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## Coal Mine Safety: Do Unions Make a Difference?

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# Coal Mine Safety: Do Unions Make a Difference?

## **Abstract**

Although the United Mine Workers of America (UMWA) has always advocated strongly for miners' safety, the empirical literature contains no evidence that unionization reduced mine injuries or fatalities during the 1970s and '80s. The author uses an updated methodology and a more comprehensive data set than previous studies to examine the relationship between unionization and underground, bituminous coal mine safety from 1993 to 2010. She finds that unionization predicts a substantial and statistically significant decline in traumatic injuries and fatalities, the two safety measures that are the least prone to reporting bias. These results are especially pronounced among larger mines. Overall, unionization is associated with a 14 to 32% drop in traumatic injuries and a 29 to 83% drop in fatalities. Yet unionization also predicts higher total and nontraumatic injuries, suggesting that injury reporting practices differ between union and nonunion mines.

## **Keywords**

safety, mining, mine, mines, MSHA, union, unions, Mine Safety and Health Administration, UMWA, United Mine Workers, injury, injuries, underreporting, reporting bias

## **Cover Page Footnote**

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# COAL MINE SAFETY: DO UNIONS MAKE A DIFFERENCE?

ALISON D. MORANTZ\*

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Although the United Mine Workers of America (UMWA) has always advocated strongly for miners' safety, the empirical literature contains no evidence that unionization reduced mine injuries or fatalities during the 1970s and '80s. The author uses an updated methodology and a more comprehensive data set than previous studies to examine the relationship between unionization and underground, bituminous coal mine safety from 1993 to 2010. She finds that unionization predicts a substantial and statistically significant decline in traumatic injuries and fatalities, the two safety measures that are the least prone to reporting bias. These results are especially pronounced among larger mines. Overall, unionization is associated with a 14 to 32% drop in traumatic injuries and a 29 to 83% drop in fatalities. Yet unionization also predicts higher total and nontraumatic injuries, suggesting that injury reporting practices differ between union and nonunion mines.

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**E**mpirical 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; giving workers incentives to take greater

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care on the job; attracting more safety-conscious workers; inducing employers to abate 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 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 safety regulations at all surface and underground coal mines (Fox 1990: 470–73). More recently, the UMWA played a critical role in broadening the provisions of the Coal Act and encouraging the formation of state regulatory agencies (Fox 1990: 462–70, 474, 504). By the 1980s, the Health and Safety Department of the UMWA 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 inspections; participating in pre- and post-inspection meetings; tracking MSHA appeals; providing various forms of safety training; and, in extreme cases, shutting down hazardous sections of a mine, a power conferred by a UMWA collective bargaining agreement with the Bituminous Coal Operator’s Association (BCOA) (Weil 1987: 117). Nevertheless, most empirical studies focusing on the 1970s and ‘80s have reported, if anything, a counterintuitive *positive* relationship between the presence of a union at a mine and the frequency of reported injuries and accidents.

This article re-examines the link between unionization and mine safety 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 several 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 that I argue are the least prone to reporting bias. My best estimates imply that overall, unionization predicts a 14 to 32%

drop in traumatic injuries and a 29 to 83% drop in fatalities.<sup>1</sup> These effects are especially pronounced among larger mines and, for traumatic injuries, after the mid-1990s. At the same time, however, unionization is associated with a significant *increase* in total and nontraumatic injuries, measures that are highly susceptible to reporting bias. Taken together, these findings lend credence to concerns that injury reporting practices vary significantly across union and nonunion settings.

### 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, Champagne, and German 1990), U.S. manufacturing (Fairris 1995), British manufacturing (Reilly, Paci, and Holl 1995; Nichols, Walters, and Tasiran 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 relying on aggregate cross-industry data from the United States, Canada, and Great Britain has rarely reported any robust evidence of a salutary union effect (Morantz 2009).

Given its inherent dangers, the mining sector has attracted a disproportionate share of scholarly attention. Several historical studies suggest that unions did not harm, and may have improved, miners' safety during the early twentieth century (Fishback 1986, 1987: 324; Boal 2009); however, empirical scholarship focusing on the decades after 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 mines sponsored by the National Research Council (1982), examining data from 1978–80, also briefly addresses the relationship between unionization and mine safety. The authors observe that the positive statistical relationship between union status and disabling injuries disappears when they confine attention to a measure of injuries that is less prone to reporting bias than total injuries, and that a (negative) correlation between unionization and mine fatalities also vanishes when one accounts for mine size.<sup>2</sup> On these grounds,

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<sup>1</sup>These ranges represent 95% confidence intervals for the coefficients on the "union" indicator variables in the public-fields version of the baseline (hours worked) specification presented in Table 2.

<sup>2</sup>"Intermediate" injuries, adjudged by the study's authors to be less prone to reporting bias than total injuries, are defined to comprise "all fatal and permanent disability injuries as well as all injuries resulting

the authors suggest that no relationship exists between unionization and underground coal mine safety (NRC 1982: 95–96).

Appleton and Baker (1984), the first study to focus squarely on the effect of union status, 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 these results. Several later commentators (Bennett and Passmore 1985; Weeks 1985) critique Appleton and Baker's conclusions by pointing out limitations in their data and methodology.

In sum, scholars have generally reported a *positive* relationship, if any at all, between union status and reported mining injuries 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 are geographically restricted, highly aggregated, time-invariant, and/or prone to small-sample bias. For instance, the 213 mines analyzed in Appleton and Baker (1984) were restricted to a single geographic region and constituted less than 10% of all coal mines that were active in 1978.

