Coal Mine Safety: Do Unions Make a Difference?

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Abstract

Although the United Mine Workers of America (UMWA) has always advocated strongly for miners' safety, prior empirical literature contains no evidence that unionization reduced mine injuries or fatalities during the 1970s and '80s. This study uses a more comprehensive dataset and updated methodology to examine the relationship between unionization and underground, bituminous coal mine safety from 1993 to 2010. I find that unionization predicts a substantial and significant decline in traumatic mining injuries and fatalities, the two measures that I argue are the least prone to reporting bias. These disparities are especially pronounced among larger mines. My best estimates imply that overall, unionization predicts a 13-31% drop in traumatic injuries and a 27-83% drop in fatalities. Yet unionization was also associated with higher total and non-traumatic injuries during this period, suggesting that injury reporting practices differ substantially between union and nonunion mines.

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1 Introduction

Empirical literature on the relationship between unionization and workplace safety presents a curious puzzle. On one hand, scholars have documented numerous ways in which unions help to promote safe work practices. For example, unions typically play a critical role in educating workers about on-the-job hazards; incentivizing workers to take greater care on the job; attracting more safety-conscious workers; inducing employers to mitigate known hazards; increasing regulatory scrutiny; and developing safety-related innovations. Yet most empirical studies of the relationship between unionization and important safety outcomes, such as injuries and fatalities, have failed to find any statistically significant evidence of a "union safety effect" (Morantz 2009).

Prior research on the coal mining industry typifies this perplexing pattern. Coal miners' unions, especially the dominant United Mine Workers of America (UMWA), have advocated vigorously for improved worker safety since their inception. When the UMWA adopted its first Constitution in 1890, for example, three of its "Eleven Points" called for improvements in the safety and health conditions of miners (Fox 1990:22-25). Organized labor was also instrumental in the passage of the Mining Safety and Health Act of 1969 (the "Coal Act"), the statute that paved the way for comprehensive federal enforcement of occupational hazards at all surface and underground coal mines (Fox 1990:470-73). More recently, the UMWA played a particularly critical role in broadening the provisions of the Coal Act and encouraging the formation of state regulatory agencies (Fox 1990:462-470, 474, 504). By the 1980s, the UMWA's Health and Safety Department had developed an extensive tripartite structure including a Washington, D.C.-based international staff; regionally-based health and safety representatives tasked with liaising with Mining Safety and Health Administration (MSHA) District Offices; and mine-level health and safety committees that surveil day-to-day mine conditions. The myriad activities of mine-level health and safety committees include advocating on behalf of individual miners; conducting independent inspections; accompanying MSHA inspectors during official inspections; participating in pre- and post-inspection meetings; tracking MSHA appeals; providing training for miners; and, in extreme cases, shutting down hazardous sections of a mine, a power conferred by the UMWA's collective bargaining agreement with the Bituminous Coal Operator's Association (BCOA) (Weil 1987; Weil 1994). Nevertheless, most empirical studies focusing on the 1970s and '80s have reported, if anything, a counterintuitive *positive* relationship between a union's presence at a mine and the frequency of reported injuries and accidents.

This paper re-examines the link between unionization and mining hazards using more recent data, a broader set of control variables, and updated statistical techniques. Highly granular MSHA data on injuries and mine characteristics, combined with data from the National Institute for Occupational Safety and Health (NIOSH) and confidential data obtained from the Department of Energy, enable me to examine whether discrete safety outcomes differ significantly between union and nonunion mines. Focusing on underground mines that extract bituminous coal, I find that unionization is robustly associated with lower levels of traumatic injuries and fatalities, the two safety outcomes in my study that I argue are the least prone to reporting bias. These effects are especially pronounced among larger mines, and for traumatic injuries, in the period since the early 1990s. At the same time, however, unionization is associated with a significant *increase* in total and non-traumatic injuries, measures that are highly susceptible to reporting bias. Taken together, these findings lend credence to concerns that injury reporting practices differ significantly between union and nonunion settings.

The remainder of the paper is organized as follows. Section Two summarizes prior literature on the relationship between unions and mine safety. Section Three describes in detail the datasets upon which I rely. Section Four outlines my identification strategy and considers several potential sources of bias. Section Five presents my main empirical findings. Section Six further explores the likelihood of omitted variable bias and offers several possible explanations for why the union safety effect might have intensified around the turn of the century. Section Seven concludes.

2 Literature Review

In the past few decades, scholars have examined the relationship between unions and workplace safety in a wide range of industries, such as the U.S. construction sector (Dedobbeleer et al. 1990), U.S. manufacturing (Fairris 1995), British manufacturing (Reilly et al. 1995, Nichols et al. 2007), forest product mills in British Columbia (Havlovic and McShane 1997), and the New Jersey public sector (Eaton and Nocerino 2000). Most such studies have failed to find a statistically significant negative relationship between unionization and the frequency of workplace accidents. Similarly, empirical scholarship examining aggregate cross-industry data from the U.S., Canada, and Great Britain has rarely reported any robust evidence of a union safety effect. (Morantz 2009).

Given its inherent hazardousness, the mining sector has attracted a disproportionate share of scholarly attention. Several recent historical studies suggest that unions exerted, if anything, a salutary effect on miners' safety during the early twentieth century (Fishback 1986; 1987:324; Boal 2009). However, empirical scholarship focusing on the decades since the passage of the Coal Act (1969) has reached very different conclusions. Boden (1977:116) and Connerton (1978), the first two empirical studies focusing on the latter part of the twentieth century, examine data from 1973-75 and 1974-75, respectively. Although neither study focuses specifically on unionization, both include union status as a control variable and report that union mines experienced significantly more disabling injuries, *ceteris paribus*, than their nonunion counterparts. A landmark study on underground coal mine safety sponsored by the National Research Council (1982) also briefly addresses the relationship between unionization and mine safety. Examining data from 1978-80, the authors observe that the seemingly perverse positive relationship between union status and disabling injuries disappears when one focuses on the subset of injuries that are least susceptible to differences in reporting practices.[1] The authors also report that the lower fatality rate among union mines disappears when one accounts for mine size. On this basis, the NRC study suggests that there is probably no relationship at all between unionization and underground coal mine safety (NRC 1982:95-96).

Appleton and Baker (1984), the first study to focus specifically on the relationship between mine unionization and occupational safety, analyzes cross-sectional data from a single year (1978) culled from 213 mines in eastern Kentucky and western Virginia. Controlling for several mine-specific covariates, the authors report that both total injuries and relatively serious injuries are significantly higher at union mines. They hypothesize that the union job-bidding system, and/or union miners' postulated lower job motivation and productivity, could explain

[1] "Intermediate" injuries, adjudged by the study's authors to be the least prone to reporting bias, are defined so as to comprise "all fatal and permanent disability injuries as well as all injuries resulting from roof/side falls, machinery, haulage, or electrical/explosive accidents" (NRC 1982:82). The report states, "The rationale for defining [the intermediate injury rate] rested on the belief that reporting inconsistencies would occur most frequently for the degree 3-5 material handling and slipping/bumping injuries. Consequently, for consistency in reporting, [the intermediate injury rate] is felt to lie somewhere between the [fatality and permanent disability rate], where reporting differences are felt to be negligible, and the [disabling injury rate], where they might not be. We thus regard [the intermediate injury rate] as a compromise measure of safety that includes ample numbers of injuries for most statistical purposes and provides for reasonably good consistency between mines in the reporting of injuries" (NRC 1982:83-84).

these results. Several later comments (Bennett and Passmore 1985; Weeks 1985) critique Appleton and Baker's conclusions by pointing out limitations in their data and methodology.

In short, scholars have generally reported a *positive* relationship, if any at all, between union status and reported mining inuries since the New Deal. There are, however, several compelling reasons to question the accuracy and contemporary relevance of these findings.

First, as Appleton and Baker (1984:140) point out, the accident reporting system in use before 1978 suffered from extremely poor reporting practices, and therefore underreporting of injuries by nonunion mines could have biased the results of Boden (1977) and Connerton (1978).

Second, most prior scholarship relies upon data that is geographically restricted, highly aggregated, time-invariant, or otherwise small in sample size. For instance, the 213 mines analyzed in Appleton and Baker (1984) comprised less than 10% of all coal mines that were active in 1978.

Third, all of the statistical analysis in prior studies relies on ordinary least squares regression modeling. Under standard assumptions, Poisson and negative binomial models are known to yield less biased estimates, and therefore have become the preferred approach for analysis of "count data" such as injuries and fatalities (Cameron and Trivedi 1998:1-3).

Finally, the labor strife that characterized most of the 1970s, which included periodic strikes and work stoppages, may have limited unions' capacity to improve safety practices. Although Appleton and Baker limit their study of bituminous mining to what they characterize as a single "non-strike year" (1978) in the hopes of circumventing this problem, government statistics indicate that 414 bituminous coal mine strikes took place in 1978 and that the national labor-management climate remained highly adversarial (Staats 1981: 12-25; Darmstadter 1997: 27-31). Moreover, even if unions were relatively ineffectual during the 1970s, their impact may have changed in recent decades, as the UMWA become more familiar with MSHA's regulatory procedures and expanded the scope of its internal health and safety programs (Weil 1994: 197).

In short, analysis of more recent data may not only bear more directly on unions' contemporary relevance, but may also yield more credible estimates of unions' true long-term effect. To my knowledge, no study has directly investigated the relationship between unionization and mine safety since 1980.[2]

The goal of the present article is to fill this gap in the literature by examining the 1993-2010 period with comprehensive, granular data and up-to-date econometric methods. I pose, in turn, a series of questions regarding the relationship between unionization and mine safety during this period. First, are there statistically significant disparities, *ceteris paribus*, between the rate of occupational injuries in union and nonunion coal mines? Second, do any such disparities persist if one focuses on measures of injury rates that are relatively impervious to reporting bias? Third, have such disparities remained constant, or have they fluctuated over time? Finally, given the inherent limitations of this observational study, what plausible inferences can be drawn regarding the true relationship between unionization and mine safety?

