

Dix, K. (1988). *What's a miner to do? The mechanization of coal mining*. Pittsburgh: University of Pittsburgh Press.

Fishback, P. V. (1986). Workplace safety during the progressive era: fatal accidents in bituminous coal mining, 1912-1923. *Explorations in Economic History, 23*(3), 269-298.

Fishback, P. V. (1987). Liability rules and accident prevention in the workplace: empirical evidence from the early twentieth century. *Journal of Legal Studies, 16*(2), 305-328.

Fishback, P. V. (1992). *Soft coal, hard choices: the economic welfare of bituminous coal miners, 1890-1930*. Oxford: Oxford University Press.

Fishback, P. V., & Kantor, S. E. (1992). "Square deal" or raw deal? Market compensation for workplace disamenities, 1884-1903. *Journal of Economic History, 52*(4), 826-848.

Fishback, P. V., & Kantor, S. E. (1995). Did workers pay for the passage of Worker's Compensation Laws? *Quarterly Journal of Economics, 110*(3), 713-742.

Fishback, P. V., & Kantor, S. E. (2000). *A prelude to the welfare state: the origins of Workers' Compensation*. Chicago: University of Chicago Press.

Freeman, R. B. (1984). Longitudinal analyses of the effects of trade unions. *Journal of Labor Economics, 2*(1), 1-26.

Freeman, R. B., & Kleiner, M. M. (2005). The last American shoe manufacturers: decreasing productivity and increasing profits in the shift from piece rates to continuous flow production. *Industrial Relations, 44*(2), 307-330. doi:10.1111/j.0019-8676.2005.00385.x

Goodrich, C. (1925). *The miner's freedom: a study of the working life in a changing industry*. Boston: Marshall Jones Company.

Graebner, W. (Ed.) (1976). *Coal-mining safety in the progressive period: the political economy of reform*. Lexington: University Press of Kentucky.

Grayson, R. L. (2001). Safety versus productivity and other factors in U.S. underground coal mines. *Mining Engineering, 53*(8), 41-44.

Hopkins, A., & Palser, J. (1987). The causes of coal mine accidents. *Industrial Relations Journal, 18*(1), 26-39.

Kim, S.-W., & Fishback, P. V. (1993). Institutional change, compensating differentials, and accident risk in American railroading, 1892-1945. *Journal of Economic History, 53*(4), 796-823.

Kuczynski, J. (1943). *A short history of labour conditions under industrial capitalism, volume 2: the United States of America 1789 to the present day*. London: Frederick Muller Ltd.

Lewis, H. G. (1986). *Union relative wage effects: a survey*. Chicago: University of Chicago Press.

Mitchell, J. (1908). Conservation in the coal industry. *American Mining Congress Proceedings, 11*, 185-195.

Morantz, A. D. (2013). Coal mine safety: do unions make a difference? *Industrial and Labor Relations Review, 66*(1), 88-116.

National Research Council. (1982). *Toward safer underground coal mines*. Washington, D.C.: National Academy Press.

Oi, W. Y. (1973). An essay on Workmen's Compensation and industrial safety. In P. S. Barth, M. Berkowitz, M. Rosenblum, & N. L. Watkins (Eds.), *Supplemental studies for the National Commission on State Workmen's Compensation Laws* (Vol. 1, pp. 41-106). Washington, D.C.

Oi, W. Y. (1974). On the economics of industrial safety. *Law and Contemporary Problems, 38*(4), 669-699.

Pencavel, J. H. (2015). The productivity of working hours. *Economic Journal, 125*(589), 2052-2076. doi:10.1111/ecoj.12166

Sider, H. (1983). Safety and productivity in underground coal mining. *Review of Economics and Statistics, 65*(2), 225-233.

Suffern, A. E. (1926). *The coal miners' struggle for industrial status: a study of the evolution of organized relations and industrial principles in the coal industry*. New York: Macmillan.

Thaler, R., & Rosen, S. (1976). The value of saving a life: evidence from the labor market. In N. E. Terleckyz (Ed.), *Household production and consumption* (pp. 265-302). New York: Columbia University Press.

U.S. Bureau of Labor Statistics. (1919). Wages and hours of labor in the coal mining industry in 1919. *Monthly Labor Review, 9*(6), 207-229.

U.S. Bureau of Labor Statistics. (2016). *CPI detailed report*. Washington, D.C.

U.S. Coal Commission. (1925). *Report, Part III Bituminous Coal--Detailed Labor and Engineering Studies* (Vol. 3 Bituminous Coal--Detailed Labor and Engineering Studies). Washington, D.C.: Government Printing Office.

Vegso, S., Cantley, L., Slade, M., Taiwo, O., Sircar, K., Rabinowitz, P., . . . Cullen, M. R. (2007). Extended work hours and risk of acute occupational injury: a case-crossover study of workers in manufacturing. *American Journal of Industrial Medicine, 50*(8), 597-603. doi:10.1002/ajim.20486

Viscusi, W. K., & Aldy, J. E. (2003). The value of a statistical life: a critical review of market estimates throughout the world. *Journal of Risk and Uncertainty, 27*(1), 5-76.

Wallace, M. (1987). Dying for coal: the struggle for health and safety conditions in American Coal Mining, 1930-82. *Social Forces, 66*(2), 336-364.

West Virginia Department of Mines. Annual report. Charleston: Tribune Printing Company.

Wieck, E. A. (1942). *Preventing fatal explosions in coal mines: a study of recent major disasters in the United States as accompaniments of technological change*. New York: Russell Sage Foundation.

Appendix A: Data appendix

Union status

This panel data set was originally assembled to measure the influence of the United Mine Workers on 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-third 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.

Coal output and mine inputs

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 (hereafter WVDM). Coal output, number of workers, coal mined by machine, and days of operation are given by the *Annual Report* at the mine level in 1897 and from 1899 through 1928. (Data are given only at the company level in 1898. Workers and days of operation are not reported at the mine level after 1928.) The data are reported on a fiscal year basis (ending June 30) through 1924, and on a calendar year basis thereafter. Workers include those employed both inside and outside the mine, but exclude supervisory personnel and coke plant workers. 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.

Fatalities

Fatalities and injuries are given at the mine level in the *Annual Report.* The injury data seem less trustworthy than the fatality data. For example, from 1914 to 1915, the number of nonfatal accidents in West Virginia coal jumped from 870 to 1628 while the number of fatalities decreased slightly; the *Annual Report* blamed changes in reporting after the introduction of Workmen's Compensation (WVDM 1915, p. 13). Muddying the waters further, in 1917 the *Annual Report* began listing a second injury category called "minor accidents," defined as "accidents which caused no loss of time;" it is difficult to infer how many such accidents were previously included in "nonfatal accidents." Much later, the *Annual Report* noted an increase in both injury categories over time, due to "more complete reports" (WVDM 1934, p. 12). In sum, apparent changes in reporting standards cast doubt on the usefulness of the injury data in statistical analysis.

Fatalities from disasters were taken from www.wvminesafety.org/disaster.htm, a web page maintained by the West Virginia State Office of Miners' Health, Safety and Training, and accessed June 8, 2014. See also WVDM (1938, pp. 120-121). For a list of all U.S. coal mine disasters during this era, see Adams (table 18, pp. 23-28).

Matching mines over time

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.