Third, all of the statistical analysis in prior studies consists of ordinary least squares regression modeling. Under standard assumptions, Poisson and negative binomial models 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

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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).

(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 became 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 recent data may bear more directly on unions’ contemporary relevance and may also yield more credible estimates of their long-term effect. To my knowledge, no study has directly investigated the relationship between unionization and mine safety since 1980.<sup>3</sup>

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 rates of occupational injuries in union and nonunion coal mines? Second, do such disparities persist if one focuses on measures of injury rates that are relatively impervious to reporting bias? Third, have the disparities remained constant, or have they fluctuated over time? Finally, what might explain these empirical findings?

### Data

The analysis presented here 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 data set 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.<sup>4</sup> In 2007, MSHA conducted a one-time survey of mines in an effort to identify which ones were operating under union contracts and in what year those mines became unionized. Using these data, one can obtain a snapshot of the union status of U.S. mines in 2007. However, determining whether any given mine was unionized in prior years and, if so, for how long, is impossible. 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 the mine is a subsidiary of a larger firm), and predominant extraction methods (such as the relative prevalence of longwall, shortwall, continuous, and conventional mining).

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<sup>3</sup>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.

<sup>4</sup>Phone conversation with George Fesak, Director of Program Evaluation and Information Resources, MSHA, on August 14, 2008.

To remedy these shortcomings, I supplement the MSHA database with information obtained from NIOSH and the Energy Information Administration (EIA) of the Department of Energy. The EIA database encompasses every mine in the United States that produces an appreciable amount of coal.<sup>5</sup> Most important 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.<sup>6</sup> 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.<sup>7</sup> Finally, the NIOSH data set contains an alternative (binary) measure for whether or not a mine utilizes longwall mining.<sup>8</sup> Merging the MSHA, EIA, and NIOSH data sets 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 data set, along with their respective sources, are presented in Appendix C.)

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. First, like most previous scholars, I confine my analysis to underground coal mines. (Surface coal mines, which have risk profiles and production characteristics different from underground coal mines, are also much less likely to be unionized.) Second, since none of the underground anthracite and lignite coal mines in the data set operated under a union contract during the sample period, I restrict the sample to bituminous coal mines. Third, I drop any mine-quarters in which a mine reported zero coal production and/or zero hours worked.<sup>9</sup>

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<sup>5</sup>According to the EIA Coal Production and Preparation Report (Form EIA-7A), the EIA collects data annually 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 (from MSHA) of underground, bituminous coal mines with active production for the years 1993–2010, 0.42% of mine-years do not have corresponding EIA data. These observations were dropped from the data set.

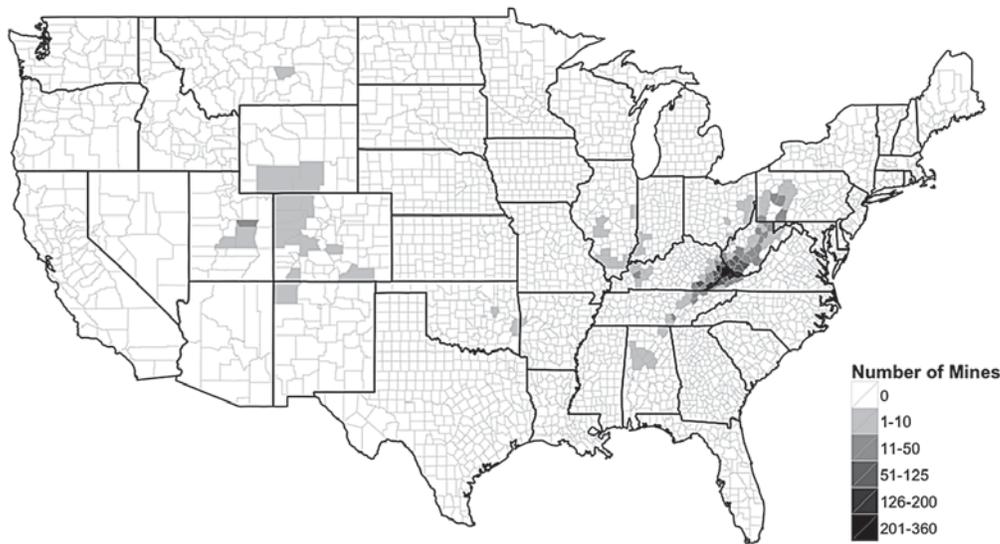
<sup>6</sup>The EIA considers this data unreliable prior to 1993 (Phone conversation with Vlad Dorjets, Lead Economist at EIA, on February 25, 2010). Since the EIA’s union data are reported annually, whereas MSHA’s injury data are reported quarterly, I make the simplifying assumption that the union status recorded for a particular year applies to all four quarters of that year.

<sup>7</sup>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 percent captive production, are unreliable before 1998 (e-mail correspondence with William Watson, EIA, December 7, 2010). Results including these confidential fields are presented in the “confidential-fields” specifications for 1998 onward.

<sup>8</sup>Because of the uncertainty surrounding which way of coding each mine’s extraction method is more accurate—the multifaceted approach used by EIA, or the binary approach used by NIOSH—I use the NIOSH indicator variable in the public-fields version of the models, and the mining method percentages (from EIA) in the confidential-fields versions of the models.