3 Data

The analysis presented in this paper relies primarily on MSHA's historical database from 1993-2010. This database includes quarterly data on the characteristics of each coal mine under MSHA's purview, and on each accident or injury that was reported to MSHA during this period. Although enormously detailed, the dataset has two important limitations. First and foremost, it contains little information on the union status of individual mines. Although MSHA originally collected data on unionization, the survey fell into disuse by the 1990s and historical records on union status were not preserved.[3] In 2007 MSHA conducted a one-time survey of mines in an effort to identify which were operating under union contracts, and in what year those mines became unionized. One can thus obtain a snapshot of the union status of U.S. mines in 2007, but it is impossible to determine from this source whether a particular mine was unionized in prior years (and, if so, for how long). Second, although the MSHA database contains comprehensive data on coal production and employment, it lacks information on each mine's geological characteristics (such as mean coal bed thickness), economic constraints (such as whether it is a subsidiary of a larger firm), and predominant methodological approach (such as the relative prevalence of longwall, shortwall, continuous, and conventional mining techniques).

To remedy these shortcomings, I supplement the MSHA database with data from the

[2] Reardon (1996) analyzes coal mining data from 1986-88, but he does not compare the probabilities of accidents occurring across union and nonunion settings. Rather, he focuses on the probability that a *reported accident* has already resulted (or will likely result) in a fatality or permanently disabling injury.
[3] Phone conversation with MSHA's George Fesak, Director of Program Evaluation and Information Resources, on 8/14/08.

Department of Energy's Energy Information Administration (EIA) and data from NIOSH. The EIA database encompasses every mine in the U.S. that produces an appreciable amount of coal.[4] Most importantly for my purposes, the EIA database contains a "union ID" field indicating whether each mine was unionized in a given year and, if so, by which union.[5] The data also contain detailed information on the geological and economic characteristics of each mine, including the number of coal beds, the thickness of each coal bed, the value of captive and open production, productive capacity, recoverable reserves, and (for underground mines) the share of production attributable to conventional, continuous, longwall, shortwall, and other mining methods.[6] The NIOSH dataset specifies whether or not a given mine utilizes longwall mining. Merging the MSHA, EIA, and NIOSH datasets allows me to assemble a detailed picture of safety-related outcomes at each union and nonunion coal mine in the country between 1993 and 2010. (Precise definitions of the variables included in this final dataset are presented, along with their respective sources, in Appendix B.)

I restrict the sample in several ways to ensure that the attributes of the union and nonunion mines being compared are as similar as possible.[7] First, like most previous scholars, I confine my analysis to underground coal mines. (Surface coal mines, which have very different risk profiles and production characteristics, are also much less likely to be unionized.) Second, I restrict the sample to bituminous coal mines, since none of the underground anthracite and lignite coal mines in the dataset operated under union contracts. Third, I drop any mine-quarters

[4]According to the EIA Coal Production and Preparation Report (Form EIA-7A), the EIA collects data on mines with operations that "produced and/or processed 10,000 or more short tons of coal and/or worked 5,000 hours or more during the reporting year." Of our sample of underground, bituminous coal mines with active production for the years 1993-2010, 0.41% of mine-years (since EIA data is yearly) do not have EIA data.

[5]The EIA considers this data unreliable prior to 1993. Phone Conversation with Vlad Dorjets, Lead Economist at EIA, on 2/25/2010. Since the EIA's union data are reported annually, whereas injury data are reported quarterly, I make the simplifying assumption that the union status recorded for a particular year applies to all four quarters of that year.

[6] Since some of these variables are considered trade secrets by the mines that provide them, I obtained these data on a confidential basis. EIA staff indicated that two of these variables, recoverable reserves and captive production, are unreliable for observations before 1998 (E-mail correspondence with William Watson, EIA, 12/7/2010). Results including these confidential fields are presented in the "confidential-fields" specifications.

[7] As a robustness check, I refine the sample further using matching methods. The purpose of this procedure, as described by Ho et al. (2007), is to balance the distributions of the covariates across the "treatment" and "control" groups. The "balanced" sample consists of 10,248 mine-quarters for which the estimated likelihoods of unionization are similarly distributed across the union and nonunion subsamples. Results for this sample, available on the *Companion Website* (http://amorantz.stanford.edu/papers/union-coal-mine-safety/); generally echo the findings presented in Section Five, albeit often at lower levels of statistical significance.

in which a mine reported zero coal production and/or zero hours worked.[8] (While injuries do occasionally occur when a mine is not producing coal, the circumstances and triggering causes of such accidents are likely to differ from those that occur during active production periods.)

Once these restrictions are imposed, the final sample contains 2,516 mines,[9] each of which was active, on average, for 15 of the 72 quarters under observation.[10] Figure 1 shows the geographical distribution of the mines in the sample. While the mines are spread across 17 states, 89% are located in the coal mining regions of Kentucky, Pennsylvania, West Virginia, and Virginia. Figure 2 displays the percentage of active mines that were unionized in each quarter. In keeping with the general trend for most U.S. industries, the unionization rate declined steadily, from 18.7% in 1993 to 9.3% in 2010.

Each injury report submitted to MSHA contains information on the nature and source of the injury, the body part(s) affected, the activity the employee was engaged in at the time of the incident, and the severity of the injury (which ranges from "first aid" to "fatality"). Using these fields, I tabulate four different injury counts: fatal injuries ("fatalities"), "traumatic" injuries,[11]

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[8] Out of 40,807 initial mine-quarters, 3,876 (9.5%) have either zero coal production or zero hours worked, and were dropped from the analysis.

[9] This is the number of mines in the quarterly data used for all models except those with number of fatalities as the dependent variable. Because the historical variables in the models (lost-work injuries and penalty points) are summed up for the previous four quarters for the non-traumatic, total, and traumatic injuries regressions and are summed up for the previous calendar year for the fatality regressions, there are some mines that are included in the fatality models but are excluded for other models. For example, for a mine that shuts down in the first quarter of 1992 and then reopens for a single quarter during the fourth quarter of 1993, the total number of lost-work injuries in the four quarters preceding the fourth quarter of 1993 (in the quarterly data) will be missing (because the mine was closed), while the number of lost-work injuries in the calendar year before 1993 (in the yearly data) will be non-missing, since we have at least one quarter of data from 1992. Thus, that mine will not be in the sample for the quarterly regressions (non-traumatic, total, and traumatic injury models) but *will* be in the yearly regressions (i.e. the fatality models). The sample for the fatality models consists of 2,568 mines.

[10] The underground coal mining industry exhibits high rates of entry and exit due to periodic fluctuations in demand and the costs of production. For example, out of the 780 mines that were active in the first quarter of 1993, only 18% were still active in the first quarter 2000 and only 6.5% remained active in the final quarter of 2010. Similarly, out of the 415 mines that were active in the final quarter of 2010, less than 22% had been active in the first quarter of 2000, and only 11% had been active in the first quarter of 1993.

[11] Because a "traumatic" injury, by definition, is caused by a discrete accident that a miner sustains during working hours, its work-relatedness is rarely in dispute as long as the miner's account of the incident is deemed credible. In contrast, the diagnosis of non-traumatic injuries, such as cumulative or repetitive-motion injuries, often relies primarily on the patient's self-report of subjective symptoms. Because the existence – let alone the work-relatedness – of some of these injuries may be difficult to verify using "evidence-based medicine," the frequency with which such claims are filed and approved can vary widely across employers. The category of "traumatic" injuries, intended to encompass the subset of injuries that are the least prone to underreporting, was defined in consultation with Professor Mark Cullen, M.D., the Chief of Stanford University's Division of General Internal Medicine. According to Dr. Cullen, the critical determining factor in determining whether or not an injury is reported is not the triggering *cause* of the injury, but rather the characteristics of the injury itself. More specifically, injuries of at least moderate severity, whose effects are readily visible, that are "traumatic" (rather than cumulative) in nature are generally the

"non-traumatic" injuries,[12] and total injuries. For each tabulation, I include only injuries that occurred in the underground subunit of a mine.[13] Table 2 presents injury counts (and percentages) for both union and non-nion mines. Although fatalities uniformly comprise a very small fraction (0.3-0.6%) of total accidents, the relative share of non-traumatic injuries is higher at union mines than at nonunion mines (69.1% versus 57.6%).

Figure 3 provides a preliminary comparison of recent trends across union and nonunion mines by plotting, respectively, the frequencies of total and traumatic injuries (per 2,000 hours worked) from 1993 to 2010. Two general patterns are apparent. First, regardless of union status, the frequency of traumatic injuries has remained relatively constant over time, whereas the frequency of total injuries has declined steadily since the early 1990s. Secondly, although the direction and magnitude of the union-nonunion disparity fluctuated by year and injury type in the early 1990s, by the turn of the century, union mines were usually reporting lower injury rates than nonunion mines regardless of the metric examined.

4 Methodology

To explore the relationship between union status and safety outcomes, I estimate negative binomial regression models in which the dependent variables are, respectively, total injuries, non-traumatic injuries, traumatic injuries, and fatalities.[14] The total number of hours worked is used as an exposure term, and standard errors are clustered at the mine level. In addition to a dummy variable indicating the presence of a union, I include several other covariates (listed in the Appendix) that, based on prior literature and/or conversations with industry stakeholders, were deemed likely to affect mine safety. This article presents results from several leading specifications. Analyses were performed on two different versions of three models, for a total of six specifications. The two versions of each model differ in that the "public-fields" version relies solely on public data, whereas the "confidential-fields" version incorporates confidential data

least prone to reporting bias. The following injuries were deemed to meet these criteria: amputations; enucleations; fractures; chips; dislocations; foreign bodies in eyes; cuts and lacerations; punctures; burns/scalds; crushings; and chemical, electrical, and laser burns. Furthermore, fatalities of any type are included as traumatic injuries. So defined, "traumatic" injuries account for 38% of the injuries reported during the period of observation.

[12] All injuries that are not classified as "traumatic" injuries are classified as "non-traumatic" injuries.

[13] As a robustness check, I also estimate models in which *all* injuries occurring at underground mines – including those that occur above ground – are included in the injury counts. These results, presented on the Companion Website, do not materially change my findings.

[14] Tests of overdispersion consistently indicate that a negative binomial model is preferable to a Poisson model.

fields obtained from EIA.[15] The first model uses full-time equivalents (FTEs)[16] as the measure of mine size. Since it is conventional to use FTEs as a metric of size when comparing the frequency of workplace-related events, this is designated as the "baseline" model, as in Morantz (2012). The second and third models use employees[17] and coal tonnage[18] as alternative measures of mine size.