<sup>9</sup>While injuries occur occasionally when a mine is not producing coal, the underlying causes of such accidents are likely to differ from those that occur during active production. Out of 54,238 initial mine-

Figure 1. Number of Underground Bituminous Coal Mines per County, 1993–2010



Notes: County information was provided by MSHA. The county-level mine counts displayed in the figure include all 2,645 underground bituminous coal mines that were active for at least one quarter between 1993 and 2010. (Note that 10 mines depicted in this figure were missing information on controller, without which controller size could not be calculated, and therefore they were excluded from the final sample of 2,635 mines used in the regression analysis.) Because of high rates of entry and exit in the industry, no more than half of the sample was active in any given quarter.

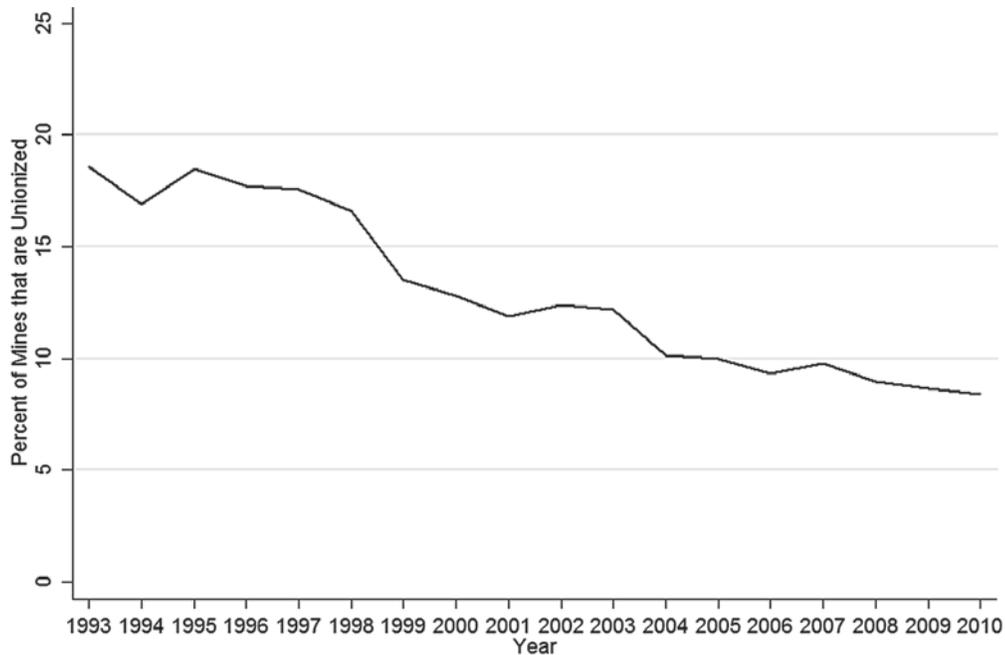
Once these restrictions are imposed, the final sample contains 38,890 mine-quarters and 2,645 mines.<sup>10</sup> Each mine was active, on average, for 15 of the 72 quarters under observation.<sup>11</sup> Figure 1 shows the geographical

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quarters, 15,348 (28%) reported zero coal production and/or zero hours worked; these were dropped from the analysis.

<sup>10</sup>Note that the total number of mines or mine-quarters in the sample does not necessarily correspond to the number of mines or mine-quarters analyzed in any given portion of the empirical analysis. For example, ten mines in the sample lack information on controller, without which controller size (a covariate included in all models) could not be calculated, reducing the effective sample size in the nontraumatic, total, and traumatic injury models to 2,635. Another change in effective sample size stems from the fact that while the historical variables (lost-work injuries and penalty points) are summed up over the previous four *quarters* in the nontraumatic, total, and traumatic injury regressions, they are summed up over the previous *calendar year* in the fatality regressions. Some recently opened mines are consequently excluded from the fatality models yet included in the other models. (For example, if a mine is open for all of just one calendar year, it will lack any historical data at the *yearly* level, but it will have historical data for three of the four *quarters* it was open.) The sample used for the public-fields versions of the fatality models therefore contains only 2,568 mines. Finally, the sample contains 166 mines that were unionized for part of the sample period and nonunionized for the remaining portion. All of these mines are double-counted in Appendix Table A.1, which compares sample means among unionized and nonunionized mines, yielding a total of 2,811 mines (356 union mines and 2,455 nonunion mines). Of these 166 mines, only 164 contain information on controller. Therefore, the sample size in the public-fields version of the fixed-effects models presented in Appendix Table A.3—focusing exclusively on mines that changed union status during the sample period—is 164.

<sup>11</sup>The underground coal mining industry exhibits high rates of entry and exit due to fluctuating demand and costs of production. For example, out of 949 mines that were active in the first quarter of 1993,

*Figure 2. Union Penetration*

*Notes:* For each year from 1993 to 2010, the figure displays the percentage of all underground, bituminous coal mines with non-zero production and hours worked that were unionized.

distribution of the mines in the sample. While the mines are spread across 17 states, 92% of them 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. Mirroring the general trend for most U.S. industries, the unionization rate declined steadily, from 18.4% in 1993 to 8.9% 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 in which the employee was engaged when the incident occurred, and the severity of the injury (ranging from “first aid” to “fatality”). Using these fields, I tabulate four different injury counts: fatal injuries (“fatalities”), “traumatic” injuries,<sup>12</sup>

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only 17% were still active in the first quarter of 2000 and only 4% remained active in the final quarter of 2010. Similarly, out of 433 mines that were active in the final quarter of 2010, only 30% had been active in the first quarter of 2000, and only 12% had been active in the first quarter of 1993.