Several prior studies by Weil (1987:181-84; 1991:23; 1992:124-25) suggest that unions' effects on workplace safety may vary by employer size. For example, unions at large and small facilities may differ in their capacity to exercise their "walk around" rights during MSHA inspections; to form powerful health and safety committees; to independently conduct inspections; and to enforce open-door policies among safety and health personnel. To explore whether unions' impact varies by mine size, I fit several models including interaction terms between union status and mine size quartiles.

The final public-fields specification includes the following regressors: union dummy, union-size interaction term, mine size measure, logged controller size measure, mine age, productivity, number of lost-work injuries (in hundreds) in the previous four quarters, total penalty points (in thousands) in the previous four quarters, a constant term, dummies indicating presence of each type of mine subunit, quarter dummies, MSHA district dummies, and a longwall indicator. The confidential-fields version replaces the longwall indicator with mining method percentages and also includes the number of coal beds, mean coal bed thickness (in yards), subsidiary indicator, captive production as a percentage of total production, and recoverable coal reserves. Table 1 presents descriptive statistics for each of these covariates.

For total, traumatic, and non-traumatic injuries, I use the most granular time period available, the "mine-quarter," as the unit of analysis. However, because fatalities are such rare events, using quarterly data is problematic when modeling fatality counts. There is often too little variation across observations to obtain valid estimates. Therefore, I use the "mine-year" as the unit of analysis in all fatality regressions.

By including a broader set of covariates than has been used in previous studies, I attempt to minimize omitted variable bias. Nevertheless, there are several potentially confounding

[15] See Appendix A for a complete description of model specifications.
[16] Yearly FTEs are defined as 2,000 hours worked, and quarterly FTEs are defined as 500 hours worked.
[17] MSHA defines employees as the average number of persons working during a given quarter, rounded to the nearest whole number.
[18] Tonnage is the total coal production of all sections (including surface operations) at an underground mine.

characteristics of union and nonunion miners – such as disparities in miners' demographics and remuneration levels – for which I cannot control. These limitations, including their implications for the interpretation of my findings, are discussed in Section Six.

Other types of unobservable, mine-level heterogeneity could also bias my analysis. For example, unusually hazardous geological conditions may affect a mine's injury rate as well as the likelihood that its employees will vote for unionization. In theory, a promising way to control for unobservable heterogeneity across mines is to use (mine-level) fixed effects to explore whether a given mine's safety record changes in predictable ways when it ceases (or begins) operating under a union contract. In practice, however, estimating fixed-effects models in this context creates more identification problems than it solves. First, only a small proportion of underground coal mines (18.2%) changed union status during the period examined. Second, these mines seem to be highly unrepresentative of the population as a whole.[19] Any identification strategy predicated upon this idiosyncratic subgroup would likely yield biased estimates of unionization's true effect. In short, despite its intuitive appeal, a fixed-effects modeling approach appears ill-suited to the peculiarities of the mining industry during this period.[20]

Importantly, most of the statistical biases discussed in prior literature will tend, if anything, to attenuate unionization's measured effect. For example, virtually all scholars that consider the possibility of selection bias have argued, on both theoretical and empirical grounds, that inherently hazardous mines are *more* likely to unionize (Brown 1995; Leigh 1982; Worrall and Butler 1983; Hirsch and Berger 1984; Hills 1985; Robinson 1988b; Robinson 1991). If this is correct, then because I cannot control for each mine's inherent perilousness, any estimates of unions' beneficial impact will most likely be biased *downward*.[21]

[19] Industry stakeholders recounted that, in recent decades, mines that underwent changes in union status typically did so in the wake of adverse economic shocks, such as sudden changes in the regulatory environment. The data seem to bear out this claim. At least 20% of coal mines that de-unionized and 76% of mines that became unionized during the sample period experienced major disruptions (defined as production, employment, or hours worked dropping by over 50%; a year or more of inactivity; or change of the mine operator or mine controller) during the same year in which the transition took place. Such operational discontinuities are likely to have exerted an independent effect on safety practices, making it difficult to empirically isolate the effect of (de-)unionization. Moreover, the unusually precarious environment in which unions were forced to operate before or after these transitions may have constrained their capacity to influence mine safety practices.

[20] Notwithstanding these significant methodological concerns, for the benefit of the interested reader, Appendix C presents results from mine-level fixed-effects models.

[21] One might imagine, alternatively, a form of adverse selection in which the *most* dangerous mines are the *least* likely to unionize. For example, if the most dangerous mines are the least profitable, and therefore the most likely to shut down in adverse economic conditions, workers may vote against unions for fear that any increase in marginal (or fixed) costs would trigger a mine shutdown. Alternatively, mine operators that invest the least in workplace

Another type of bias that has received much attention in the literature, often referred to as "reporting bias," stems from the fact that injury reporting practices may differ across union and nonunion environments. For example, nonunion miners may fail to report legitimate injuries due to a fear of reprisal from their employers. On the other hand, some unions may encourage, or at least facilitate, the reporting of fraudulent or exaggerated claims (Hirsch et al. 1997; Morse et al. 2003). Even in the absence of outright employer intimidation or employee fraud, institutional norms may differ regarding what "counts" as a compensable occupational injury. For example, Azaroff et al. (2002) suggest that an array of subtle attitudinal barriers that impede the detection and reporting of injuries are less pronounced in unionized workplaces, especially for injuries that are relatively minor and/or hard to diagnose. In apparent support of this hypothesis, Hirsch et al. (1997) and Morse et al. (2003) find that even among workers that self-report similar rates of occupational injuries, union workers are more likely to receive workers' compensation benefits. In short, reporting bias also will tend to diminish the measured impact of unionization.

Fortunately, my data enable me to explore the magnitude of reporting bias indirectly. I examine four different injury categories that differ in their relative susceptibility to this bias: non-traumatic injuries, total injuries, traumatic injuries, and fatalities. As illustrated in Figure 4, non-traumatic injuries are hypothesized to be the most prone to reporting bias because they (by definition) include cumulative injuries whose work-relatedness can be difficult to confirm. At the opposite end of the continuum are workplace fatalities, which are virtually impossible to hide from authorities and regulators. The remaining two measures – total and traumatic injuries – are expected to fall in between these two extremes. Total injuries are less prone to reporting bias than non-traumatic injuries, since they include fatalities and severe traumatic injuries as well as minor injuries. Traumatic injuries are hypothesized to be even less susceptible to reporting bias than total injuries, since they exclude (by definition) cumulative injuries.

If there is significant reporting bias across union and nonunion mines, the union safety effect (if any) should appear strongest in the fatality rate models; somewhat weaker in the traumatic injury rate models; weaker still in the total injury rate models; and weakest of all in the non-traumatic injury rate models. In other words, I hypothesize that union status will be associated with more and more reported injuries as the focus of inquiry shifts from fatalities, to

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safety may invest the most in (or become especially skilled at) defeating union certification elections. Although this form of adverse selection seems plausible – especially in monopsonistic or oligopsonistic labor markets – I am unaware of any prior literature that confirms its existence.

traumatic injuries, to total injuries, and then to non-traumatic injuries. Although the following section summarizes my main findings, space constraints preclude me from reproducing detailed results from each and every model specification and robustness check that was performed. For the benefit of the interested reader, an ancillary website[22] presents a number of additional model specifications and robustness checks.

5 Results

Tables 3-5 present the study's main findings for the four different outcome measures described earlier: non-traumatic injuries, total injuries, traumatic injuries, and fatalities. For ease of interpretation, I transform each coefficient into an incident rate ratio (IRR), whereby a coefficient of 1 indicates no change at all in predicted injuries; coefficients between 0 and 1 represent a predicted fall in injuries (e.g. a coefficient of 0.97 represents a 3% decline); and coefficients greater than one represent predicted increases (e.g. a coefficient of 1.03 represents a 3% rise).

The results of the leading models presented in Table 3, which capture the average or "net" effect of unionization across all mines, display a striking pattern. On one hand, unionization is associated with a very sizable (more than 20%), robust, and statistically significant *increase* in non-traumatic injuries across all specifications. The results for total injuries are similar but more muted: although unionization is associated with an increase in total injuries, the disparity is smaller in magnitude, when significant, and is not robust across all specifications. Traumatic injuries, on the other hand, present a very different picture; unionization is now associated with a sizable (more than 20%) and highly significant *decline* in traumatic injuries across all specifications. In the models of fatal injuries, unionization is associated with an even larger (at least 50%) fall in fatal injuries across all six specifications.

In short, the model results are broadly consistent with both of the hypotheses originally posed. First and foremost, unionization is associated with a significant decline in those mine accidents that are least vulnerable to reporting bias. Secondly, the dramatic extent to which unions' measured impact varies by injury type suggests that there are indeed significant

[22] http://amorantz.stanford.edu/papers/union-coal-mine-safety/

discrepancies in reporting practices across union and nonunion mines.[23]

Table 4 probes the extent to which the trends observed differ by mine size. Although the analysis is restricted to the baseline specification, the continuous mine size term is replaced by discrete size quartile dummies (defined such that a fourth of all mine-quarters fall in each quartile) and the "union" and "union X size" terms are replaced with "union X size quartile" interaction terms. Viewed in light of prior literature, the results presented in Table 4 are somewhat counterintuitive. Most scholarship suggests that larger firms – regardless of union status – have the strongest intrinsic incentives to invest in workplace safety (Weil 1987:124-28, Genn 1993:220-230, Fenn and Veljanovski 1988:1065; Reilly et al. 1995:280; Ruser 1985:485; Frick and Walters 1998:368). Therefore, one might expect unions' impact on workplace safety to be the greatest in smaller mines. Yet Table 4 reveals the opposite trend: unionization's depressive effect on traumatic and fatal injuries is the greatest and most robust among larger mines. What might explain this seemingly counterintuitive finding? Perhaps unions are better equipped to influence workplace safety and injury reporting policies in mines that exceed a certain size threshold. For example, it may be difficult for unions in small mines to establish active health and safety committees, to routinely conduct independent inspections, or to consistently accompany MSHA inspectors on their tours.

Table 5 probes changes over time by breaking the analysis into three discrete time periods (1993-1998, 1999-2004, and 2005-2010) using the baseline specification. The disparity between union and nonunion mines in non-traumatic injuries diminishes over time. The results for total injuries tell a similar story: although unionization is associated with a significant and sizable (32%) increase in total injuries in the mid 1990s, the disparity diminishes and loses significance in the later years. Traumatic injuries, however, reveal a different pattern: although there is no significant disparity across groups in the mid 1990s, unionization is associated with a significant and sizable *decline* in traumatic injuries in later years. Fatal injuries exhibit a mixed pattern: although unionization is associated with a large decrease in the number of fatalities around the turn of the century, the disparity lacks statistical significance in earlier and later years. In short, especially if one confines scrutiny to traumatic injuries, the union safety effect appears to be a relatively recent phenomenon.

[23] The fact that as noted in Table 2, traumatic injuries comprise a much smaller percentage of total injuries in union mines (30.9%) than in nonunion mines (42.4%) might also be construed as circumstantial evidence of reporting bias.

Although not the focus of this study, the other covariates included as right-hand-side variables reveal several interesting patterns. Table 6 displays the full regression coefficients for all of the baseline models. Although many of the estimated effects mirror those of prior studies, some either conflict with previous estimates or illuminate relationships that prior scholarship has not fully explored. The Companion Website discusses these and other ancillary findings.[24]

6 Interpretation

Taken at face value, my results are broadly consistent with three hypotheses regarding the relationship between unionization and coal mine safety. First, unionization improved "real" mine safety levels (as reflected in traumatic and fatal injury rates) around the turn of the twenty-first century. Second, reporting bias has probably confounded prior studies of the union safety effect, especially when the outcome measures examined have included minor and non-traumatic injuries. Finally, the union safety effect may not have existed at all (in the modern era) until the early 1990s.

Several important questions remain. First, what is the likelihood that omitted variable bias has confounded my identification strategy?

One potentially consequential mine-level characteristic that I cannot observe is the age distribution of the workforce. Although some epidemiological literature on the frequency of accidents by age group suggests that younger and less experienced miners sustain more injuries on the job (e.g. Laflamme and Blank 1996), the scholarship is not unanimous on this point. (See, for example, Souza 2009.) Based on a careful review of existing literature, Salminen (2004) reports a bifurcated pattern, in which young workers are more susceptible to non-fatal injuries and older workers are more prone to occupational fatalities. If the distribution of age or experience differs substantially across union and nonunion mines—and if such age differentials independently affect miners' likelihood of sustaining traumatic or fatal injuries – this could bias my results. Unfortunately, demographic variables are unavailable at the mine level, making it

[24] The robustness checks described on the website include the following: using preprocessing to define a subset of homogenous mines and replicating the same models on this subset; expanding the sample to include surface injuries at underground mines; fitting models in which three alternative subsets of injuries (intermediate injuries, fatalities excluding major disasters, and fatalities only from explosions and collapses) are the dependent variables; using alternative discrete size measures; alternative time-trend models; and various other robustness checks that include/exclude certain variables.

difficult to verify the existence, let alone to estimate the magnitude, of such biases.[25] The only source that facilitates any age comparisons is the Current Population Survey (CPS), which includes questions regarding age, occupation, and union membership. Although the small sample size allows for only rough comparisons, the data suggest that the average miner is older today than he was in 1990, and that the age difference between union and nonunion miners has grown over time.[26]

Even so, this discrepancy in age seems unlikely to explain much of the estimated union safety effect, for two reasons. First, although the union–nonunion gap in the frequency of traumatic injuries widened during the 1990s, the gap in the proportions of young miners (under age 30) at union and nonunion mines changed little during this period.[27] Secondly, the union–nonunion differential in the proportion of miners that are over 50 years old widened during the 1990s.[28] If Salminen (2004) is correct that the likelihood of sustaining a fatal injury increases with age, one would expect fatality rates to have risen disproportionately in union mines, biasing my results downward. Yet if anything, unions' salutary effect on mining fatalities slightly intensified during this period.

Several stakeholders suggested that unionized miners are also somewhat more experienced than their nonunionized counterparts, and that total compensation (including fringe benefits) is higher at union mines, although both of these disparities have diminished in recent decades. Unfortunately, there are no data available with which to test the validity of these

[25] The decennial survey administered by the U.S. Census Bureau – even the "long" form administered to 5% of the population for the Public-Use Microdata Samples (PUMS) – contains no information on union membership. The U.S. Census Bureau's Longitudinal Employer-Household Dynamics Program (LEHD) does contain mine-level demographic data. However, the LEHD dataset excludes Kentucky and Pennsylvania, which contain 43% of all underground, bituminous mines in the U.S., and data for West Virginia and Virginia – which contain an additional 46% of mines in our sample – are available only for 1997 onwards. The current version of the LEHD dataset only includes data through 2004, although the Census plans to augment the LEHD with data through 2008 by the end of 2011. Additionally, since the Census Bureau and MSHA use different employer identifiers, merging these two datasets would pose significant challenges. (Interview with Angela Andrus, Census Research Data Center, February 9, 2011; Interview with Emily Isenberg at the LEHD Program, U.S. Census.)

[26] For example, the typical (median) unionized miner was 41 in 1990; 46 in 2000; and 51 in 2010. In contrast, the median nonunion miner was 38 in 1990, 45 in 2000, and 45.5 in 2010. A t-test comparing the mean ages of union and nonunion miners reveals that union miners are older at a 10% level of significance. I use CPS Outgoing Rotation Group (ORG) survey data to derive these statistics, restricting the CPS data to observations within the Coal Mining Industry, in the labor force, and not self-employed.

[27] CPS data from 1990 indicates that 5% of union miners and 16% of nonunion miners were under the age of 30. In 2000, the percentage of union miners below 30 was 0%, versus 12% of nonunion miners.

[28] CPS data from 1990 indicates that 16% of union miners and 10% of nonunion miners were over the age of 50. By 2000, 29% of union miners and 21% of nonunion miners were over the age of 50.

claims.[29]

In short, I cannot rule out the possibility that omitted variable bias – such as differentials in age, experience, or total remuneration between union and nonunion mines – have confounded my analysis. Nevertheless, the scant information available on disparities in miner demographics do not correlate particularly well with the trends observed in the data.

If my findings do in fact reflect genuine disparities in workplace safety, this raises a second important question: why do my estimates differ so sharply from prior literature? There are two possibilities.

First, it could be that a union safety effect has always existed, but has simply eluded detection due to data constraints and the methodological limitations of prior work. Although I cannot replicate my analysis on data from prior to 1993 (since the unionization data no longer exist), when I analyze my own data using a methodology similar to that of Appleton and Baker (1984), the results are substantively very similar to those reported above.[30] Although far from conclusive, this replication exercise suggests that the union safety effect may indeed be a relatively recent phenomenon.

If so, then a final puzzle demands careful scrutiny: why didn't these same disparities emerge in the 1970s? Several possibilities merit investigation.

First, fluctuations over time in the stringency of MSHA's enforcement scrutiny may affect union and nonunion mines differently. For example, Weil (1987), examining data from the early 1980s, finds that union mines were subject to more stringent enforcement scrutiny.[31] Examining data from 1995-2009, Morantz (2012) finds that this disparity persists along several measures of regulatory enforcement.[32] If MSHA inspects union mines more intensively than

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[29] The CPS does not ask any questions regarding the prevalence or magnitude of "fringe" benefits such as pensions or life insurance. Questions regarding job tenure are collected every other year as part of the January supplement, which typically includes about fifteen respondents from the mining industry, of whom only a handful belong to a union. Due to these extremely small sample sizes, one cannot draw any meaningful inferences regarding whether (and to what extent) the average tenure of union and nonunion miners has differed in recent years.

[30] See the Companion Website for a detailed description of my attempt to replicate Appleton and Baker's methodology using the more recent dataset.

[31] Weil (1987) finds that union mines are more likely to designate employee representatives; receive more frequent MSHA inspections of longer average duration; are granted shorter periods in which to abate violations; are granted fewer abatement extensions; receive more citations per inspection; pay higher penalties per violation; and are less successful in reducing penalty amounts through MSHA's internal administrative appeals process than nonunion mines (pp. 120-185).

[32] Morantz (2012) finds that unionization is associated with increases in regular inspection hours per mine quarter, total inspection hours per regular inspection, the proportion of total inspection hours spent onsite, and the proposed fine assessed for significant and substantial violations.

nonunion mines -- and if this differential has widened over time -- it might help explain the observed trends. However, detailed comparison of the results presented here with those reported in Morantz (2012) does not provide strong support for this hypothesis. Whereas the "union safety effect" described in Section 5 is strongest among large mines, the enforcement disparities reported in Morantz (2012) diminish sharply with mine size.

Secondly, unions may have shifted their institutional priorities near the turn of the century, deliberately choosing to forfeit potential wage increases in exchange for enhanced levels of workplace safety. CPS data do show some convergence in median (real) wages of union and nonunion miners since the early 2000s. However, there are several reasons to doubt that the UMWA's leadership has pursued such a strategy.[33]

Finally and most importantly, it may have taken time for the UMWA's leadership to train a cadre of union members capable of effectively exercising their statutory and contractual rights. In the words of one union official, "It can take a generation to institutionalize a robust safety culture and build a corps of experienced miners who can train the newcomers."[34] The labor strife that characterized much of the 1970s (and to a lesser extent the 1980s) likely impeded unions' capacity to enact meaningful changes. Weil (1994:199-200) has identified the election of Rich Trumka in 1982 to the presidency of the UMWA as a critical turning point, after which the union prioritized and funded the training of health and safety committee members. By the late 1980s and early 1990s, under the leadership of Joseph Main, the UMWA's Department of Health and Safety took more systematic measures to train its rank and file, such as the institution of local union training programs.[35] In short, changes in the leadership and institutional focus of the UMWA during the 1970s and '80s, designed to increase the union's long-term impact on mine

[33] First, according to the UMWA leadership, the disparity in benefits between union and nonunion miners has progressively widened even as the gap in hourly wages has narrowed. Therefore, they claimed, the true overall disparity in union–nonunion compensation has changed little in recent years. To the best of my knowledge, this assertion cannot be tested with available data. (Telephone conferences with Brian Sanson, May 21, 2010; and Phil Smith, May 28, 2010.) Second, the UMWA's leadership explained that young miners that began entering the workforce in large numbers in the first decade of the 21st century are much less likely to have family members who are miners, or to have grown up in "mining towns" where explosions and collapses are part of the collective memory. As a result, they show comparatively little interest in safety issues. As one official put it, "it has become very difficult to organize on safety issues." (Telephone conference with Phil Smith, May 28, 2010.) Finally, CPS data show no significant convergence in *mean* real wages of union and nonunion miners. The recent convergence in *median* wages could be driven, therefore, by a growing similarity in the respective proportions of inexperienced miners on the payroll, rather than a more general congruity in pay scales. The extreme paucity of miners surveyed for the CPS sample makes it difficult to conclusively resolve the issue.