<sup>12</sup>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 nontraumatic injuries, such as cumulative or repetitive-motion injuries, often relies on the patient’s self-report of subjective symptoms. Because the existence—let alone the work-relatedness—of the latter 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 the Division of General Internal Medicine at Stanford University. According to Dr. Cullen, the critical determining factor in 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 ef-

Table 1. Injury Type Breakdown

Injury type	All mines		Union mines		Nonunion mines	
	Frequency	% of Total	Frequency	% of Total	Frequency	% of Total
Nontraumatic <sup>a</sup>	48,873	62.6	20,506	70.0	28,367	58.1
Total	78,102	100	29,326	100	48,776	100
Traumatic <sup>b</sup>	29,229	37.4	8820	30.0	20,409	41.9
Fatality	353	0.5	75	0.3	278	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. The sample used includes all underground bituminous mine-quarters from 1993 to 2010 with positive coal production and positive hours worked.

<sup>a</sup>The nontraumatic injury category comprises all injuries not classified as traumatic (see below). Note that the nontraumatic and traumatic injury counts sum to the total injury count.

<sup>b</sup>The traumatic injury category comprises 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 12 for more details on this injury category.

“nontraumatic” injuries,<sup>13</sup> and total injuries. For each tabulation, I include only injuries that occurred in the underground subunit of a mine. Table 1 presents injury counts (and percentages) for both union and nonunion mines. Although fatalities uniformly make up a very small fraction (0.3–0.6%) of total accidents, the fraction of nontraumatic injuries is typically higher at union mines than at nonunion mines (70.0% compared with 58.1%).

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. Second, 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 millenium, union mines were reporting lower injury rates than nonunion mines regardless of the metric examined.

## Methodology

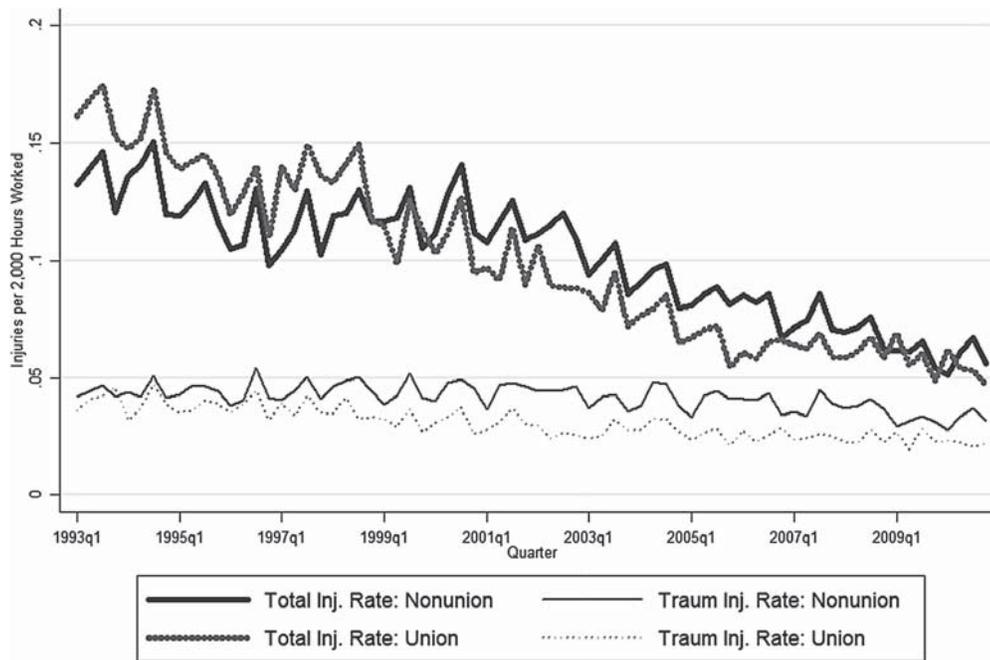
To explore the relationship between union status and safety outcomes, I estimate negative binomial regression models in which the dependent variables are, respectively, nontraumatic injuries, total injuries, traumatic

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fects are readily visible, that are “traumatic” (rather than cumulative) in nature are generally the least prone to reporting bias. The following injuries were deemed by Dr. Cullen 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. Fatalities of any type are also treated as traumatic injuries. So defined, “traumatic” injuries account for 37.4% of the injuries reported during the period of observation.

<sup>13</sup>All injuries that are not classified as “traumatic” injuries are classified as “nontraumatic” injuries.

Figure 3. Rates of Total and Traumatic Injuries



Notes: For each year from 1993 to 2010, the figure displays, respectively, total injuries and traumatic injuries per 2,000 hours worked for underground, bituminous coal mines. Figures are reported separately for unionized and nonunionized mines. For each given year and mine type, injuries and hours are summed across all mines.

injuries, and fatalities.<sup>14</sup> 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, are deemed likely to affect mine safety. This article presents results from several leading models. Two versions of three model specifications were estimated, for a total of six specifications. The two versions differ in that the “public-fields” version relies solely on public data, whereas the “confidential-fields” version incorporates confidential data from EIA.<sup>15</sup> The first model specification uses full-time equivalents (FTEs)<sup>16</sup> as the measure of mine size. Because the convention is to use FTEs to calculate the frequency of workplace accidents, this is designated as the “baseline” specification, as in Morantz (2012). The second and third specifications use employees<sup>17</sup> and coal tonnage<sup>18</sup> as alternative measures of mine size.

<sup>14</sup>Tests of overdispersion consistently indicate that a negative binomial model is preferable to a Poisson model.

<sup>15</sup>See Appendix B for a complete description of model specifications.