[34] Telephone interview with Phil Smith, UMWA, May 28, 2010.

[35] Weil (1987:200); Telephone interview with Michael Buckner, UMWA's Director of Research from 1981-2005, on March 3, 2011.

safety, may not have come to fruition until the 1990s.

7 Conclusion

Although the United Mine Workers of America has always been a vigorous advocate for miners' safety, prior empirical literature has failed to detect any evidence of a union safety effect on injury or fatality rates. If anything, prior scholarship has reported a puzzling negative relationship between unionization and mine safety during the 1970s, the decade immediately following the Coal Act's passage. This study uses more comprehensive data and updated statistical methods to re-examine the relationship between unionization and mine safety. I focus on the 1993-2010 period, for which reliable mine-level information on union status is available, and use a variety of techniques to mitigate potential sources of bias.

I find that unionization is associated with a sizable and robust decline in both traumatic injuries and fatalities, the two safety outcomes that I argue are least prone to reporting bias. I construe these results as evidence for a "real" union safety effect in U.S. underground coal mining. At the same time, I find that unionization is associated with higher total and non-traumatic injuries, lending credence to claims that injury reporting practices differ significantly between union and nonunion mines.

Interestingly, my analysis also suggests that the union safety effect on traumatic injuries has become more significant in recent years. I propose several possible explanations for this trend, including an overall improvement in labor relations since the 1970s, fluctuations over time in the stringency of MSHA's enforcement scrutiny, the growing competitive pressures faced by union leaders, and the increasing sophistication and professionalization of UMWA safety programs. The empirical evidence available, although scant, suggests that the latter hypothesis is the most promising. Exploring the historical relationship between UMWA activities and mine safety in greater detail –including a richer, updated institutional account of the precise mechanisms whereby organized labor affects safety outcomes—would be a promising topic for future inquiry.

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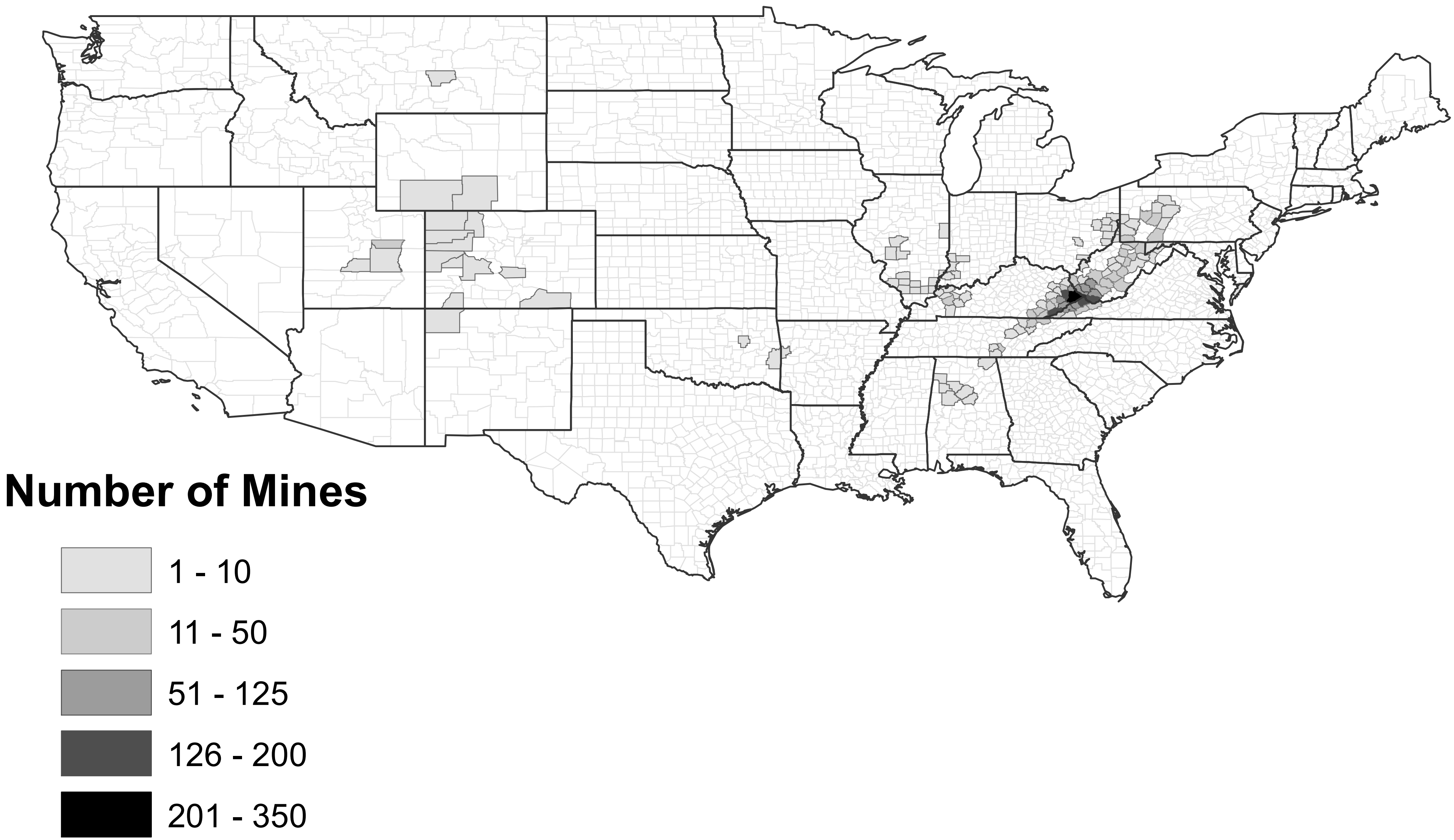
Figure 1. Underground Bituminous Coal Mines by County



County information was provided by MSHA. The county-level mine counts incorporate all 2,662 underground bituminous coal mines that were active for at least one quarter between 1993 and 2010. Note that, due to high rates of entry and exit in the industry, no more than half of the sample was active in any given quarter.

Figure 2. Union Penetration

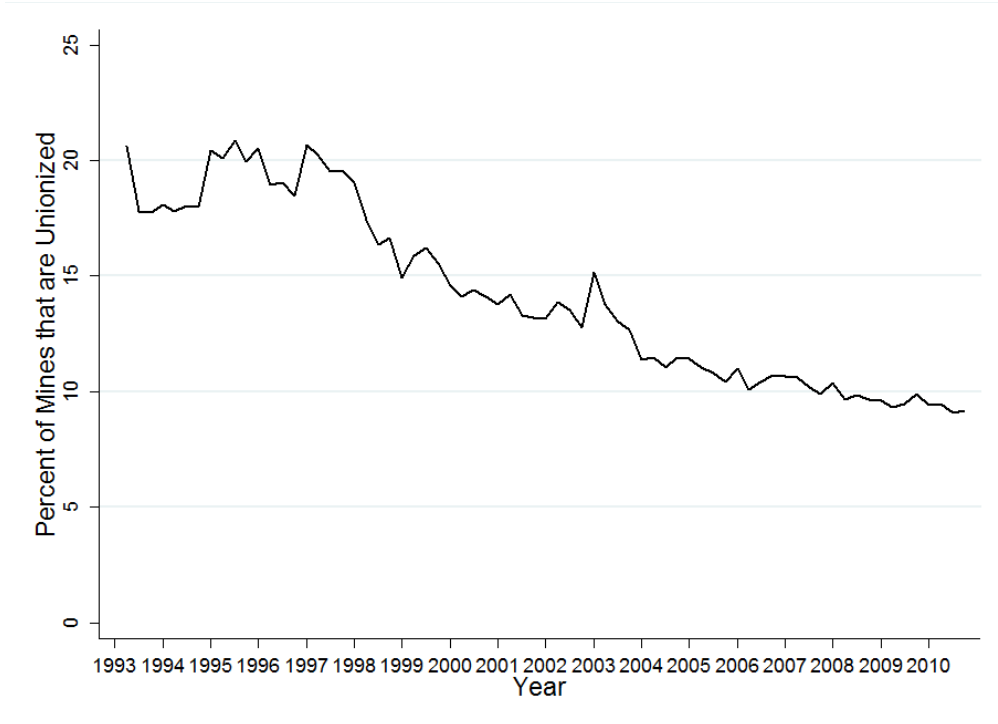


Figure 3. Rates of Total and Traumatic Injuries

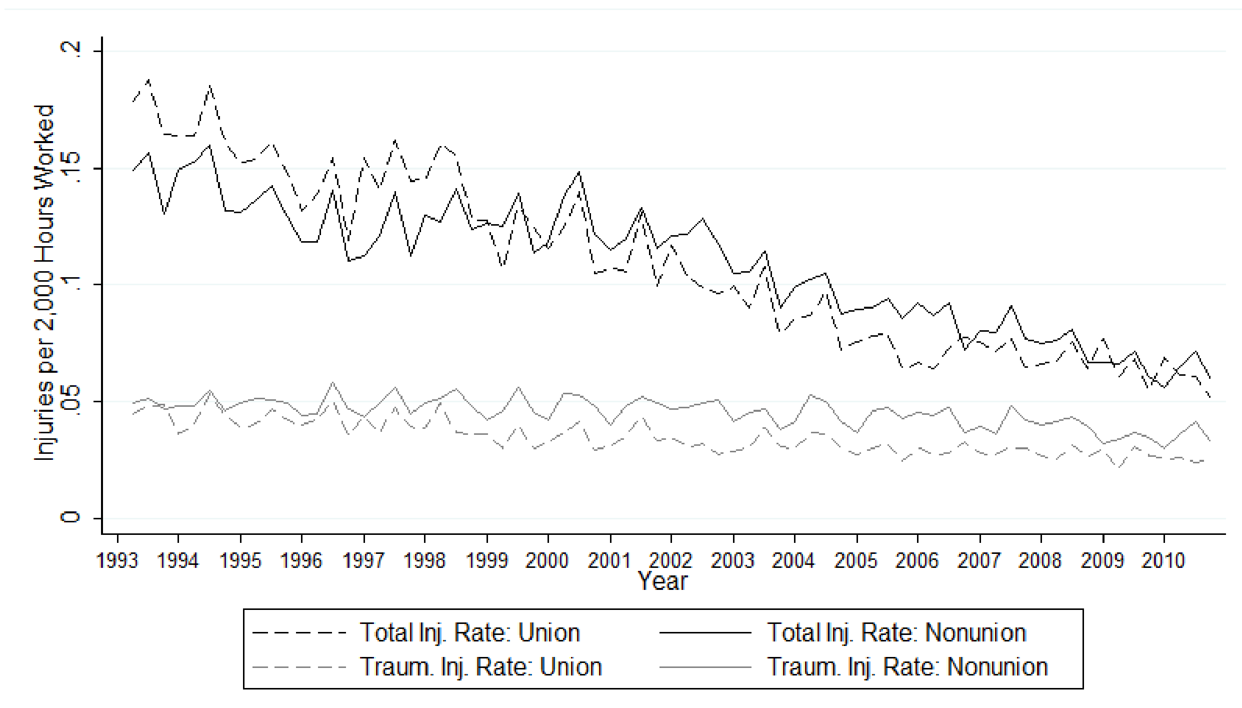


Figure 4. Susceptibility of Injury Types to Reporting Bias

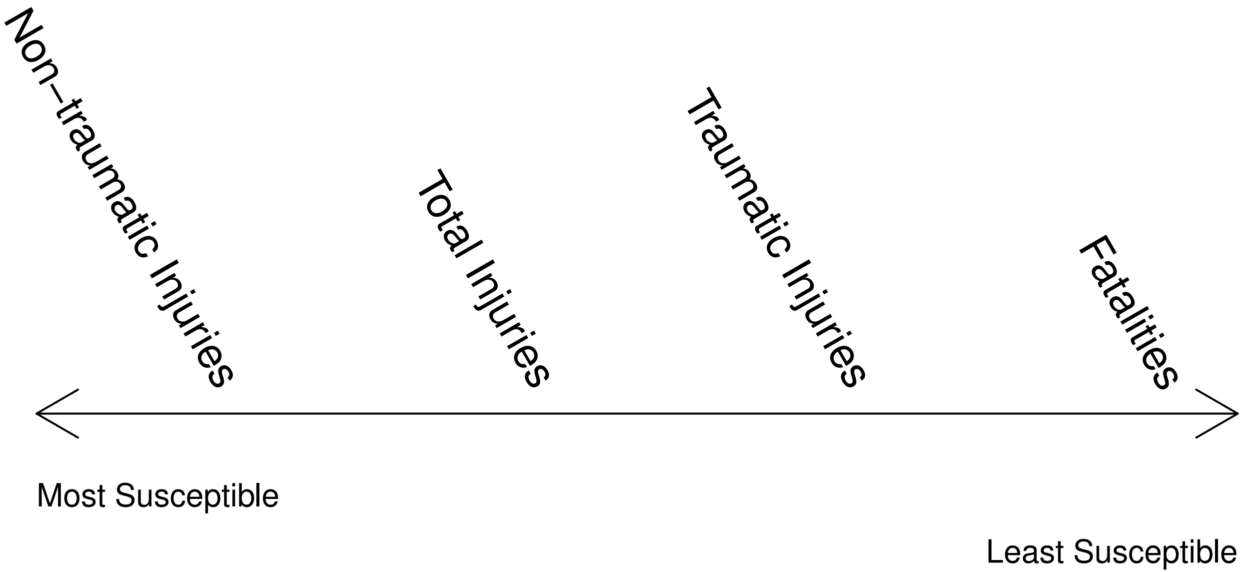


Table 1. Descriptive Statistics

Variable	Union Mines	Nonunion Mines
Injury Rates (per annual FTE)		
Total injuries	0.1427	0.1224
Traumatic injuries	0.0397	0.0447
Non-traumatic injuries	0.103	0.0777
Fatalities	0.0004	0.0011
Basic operational characteristics		
Mine age (years)	16.44	6.66
	(16.19)	(7.19)
Productivity	7.44	6.98
	(4.05)	(4.61)
FTEs	197.55	60.63
	(208.86)	(88.89)
Size Quartile 1	9.79	10.08
	(4.09)	(4.36)
Size Quartile 2	26.41	25.42
	(5.27)	(5.32)
Size Quartile 3	51.55	49.41
	(10.58)	(10.13)
Size Quartile 4	323.05	179.30
	(200.96)	(135.77)
Employees	179.00	53.36
	(182.51)	(74.75)
Tonnage	376,076	127,645
	(464,629)	(272,945)
Geological variables		
Coal beds	1.0224	1.0082
	(0.1565)	(0.1634)
Mean coal bed thickness (yards)	1.0345	0.9211
	(0.8893)	(0.7222)
Recoverable reserves (millions of tons)	21,045	7,383
	(33,181)	(29,135)

Variable	Union Mines	Nonunion Mines
Detailed operational characteristics		
Controller FTEs	2,120.9	981.8
	(2,517.9)	(1,736.0)
Controller employees	1,891.6	833.5
	(2,222.7)	(1,465.7)
Controller tonnage	7,205,267	2,471,185
	(11,321,615)	(5,941,978)
Subsidiary indicator	36.45%	21.39%
Longwall indicator	32.00%	4.26%
Subunits contained		
Surface	86.42%	83.09%
Mill or prep plant	28.23%	4.54%
Mining method percentages		
Conventional	0.071	0.153
	(0.257)	(0.359)
Continuous	0.652	0.786
	(0.427)	(0.402)
Longwall	0.270	0.036
	(0.391)	(0.168)
Shortwall	0.0018	0.0001
	(0.0373)	(0.0113)
Total sample size		
Mine-quarters	5,484	31,447
Mines	266	2,250

See Appendix B for complete variable definitions.

Table 2: Injury Type Breakdown

	All Mines:		Union Mines:		Nonunion Mines:	
Injury Type	**Frequency**	**% of Total**	**Frequency**	**% of Total**	**Frequency**	**% of Total**
Non-Traumatic[a]	50,127	62.0%	21,308	69.1%	28,819	57.6%
Total	80,844	100%	30,828	100%	50,016	100%
Traumatic[b]	30,717	38%	9,520	30.9%	21,197	42.4%
Fatality	375	0.4%	87	0.3%	288	0.6%

Notes:
This table reports the frequency of each injury type, as well as the share of total injuries that each category represents. Note that these categories are not mutually exclusive.
a The non-traumatic injury category is comprised of all injuries not classified as traumatic (see below). Note that the non-traumatic and traumatic injury counts sum to the total injury count.
b The traumatic injury category is comprised of the following: amputations; enucleations; fractures; chips; dislocations; foreign bodies in eyes; cuts and lacerations; punctures; burns/scalds; crushings; chemical, electrical, and laser burns; and fatalities. See footnote 11 for more details on this injury category.

Table 3: Effect of Union Status on Injury Frequency: Baseline Models

Specification	Baseline (Hours Worked)		Employees		Tonnage	
Model	Public-Fields Version	Confid.-Fields Version	Public-Fields Version	Confid.-Fields Version	Public-Fields Version	Confid.-Fields Version
Mine/Controller Size Units:	100 Quarterly FTEs	100 Quarterly FTEs	100 Employees	100 Employees	Millions of Tons	Millions of Tons
Non-Traumatic	1.344*** (0.07)	1.246*** (0.09)	1.367*** (0.07)	1.279*** (0.09)	1.368*** (0.07)	1.291*** (0.09)
Total	1.145*** (0.05)	1.041 (0.06)	1.159*** (0.05)	1.060 (0.07)	1.144*** (0.05)	1.047 (0.06)
Traumatic	0.776*** (0.04)	0.698*** (0.05)	0.778*** (0.04)	0.699*** (0.05)	0.771*** (0.04)	0.692*** (0.04)
Observations	36,931	23,961	36,931	23,961	36,931	23,961
# of Union Mines / # of Total Mines	341 / 2,516	184 / 1,652	341 / 2,516	184 / 1,652	341 / 2,516	184 / 1,652
Fatality	0.356*** (0.13)	0.417* (0.19)	0.370*** (0.13)	0.433* (0.20)	0.375*** (0.13)	0.417** (0.18)
Observations	11,045	6,948	11,045	6,948	11,045	6,948
# of Union Mines / # of Total Mines	352 / 2,568	182 / 1,644	352 / 2,568	182 / 1,644	352 / 2,568	182 / 1,644

Definitions: Significance levels: *** 1%, ** 5%, * 10%. A quarterly FTE is defined as 500 hours worked.
IRR Estimates: The table reports IRR (incidence rate ratio) coefficients on the union variables and union-size interaction variables in negative binomial regressions on injuries of each type. A coefficient of 1 thus indicates no change at all in predicted injuries; coefficients between 0 and 1 represent a predicted fall in injuries (e.g. a coefficient of 0.97 represents a 3% decline); and coefficients greater than one represent predicted increases (e.g. a coefficient of 1.03 represents a 3% rise). Hours worked is used as the exposure term. Standard errors are shown in parentheses and are clustered at the mine level.
Dependent Variables: *Non-traumatic injuries* is a tally of all underground injuries that were not classified as "traumatic" by my definition. *Total injuries* is a tally of all underground injuries at the mine. *Traumatic injuries* is a tally of all underground, traumatic injuries at each mine. The traumatic injury category is comprised of the following: amputations; enucleations; fractures; chips; dislocations; foreign bodies in eyes; cuts and lacerations; punctures; burns/scalds; crushings; chemical, electrical, and laser burns; and fatalities. See footnote 11 for more details on this injury category. *Fatalities* is a tally of all underground fatalities at each mine.
Independent Variables: All models include the following regressors: union dummy, union X size, mine size measure (a continuous measure defined with units as specified in column headers), logged controller size measure (a continuous measure defined with units as specified in column headers), mine age, productivity, total lost-work injuries (in hundreds) in previous four quarters (for non-fatality models) or previous calendar year (for fatality models), total penalty points (in thousands) in previous four quarters (for non-fatality models) or previous calendar year (for fatality models), constant term, dummies indicating presence of each type of mine subunit, quarter dummies, and district dummies. Public-fields version models include a longwall indicator. Confidential-fields version models include number of coal beds, mean coal bed thickness (in yards), subsidiary indicator, captive production as a percentage of total production, recoverable coal reserves, and mining method percentages. See Appendix B for full definitions of all variables. An expanded version of this table which includes all covariates is available on the companion website (http://amorantz.stanford.edu/papers/union-coal-mine-safety/).