<sup>16</sup>Yearly FTEs are defined as 2,000 hours worked, and quarterly FTEs are defined as 500 hours worked.

<sup>17</sup>MSHA defines employees as the average number of persons working during each pay period of a given quarter, rounded to the nearest whole number (see <http://www.msha.gov/stats/part50/rptonpart50.pdf>). Results presented here include only employees working in the underground subunit.

<sup>18</sup>Tonnage is defined as the total tons of coal produced in the underground subunit of a mine.

Several studies by Weil (1987: 181–84, 1991: 23, 1992: 124–25) suggest that unions' effects on workplace safety vary by employer size. For example, unions at large and small facilities may differ in their respective capacities 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, mine size, union-size interaction term(s), logged controller size, mine age, mine productivity, number of lost-work injuries (in hundreds) in the previous four quarters (or in the previous year for fatality regressions), total penalty points (in thousands) in the previous four quarters (or in the previous year for fatality regressions), 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 adds as regressors 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. Appendix Table A.1 presents descriptive statistics for each included covariate.

For total, traumatic, and nontraumatic injuries, I use the most granular time period available, the "mine-quarter," as the unit of analysis. Because fatalities are such rare events, however, using quarterly data is problematic when modeling fatality counts. (Often too little variation occurs across observations to yield 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 hope to minimize omitted variable bias. Nevertheless, I cannot control for several potentially confounding characteristics of union and nonunion miners, such as disparities in miners' demographics and remuneration levels. These limitations, including their implications for the interpretation of my findings, are discussed in the Interpretation section.

Other types of unobservable, mine-level heterogeneity could bias my analysis. For example, unusually hazardous geological conditions may affect the injury rate of a given mine 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 handful of underground coal mines (6.2%) changed union status during the period examined. Second, these mines are highly unrepresentative of the population as a whole.<sup>19</sup> Any

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<sup>19</sup>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

identification strategy predicated on this idiosyncratic subgroup would likely yield biased estimates of the true effects of unionization. In short, despite its intuitive appeal, a fixed-effects modeling approach is ill-suited to the peculiarities of the mining industry during this period.<sup>20</sup>

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

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. At the same time, some unions may facilitate or even encourage the reporting of fraudulent or exaggerated claims (Hirsch, MacPherson, and Dumond 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, Levenstein, and Wegman (2002) suggest that attitudinal barriers that impede the detection and reporting of injuries are weaker 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 those who self-report similar rates of occupational injuries, union workers are more likely to receive workers' compensation benefits. In short, reporting bias may also diminish the measured impact of unionization.

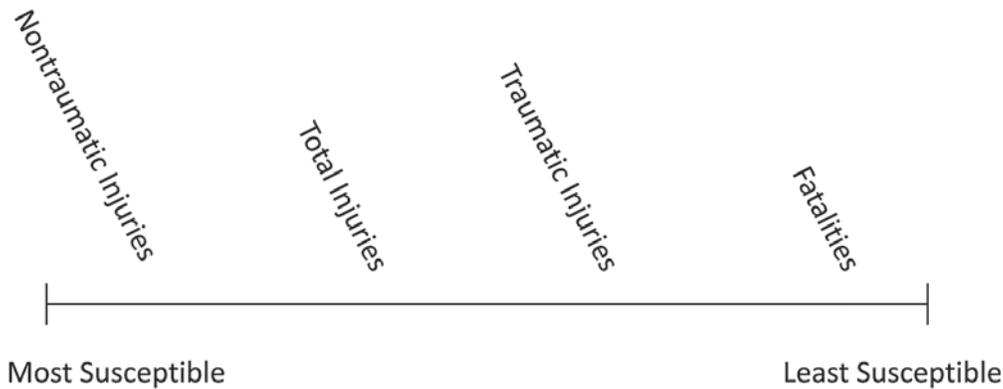
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environment. The data seem to bear out this claim. At least 53% of coal mines that de-unionized and 52% of mines that unionized during the sample period experienced a major disruption (defined as a more-than-fifty-percent drop in production, employment, or hours between two active, consecutive quarters; at least three consecutive quarters of inactivity; and/or a change in the mine's controller or operator) during the two-year period containing the change in union status. (Note that since EIA collects data on unionization only annually, we cannot pinpoint the specific quarter in which the shift took place but can identify the two-year “window” in which it occurred.) The operational discontinuities observed in the data are likely to have exerted an independent effect on mine safety, making it difficult to empirically isolate the impact of unionization. Moreover, the unusually precarious environment in which unions were forced to operate before or after these transitions may have limited their capacity to influence workplace safety.

<sup>20</sup>Notwithstanding these significant methodological concerns, for the benefit of the interested reader, Appendix Table A.3 presents results from mine-level fixed-effects models.

<sup>21</sup>One might imagine an alternative form of adverse selection in which the *most* dangerous mines are the *least* likely to unionize. For example, mine operators that invest the least in workplace 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.

Figure 4. Susceptibility of Injury Type to Reporting Bias



Fortunately, my data enable me to explore the magnitude of reporting bias indirectly by examining four different injury categories that vary in their relative susceptibility to such bias: nontraumatic injuries, total injuries, traumatic injuries, and fatalities. As illustrated in Figure 4, nontraumatic injuries are hypothesized to be the most prone to reporting bias because they (by definition) include cumulative injuries whose work-relatedness is often 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—fall in between these two extremes. Total injuries are less prone to reporting bias than nontraumatic injuries because they include fatalities and severe traumatic injuries. Traumatic injuries are hypothesized to be even less susceptible to reporting bias than total injuries since they exclude cumulative injuries.

If reporting bias is more prevalent at nonunion mines, then the union safety effect (if any) should appear strongest in the fatality rate models; weaker in the traumatic injury rate models; weaker still in the total injury rate models; and weakest of all in the nontraumatic injury rate models. In other words, union status should predict more injuries as the focus of inquiry shifts from fatalities, to traumatic injuries, to total injuries, and finally to nontraumatic injuries. The following section summarizes my main findings, but space constraints preclude me from presenting detailed results from each and every model specification and robustness check that was performed. For the benefit of the interested reader, the Companion Website<sup>22</sup> presents additional specifications and robustness checks.

## Results

Tables 2 to 4 present the main findings for the four different outcomes examined: nontraumatic injuries, total injuries, traumatic injuries, and fatalities.

<sup>22</sup>See <http://amorantz.stanford.edu/companions/union-coal-mine-safety/>.

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 an approximate 3% decline); and coefficients greater than 1 represent predicted increases (e.g., a coefficient of 1.03 represents an approximate 3% rise).

Results from the leading models presented in Table 2, which capture the average or “net” effect of unionization across all mines and time periods, display a striking pattern. On one hand, unionization is associated with a very sizable (more than 25%), robust, and statistically significant *increase* in nontraumatic injuries across all specifications. The results for total injuries are more muted: whereas in the public-fields versions the disparity is modest yet still statistically significant, it loses all significance in the confidential-fields versions. Traumatic injuries present a very different picture; unionization is now uniformly associated with a sizable (more than 20%) and highly significant *decline* in traumatic injuries. Similarly, unionization is associated with an even larger (more than 50%) fall in fatal injuries across all six specifications.

In short, the model results are broadly consistent with both of the hypotheses initially posed. First and foremost, unionization is associated with a significant decline in those mine accidents that are least vulnerable to reporting bias. Second, the dramatic extent to which unions’ measured effect varies by injury type suggests that significant discrepancies exist in reporting practices across union and nonunion mines.<sup>23</sup>

Table 3 probes whether the trends observed vary by mine size. Although the analysis resembles baseline specification, the continuous mine-size term is replaced by discrete size quartile dummies (defined such that a fourth of all mine-quarters fall into each quartile), and the “union” and “union x size” terms are replaced with “union x size quartile” interaction terms. At first glance, the results presented in Table 3 are surprising. Most prior scholarship suggests that larger firms—regardless of union status—have the strongest intrinsic incentives to invest in workplace safety (Ruser 1985: 485; Weil 1987: 124–28; Fenn and Ashby 2004: 161–80; Genn 1993: 220–30; Reilly et al. 1995: 280; Frick and Walters 1998: 368). Therefore, one might expect unions’ impact on workplace safety to be the strongest among smaller mines. Yet Table 3 reveals precisely the opposite trend: the depressive effect of unionization on traumatic and fatal injuries is the greatest and most robust among larger mines. What might explain this seemingly counterintuitive result? Perhaps unions are better equipped to influence workplace safety and injury reporting policies in mines that exceed a certain size threshold. For example, unions in small mines may find it difficult to

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<sup>23</sup>That traumatic injuries make up a much smaller percentage of total injuries in union mines (30.0%) than in nonunion mines (41.9%) (see Table 1) might also be construed as “circumstantial evidence” of reporting bias.

Table 2. Effect of Union Status on Injury Frequency: Baseline Models

Specification	Baseline (Hours worked)		Employees		Tonnage	
	100 Quarterly FTEs		100 Employees		Millions of tons	
Mine/Controller size units	Public- fields	Confid.- fields	Public- fields	Confid.- fields	Public- fields	Confid.- fields
Version	version	version	version	version	version	version
<b>Nontraumatic injury model</b>	1.351*** (0.07)	1.258*** (0.10)	1.376*** (0.07)	1.290*** (0.10)	1.363*** (0.07)	1.288*** (0.09)
<b>Total injury model</b>	1.148*** (0.05)	1.045 (0.07)	1.163*** (0.05)	1.062 (0.07)	1.141*** (0.05)	1.043 (0.06)
<b>Traumatic injury model</b>	0.765*** (0.04)	0.687*** (0.05)	0.767*** (0.04)	0.687*** (0.05)	0.762*** (0.04)	0.683*** (0.04)
Number of observations	38,890	24,593	38,890	24,593	38,890	24,593
No. of union mines / No. of total mines	355 / 2,635	186 / 1,684	355 / 2,635	186 / 1,684	355 / 2,635	186 / 1,684
<b>Fatality model</b>	0.346*** (0.13)	0.421* (0.19)	0.358*** (0.13)	0.436* (0.20)	0.369*** (0.13)	0.423** (0.18)
Number of observations	11,045	6,948	11,045	6,948	11,045	6,948
No. of union mines / No. of total mines	352 / 2,568	182 / 1,644	352 / 2,568	182 / 1,644	352 / 2,568	182 / 1,644

Notes: Significance levels: \*\*\* 1%, \*\* 5%, \* 10%. Standard errors, clustered at the mine level, are shown in parentheses.

**Results presented:** The table reports IRR (incidence rate ratio) coefficients on the union indicator variables in negative binomial regression models. 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 1 represent predicted increases (e.g., a coefficient of 1.03 represents a 3% rise). Hours worked is the exposure term.

**Definitions:** A quarterly FTE is defined as 500 hours worked.

**Unit of observation:** The unit of observation is the mine-quarter for the nontraumatic, total, and traumatic injuries regressions. The unit of observation is the mine-year for fatality regressions.