Sample: The sample consists of underground bituminous coal mines with positive coal production and positive hours worked. The public-fields version models contain mine-quarters from 1993–2010, whereas the confidential-fields version models are restricted to 1998–2010. Because the historical variables (lost-work injuries and penalty points) are summed up for the previous *four quarters* for the non-traumatic, total, and traumatic injuries regressions and are summed up for the previous *calendar year* for the fatality regressions, there are some mines that are included in the fatality models but are excluded for other models. For example, for a mine that shuts down in the first quarter of 1992 and then reopens for a single quarter during the fourth quarter of 1993, the total number of lost-work injuries in the four quarters preceding the fourth quarter of 1993 (in the quarterly data) will be missing (because the mine was closed), while the number of lost-work injuries in the calendar year before 1993 (in the yearly data) will be non-missing, since we have at least one quarter of data from 1992.
Unit of Observation: The unit of observation is the mine-quarter for the non-traumatic, total, and traumatic injuries regressions. The unit of observation is the mine-year for fatality regressions.

Table 4: Effect of Union Status on Injury Frequency: Discrete Size Groups

Model	Non-Traumatic	Total	Traumatic	Fatal
Union X Size Quartile 1	1.285*	1.260**	1.179	0.000***
	(0.17)	(0.14)	(0.18)	(0.00)
Union X Size Quartile 2	1.241**	1.184**	1.026	0.313
	(0.10)	(0.09)	(0.09)	(0.31)
Union X Size Quartile 3	1.405***	1.178***	0.800***	0.843
	(0.11)	(0.07)	(0.05)	(0.52)
Union X Size Quartile 4	1.259***	1.009	0.710***	0.312***
	(0.07)	(0.05)	(0.04)	(0.09)
Observations	36,931	36,931	36,931	11,045
# of Union Mines / # of Total Mines	341 / 2,516	341 / 2,516	341 / 2,516	352 / 2,568

Definitions: Significance levels: *** 1%, ** 5%, * 10%. A quarterly FTE is defined as 500 hours worked.
IRR Estimates: The table reports IRR (incidence rate ratio) coefficients on the union variables and union-size interaction variables in negative binomial regressions on injuries of each type. A coefficient of 1 thus indicates no change at all in predicted injuries; coefficients between 0 and 1 represent a predicted fall in injuries (e.g. a coefficient of 0.97 represents a 3% decline); and coefficients greater than one represent predicted increases (e.g. a coefficient of 1.03 represents a 3% rise). Hours worked is used as the exposure term. Standard errors are shown in parentheses and are clustered at the mine level.
Dependent Variables: *Non-traumatic injuries* is a tally of all underground injuries that were not classified as "traumatic" by my definition. *Total injuries* is a tally of all underground injuries at the mine. *Traumatic injuries* is a tally of all underground, traumatic injuries at each mine. The traumatic injury category is comprised of the following: amputations; enucleations; fractures; chips; dislocations; foreign bodies in eyes; cuts and lacerations; punctures; burns/scalds; crushings; chemical, electrical, and laser burns; and fatalities. See footnote 11 for more details on this injury category. *Fatalities* is a tally of all underground fatalities at each mine.
Independent Variables: All models include the following regressors: hours-worked size quartile dummies (the first quartile is excluded), union X size quartile interaction terms, logged controller size measure, mine age, productivity, total lost-work injuries (in hundreds) in previous four quarters (for non-fatality models) or previous calendar year (for fatality models), total penalty points (in thousands) in previous four quarters (for non-fatality models) or previous calendar year (for fatality models), constant term, dummies indicating presence of each type of mine subunit, quarter dummies, district dummies, and a longwall indicator. The size measure for all models is the quarterly FTE and no confidential fields are used. See Appendix B for full definitions of all variables. An expanded version of this table which includes all covariates is available on the companion website (http://amorantz.stanford.edu/papers/union-coal-mine-safety/).
Sample: The sample consists of underground bituminous coal mines with positive coal production and positive hours worked. The sample contains mine-quarters from 1993–2010. Because the historical variables (lost-work injuries and penalty points) are summed up for the previous *four quarters* for the non-traumatic, total, and traumatic injuries regressions and are summed up for the previous *calendar year* for the fatality regressions, there are some mines that are included in the fatality models but are excluded for other models. For example, for a mine that shuts down in the first quarter of 1992 and then reopens for a single quarter during the fourth quarter of 1993, the total number of lost-work injuries in the four quarters preceding the fourth quarter of 1993 (in the quarterly data) will be missing (because the mine was closed), while the number of lost-work injuries in the calendar year before 1993 (in the yearly data) will be non-missing, since we have at least one quarter of data from 1992.
Unit of Observation: The unit of observation is the mine-quarter for the non-traumatic, total, and traumatic injuries regressions. The unit of observation is the mine-year for fatality regressions.

Table 5: Effect of Union Status on Injury Frequency: Time Trend

Model	FTE Public (Baseline)	1993-1998	1999-2004	2005-2010
Non-Traumatic	1.344*** (0.07)	1.511*** (0.09)	1.248** (0.12)	1.205* (0.14)
Total	1.145*** (0.05)	1.324*** (0.07)	1.054 (0.09)	0.974 (0.09)
Traumatic	0.776*** (0.04)	0.910 (0.06)	0.678*** (0.06)	0.715*** (0.08)
Observations	36,931	15,241	11,126	10,564
# of Union Mines / # of Total Mines	341 / 2,516	281 / 1,646	126 / 1,105	65 / 914
Fatality	0.356*** (0.13)	0.411* (0.20)	0.334* (0.20)	0.550 (0.38)
Observations	11,045	4,763	3,308	2,974
# of Union Mines / # of Total Mines	352 / 2,568	290 / 1,690	128 / 1,093	65 / 903

Definitions: Significance levels: *** 1%, ** 5%, * 10%. A quarterly FTE is defined as 500 hours worked.
IRR Estimates: The table reports IRR (incidence rate ratio) coefficients on the union variables and union-size interaction variables in negative binomial regressions on injuries of each type. A coefficient of 1 thus indicates no change at all in predicted injuries; coefficients between 0 and 1 represent a predicted fall in injuries (e.g. a coefficient of 0.97 represents a 3% decline); and coefficients greater than one represent predicted increases (e.g. a coefficient of 1.03 represents a 3% rise). Hours worked is used as the exposure term. Standard errors are shown in parentheses and are clustered at the mine level.
Dependent Variables: *Non-traumatic injuries* is a tally of all underground injuries that were not classified as "traumatic" by my definition. *Total injuries* is a tally of all underground injuries at the mine. *Traumatic injuries* is a tally of all underground, traumatic injuries at each mine. The traumatic injury category is comprised of the following: amputations; enucleations; fractures; chips; dislocations; foreign bodies in eyes; cuts and lacerations; punctures; burns/scalds; crushings; chemical, electrical, and laser burns; and fatalities. See footnote 11 for more details on this injury category. *Fatalities* is a tally of all underground fatalities at each mine.
Independent Variables: All models include the following regressors: union dummy, union X size, mine size measure, logged controller size measure, mine age, productivity, total lost-work injuries (in hundreds) in previous four quarters (for non-fatality models) or previous calendar year (for fatality models), total penalty points (in thousands) in previous four quarters (for non-fatality models) or previous calendar year (for fatality models), constant term, dummies indicating presence of each type of mine subunit, quarter dummies, district dummies, and a longwall indicator. The size measure for all models is a continuous measure with units in quarterly FTEs, and no confidential fields are used. See Appendix B for full definitions of all variables. An expanded version of this table which includes all covariates is available on the companion website (http://amorantz.stanford.edu/papers/union-coal-mine-safety/).
Sample: The sample consists of underground bituminous coal mines with positive coal production and positive hours worked. The sample contains mine-quarters from 1993–2010. Because the historical variables (lost-work injuries and penalty points) are summed up for the previous *four quarters* for the non-traumatic, total, and traumatic injuries regressions and are summed up for the previous *calendar year* for the fatality regressions, there are some mines that are included in the fatality models but are excluded for other models. For example, for a mine that shuts down in the first quarter of 1992 and then reopens for a single quarter during the fourth quarter of 1993, the total number of lost-work injuries in the four quarters preceding the fourth quarter of 1993 (in the

quarterly data) will be missing (because the mine was closed), while the number of lost-work injuries in the calendar year before 1993 (in the yearly data) will be non-missing, since we have at least one quarter of data from 1992. See footnotes 4-6 for description on additional restrictions imposed on the sample for the confidential-fields versions.
Unit of Observation: The unit of observation is the mine-quarter for the non-traumatic, total, and traumatic injuries regressions. The unit of observation is the mine-year for fatality regressions.