**Dependent variables:** The dependent variables are counts of injuries of each type (specified in the far-left column) that occur underground. *Traumatic injuries* are defined to include 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 12 for more details on the definition of traumatic injuries.) The sum of traumatic and nontraumatic injuries make up *total injuries*.

**Independent variables:** All models include the following regressors: union dummy, mine size (a continuous variable whose units are specified in column header), union x mine size, logged controller size (a continuous variable whose units are specified in column header), mine age, mine productivity, total lost-work injuries (in hundreds) during previous calendar year (for fatality models) or previous four quarters (for non-fatality models), total penalty points (in thousands) during previous calendar year (for fatality models) or previous four quarters (for non-fatality models), dummies indicating presence of each respective mine subunit, quarter/year dummies, district dummies, and a constant term. Public-fields versions also include a longwall indicator. Confidential-fields versions also include the 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 C for complete variable definitions. An expanded version of this table, including a full covariate report, is available at <http://amorantz.stanford.edu/companions/union-coal-mine-safety/>.

**Sample:** The sample consists of underground, bituminous coal mines from 1993–2010 with positive coal production, positive hours worked, and non-missing controller size data. The public-fields versions contain mine-quarters from 1993–2010, whereas the confidential-fields versions are restricted to 1998–2010. Because the historical variables (lost-work injuries and penalty points) are summed up over the previous four *quarters* in the nontraumatic, total, and traumatic injuries regressions but are summed up over the previous *calendar year* in the fatality regressions, some mines excluded from the fatality models are included in the other models. For example, if a mine is open for all of only one calendar year, it will have no historical data at the *yearly* level, but it will have historical data for three of the four *quarters* it was open. The number of union mines is computed by counting the mines that were unionized for any of the mine-quarters in the sample period. The number of total mines is computed by counting each mine in the sample, regardless of union status. Note that the confidential-fields versions of all models exclude any observations that lack information on confidential covariates.

Table 3. Effect of Union Status on Injury Frequency: Discrete Size Groups

Variable	Nontraumatic injuries	Total injuries	Traumatic injuries	Fatalities
Union x Size quartile 1	1.223 (0.16)	1.227* (0.14)	1.221 (0.19)	0.000*** (0.00) <sup>a</sup>
Union x Size quartile 2	1.237*** (0.10)	1.170** (0.08)	0.987 (0.09)	0.321 (0.32)
Union x Size quartile 3	1.424*** (0.12)	1.195*** (0.08)	0.815*** (0.05)	0.824 (0.51)
Union x Size quartile 4	1.249*** (0.07)	1.000 <sup>a</sup> (0.05)	0.697*** (0.04)	0.307*** (0.09)
Number of observations	38,890	38,890	38,890	11,045
No. of union mines / No. of total mines	355 / 2,635	355 / 2,635	355 / 2,635	352 / 2,568

Notes: Significance levels: \*\*\* 1%, \*\* 5%, \* 10%. Standard errors, clustered at the mine level, are shown in parentheses.

**Results presented:** The table reports IRR (incidence rate ratio) coefficients on the union indicator variables in negative binomial regression models. 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 1 represent predicted increases (e.g., a coefficient of 1.03 represents a 3% rise). Hours worked is the exposure term.

**Definitions:** A quarterly FTE is defined as 500 hours worked.

**Unit of observation:** The unit of observation is the mine-quarter for the nontraumatic, total, and traumatic injuries regressions. The unit of observation is the mine-year for fatality regressions.

**Dependent variables:** The dependent variables are counts of injuries of each type (specified in the top row) that occur underground. *Traumatic injuries* are defined to include 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 12 for more details on the definition on traumatic injuries.) The sum of traumatic and nontraumatic injuries make up *total injuries*.

**Independent variables:** All specifications presented above rely exclusively on regressors that are publicly available. In addition to discrete union-size interaction terms, all models include the following regressors: size quartiles (as determined by total FTEs), logged controller size (a continuous variable reflecting the controller's total number of FTEs), mine age, mine productivity, total lost-work injuries (in hundreds) during previous calendar year (for the fatality model) or previous four quarters (for non-fatality models), total penalty points (in thousands) during previous calendar year (for the fatality model) or previous four quarters (for non-fatality models), dummies indicating presence of each respective mine subunit, quarter/year dummies, district dummies, longwall indicator, and a constant term. See Appendix C for complete variable definitions. An expanded version of this table, including a full covariate report, is available at <http://amorantz.stanford.edu/companions/union-coal-mine-safety/>.

**Sample:** The sample consists of underground bituminous coal mines from 1993–2010 with positive coal production, positive hours worked, and non-missing controller size data. Because the historical variables (lost-work injuries and penalty points) are summed up over the previous four *quarters* in the nontraumatic, total, and traumatic injuries regressions but are summed up over the previous *calendar year* in the fatality regressions, some mines excluded from the fatality models are included in the other models. For example, if a mine is open for all of only one calendar year, it will have no historical data at the *yearly* level, but it will have historical data for three of the four *quarters* it was open. The number of union mines is computed by counting the mines that were unionized for any of the mine-quarters in the sample period. The total number of mines is computed by counting each mine in the sample, regardless of union status. Note that the confidential-fields versions of all models exclude any observations that lack information on confidential covariates.

<sup>a</sup>Here and throughout, all coefficient estimates are rounded to the nearest thousandth and all standard errors are rounded to the nearest hundredth.

establish active health and safety committees, conduct independent inspections, and consistently accompany MSHA inspectors on their tours.