Table 6: Effect of Union Status on Injury Frequency: Full Covariate Report

Model	Non-Traumatic	Total	Traumatic	Fatal
Union	1.344***	1.145***	0.776***	0.356***
	(0.07)	(0.05)	(0.04)	(0.13)
Union X Size	0.975	0.964*	0.985	1.019
	(0.02)	(0.02)	(0.02)	(0.03)
Mine Size	0.871***	0.887***	0.919***	0.898***
	(0.02)	(0.02)	(0.02)	(0.03)
Log of Controller Size	0.942***	0.985**	1.048***	1.023
	(0.01)	(0.01)	(0.01)	(0.06)
Mine Age	0.999	0.999	0.999	1.002
	(0.00)	(0.00)	(0.00)	(0.01)
Productivity	0.993*	0.996	0.997	0.942***
	(0.00)	(0.00)	(0.00)	(0.02)
Lost-Day Injuries in Prev. Year	1.000***	1.000***	1.000***	1.000
	(0.00)	(0.00)	(0.00)	(0.00)
Penalty Points in Prev. Year	1.000***	1.000***	1.000***	1.000***
	(0.00)	(0.00)	(0.00)	(0.00)
Longwall Indicator	0.917	0.905*	0.922	1.593
	(0.06)	(0.05)	(0.07)	(0.54)
Mining Subunit Dummies[a]	Y	Y	Y	Y
District Fixed Effects[a]	Y	Y	Y	Y
Quarter/Year Fixed Effects[a]	Y	Y	Y	Y
Observations	36,931	36,931	36,931	11,045
# of Union Mines / # of Total Mines	341 / 2,516	341 / 2,516	341 / 2,516	352 / 2,568

Significance levels: *** 1%, ** 5%, * 10%

This table reports the full regression output for each of my baseline models, using the full sample from 1993 to 2010. The unit of observation is the mine-quarter, except for the fatalities regression, which is at the mine-year level.

[a] An expanded version of this table which includes fixed effects and dummy variables is available on the companion website (http://amorantz.stanford.edu/papers/union-coal-mine-safety/).

Appendix A: Description of Model Specifications

The list below describes the three specifications and two models that are included in each set of regressions.

Baseline Model (Hours Worked): Mine **s**ize is measured in 100 quarterly FTEs. Controller size is measured by the log of hours worked across all mines controlled by that controller, in 100 quarterly FTEs.

Employees Model: Mine size is measured in hundreds of employees. Controller size is measured by the log of employees across all mines controlled by that controller, in hundreds of employees.

Tonnage Model: Mine size is measured in millions of tons. Controller size is measured by the log of tonnage across all mines controlled by that controller, in millions of tons.

Public-Fields Specification: All models include the following regressors: union dummy, union-size interaction term, mine size measure (defined as specified in column headers or the table note), logged controller size measure (defined as specified in column headers or the table note), mine age, productivity, number of lost-work injuries (in hundreds) in the previous four quarters, total penalty points (in thousands) in the previous four quarters, a constant term, dummies indicating presence of each type of mine subunit, quarter dummies, district dummies, and a longwall indicator.

Confidential-Fields Specification: All models include the following regressors: union dummy, union-size interaction term, mine size measure (defined as specified in column headers or the table note), logged controller size measure (defined as specified in column headers or the table note), mine age, productivity, number of lost-work injuries (in hundreds) in the previous four quarters, total penalty points (in thousands) in the previous four quarters, a constant term, dummies indicating presence of each type of mine subunit, quarter dummies, district dummies, number of coal beds, mean coal bed thickness (in yards), subsidiary indicator, captive production as a percentage of total production, recoverable coal reserves, and the mining method percentages.

APPENDIX B: VARIABLE DICTIONARY

Variable Name	**Variable Definition**	**Source**
Non-traumatic injuries	Total number of injuries not classified as traumatic	MSHA
Total injuries	Total number of injuries and fatalities reported	MSHA
Traumatic injuries	A subset of injuries that are least prone to reporting bias. See footnote 11	MSHA
Fatalities	Total number of fatalities reported	MSHA
District dummies	1 if mine is located in a given MSHA district, 0 otherwise	MSHA
Ln (Controller Size)	Log of controller size measure. Controller size measure is either 100 FTEs, 100 employees, or one million tons	MSHA
Lost-workday injuries	Lost-workday injuries are those that result in time lost from work. When included as a regressor, it is the number of such injuries from the previous 4 quarters, in hundreds.	MSHA
Mine age	Age of mine in years since the first operator began work at the mine (top censored at 1970)	MSHA
Penalty Points	Thousands of penalty points in the previous year	MSHA
Productivity	Thousands of tons of coal produced per annual FTE (2,000 hours)	MSHA
Quarter/year indicators	1 if observation is for a given year or quarter, 0 otherwise	MSHA
Size Measure	Size measure is either 100 FTEs, 100 employees, or one million tons	MSHA
Subunit indicator	1 if mine contains a given subunit, 0 otherwise Subunit types include "surface" and "mill or prep plant"	MSHA
Mean coal bed thickness	The mean thickness of all coal beds at the mine, in yards	EIA[a]
Mining type	Proportion of underground operation that uses a given mining method, expressed as fraction between 0 and 1; types include conventional, continuous, longwall, shortwall, and other	EIA
Number of coal beds	Number of coal beds at the mine site	EIA[a]
Percent captive production	Percent of production for mine or parent company's own use	EIA[a,b]

Recoverable reserves	Estimated tonnage of remaining coal reserves	EIA[a,b]
Subsidiary indicator	1 if mine is a subsidiary of a larger firm, 0 otherwise	EIA[a]
Union indicator	1 if mine is unionized, 0 otherwise	EIA
Longwall Indicator	1 if mine is a longwall mine, 0 otherwise	NIOSH

Source: MSHA inspection records, 1993–2010; EIA coal mine data 1993–2010; NIOSH coal mine data 1993–2010.

[a] These data fields were obtained on a confidential basis, and are considered trade secrets by the companies that provided them.

[b] These data fields are unavailable prior to 1998.

APPENDIX C: FIXED EFFECTS MODELS

Specification	Baseline (Hours Worked)		Employees		Tonnage	
Model	Public-Fields Version	Confid.-Fields Version	Public-Fields Version	Confid.-Fields Version	Public-Fields Version	Confid.-Fields Version
Mine/Controller Size Units:	100 Quarterly FTEs	100 Quarterly FTEs	100 Employees	100 Employees	Millions of Tons	Millions of Tons
Non-Traumatic	1.387***	1.209	1.394***	1.215	1.452***	1.190
	(0.13)	(0.16)	(0.14)	(0.16)	(0.13)	(0.13)
Total	1.207**	1.114	1.202**	1.121	1.249***	1.109
	(0.09)	(0.12)	(0.09)	(0.12)	(0.09)	(0.10)
Traumatic	0.883	0.991	0.867	1.007	0.933	1.010
	(0.09)	(0.12)	(0.09)	(0.13)	(0.08)	(0.10)
Observations	3,963	1,573	3,963	1,573	3,963	1,573
# of Union Mines / # of Total Mines	164 / 164	81 / 81	164 / 164	81 / 81	164 / 164	81 / 81
Fatality	0.556	0.026	0.572	0.034	0.697	0.031
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Observations	3,963	1,573	3,963	1,573	3,963	1,573
# of Union Mines / # of Total Mines	164 / 164	81 / 81	164 / 164	81 / 81	164 / 164	81 / 81

Definitions: Significance levels: *** 1%, ** 5%, * 10%. A quarterly FTE is defined as 500 hours worked.
Limitations of Fixed Effects Model: Only a small proportion of underground coal mines (17.9%) changed union status during the period examined (1993-2010). Those that did change union status seem to be highly unrepresentative of the population as a whole: at least 22% of coal mines that de-unionized and 83% of mines that became unionized during the sample period experienced major disruptions (defined as production, employment, or hours worked dropping by over 50%; a year or more of inactivity; or change of the mine operator or mine controller) during the same year in which the transition took place. Any analysis predicated upon this idiosyncratic subgroup is likely to yield biased estimates of unionization's true effect. In short, despite its intuitive appeal, a fixed-effects modeling approach appears ill-suited to the peculiarities of the mining industry during this period, which is why I place this table in the appendix.
IRR Estimates: The table reports IRR (incidence rate ratio) coefficients on the union variables and union-size interaction variables in negative binomial regressions on injuries of each type. Hours worked is used as the exposure term. Standard errors are shown in parentheses and are clustered at the mine level.
Dependent Variables: *Non-traumatic injuries* is a tally of all underground injuries that were not classified as "traumatic" by my definition. *Total injuries* is a tally of all underground injuries at the mine. *Traumatic injuries* is a tally of all underground, traumatic injuries at each mine. The traumatic injury category is comprised of the following: amputations; enucleations; fractures; chips; dislocations; foreign bodies in eyes; cuts and lacerations; punctures; burns/scalds; crushings; chemical, electrical, and laser burns; and fatalities. See footnote **Error! Bookmark not defined.** for more details on this injury category. *Fatalities* is a tally of all underground fatalities at each mine.
Independent Variables: All models include the following regressors: union dummy, union X size, mine size measure (defined as specified in column headers), logged controller size measure (defined as specified in column headers), mine age, productivity, total lost-work injuries (in hundreds) in previous four quarters (for non-fatality models) or previous calendar year (for fatality models), total penalty points (in thousands) in previous four

quarters (for non-fatality models) or previous calendar year (for fatality models), constant term, dummies indicating presence of each type of mine subunit, quarter dummies, and district dummies. Public-fields version models include a longwall indicator. Confidential-fields version models include number of coal beds, mean coal bed thickness (in yards), subsidiary indicator, captive production as a percentage of total production, recoverable coal reserves, and mining method percentages. See Appendix B for full definitions of all variables. An expanded version of this table which includes all covariates is available on the companion website (http://amorantz.stanford.edu/papers/union-coal-mine-safety/).
Sample: The sample consists of underground bituminous coal mines with positive coal production and positive hours worked that switched union status as some point in the sample period. The public-fields version models contain mine-quarters from 1993–2010, whereas the confidential-fields version models are restricted to 1998–2010. Because the historical variables (lost-work injuries and penalty points) are summed up for the previous *four quarters* for the non-traumatic, total, and traumatic injuries regressions and are summed up for the previous *calendar year* for the fatality regressions, there are some mines that are included in the fatality models but are excluded for other models. For example, for a mine that shuts down in the first quarter of 1992 and then reopens for a single quarter during the fourth quarter of 1993, the total number of lost-work injuries in the four quarters preceding the fourth quarter of 1993 (in the quarterly data) will be missing (because the mine was closed), while the number of lost-work injuries in the calendar year before 1993 (in the yearly data) will be non-missing, since we have at least one quarter of data from 1992. See footnotes 4-6 for description on additional restrictions imposed on the sample for the confidential-fields versions.
Unit of Observation: The unit of observation is the mine-quarter for the non-traumatic, total, and traumatic injuries regressions. The unit of observation is the mine-year for fatality regressions.