Table 4 probes changes over time by subdividing the analysis into three discrete time periods (1993–1998, 1999–2004, and 2005–2010) using the baseline specification.<sup>24</sup> For both nontraumatic and total injuries, the disparity between union and nonunion mines diminishes over time. Traumatic injuries, however, display a different trend: although only a small disparity occurs across groups in the mid-1990s, unionization is associated with a significant and sizable (more than 30%) *decline* in traumatic injuries in subsequent years. Fatal injuries reveal an erratic trend: although unionization is associated with a large (albeit only at a 10% level of significance) decrease in fatalities around the turn of the century, the disparity shrinks and loses statistical significance in later years. At least if one confines scrutiny to traumatic injuries, then, the data suggest that the union safety effect could be a relatively recent phenomenon.

Although not the focus of this study, the other covariates included as right-hand-side variables reveal several interesting patterns. Appendix Table A.2 displays expanded 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 explored. The Companion Website presents other ancillary findings.

### Interpretation

Taken at face value, my results are broadly consistent with three hypotheses regarding the relationship between unionization and coal mine safety. First, unionization may have improved “real” mine safety levels (reflected in traumatic and fatal injury rates) in the 1990s and first decade of the twenty-first century. Second, reporting bias has probably confounded prior studies on the impact of unionization, especially when minor and nontraumatic injuries are included in injury counts. Finally, after the passage of the Coal Act, the union safety effect may not have existed until the turn of the millenium.

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. Epidemiological literature on the frequency of accidents by age is thin and conflicting. Some studies suggest that younger and less experienced miners sustain more injuries on the job (e.g., Laflamme and Blank 1996), but the scholarship is not unanimous on this point. (See, for example, Souza 2009.) Based on a careful review of

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<sup>24</sup>The data are broken into three time periods for clarity of presentation. Models with alternative time groupings, presented on the Companion Website, do not materially change the results for nontraumatic, total, or traumatic injuries. The findings for fatal injuries, although differing somewhat from those presented here, are similarly equivocal.

Table 4. Effect of Union Status on Injury Frequency: Time Trend

<i>Model</i>	<i>FTE Public (Baseline)</i>	<i>1993–1998</i>	<i>1999–2004</i>	<i>2005–2010</i>
<b>Nontraumatic injury model</b>	1.351*** (0.07)	1.497*** (0.09)	1.245** (0.12)	1.268* (0.15)
<b>Total injury model</b>	1.148*** (0.05)	1.316*** (0.07)	1.050 (0.09)	0.988 (0.10)
<b>Traumatic injury model</b>	0.765*** (0.04)	0.921 (0.06)	0.669*** (0.06)	0.686*** (0.08)
Number of observations	38,890	16,629	11,460	10,801
No. of union mines / No. of total mines	355 / 2,635	294 / 1,765	129 / 1,141	65 / 928
<b>Fatality model</b>	0.346*** (0.13)	0.378* (0.19)	0.331* (0.20)	0.552 (0.38)
Number of observations	11,045	4,763	3,308	2,974
No. of union mines / No. of total mines	352 / 2,568	290 / 1,690	128 / 1,093	65 / 903

*Notes:* Significance levels: \*\*\* 1%, \*\* 5%, \* 10%. Standard errors, clustered at the mine level, are shown in parentheses.

**Results presented:** The table reports IRR (incidence rate ratio) coefficients on the union indicator variables in negative binomial regression models. 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 1 represent predicted increases (e.g., a coefficient of 1.03 represents a 3% rise). Hours worked is the exposure term. The “FTE Public (Baseline)” column contains coefficient estimates from the principal baseline models (using 100 quarterly FTEs as the size measure and relying exclusively on public data) presented in Table 2. The results presented in the other three columns correspond, respectively, to coefficient estimates from identical models run on six-year subsamples.

**Definitions:** A quarterly FTE is defined as 500 hours worked.

**Unit of observation:** The unit of observation is the mine-quarter for the nontraumatic, total, and traumatic injuries regressions. The unit of observation is the mine-year for fatality regressions.

**Dependent variables:** The dependent variables are counts of injuries of each type (specified in the far-left column) that occur underground. *Traumatic injuries* are defined to include 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 12 for more details on the definition on traumatic injuries.) The sum of traumatic and nontraumatic injuries makes up *total injuries*.

**Independent variables:** All specifications presented above rely exclusively on regressors that are publicly available. All models include the following regressors: union dummy, mine size (a continuous variable reflecting the mine’s total number of FTEs), union x mine size, logged controller size (a continuous variable reflecting the controller’s total number of FTEs), mine age, mine productivity, total lost-work injuries (in hundreds) during previous calendar year (for fatality models) or previous four quarters (for non-fatality models), total penalty points (in thousands) during previous calendar year (for fatality models) or previous four quarters (for non-fatality models), dummies indicating presence of each respective mine subunit, quarter/year dummies, district dummies, a longwall indicator, and a constant term. See Appendix C for complete variable definitions. An expanded version of this table, including a full covariate report, is available at <http://amorantz.stanford.edu/companions/union-coal-mine-safety/>.

**Sample:** The sample consists of underground, bituminous coal mines from 1993–2010 with positive coal production, positive hours worked, and non-missing controller size data. Because the historical variables (lost-work injuries and penalty points) are summed up over the previous four *quarters* in the nontraumatic, total, and traumatic injuries regressions but are summed up over the previous *calendar year* in the fatality regressions, some mines excluded from the fatality models are included in the other models. For example, if a mine is open for all of only one calendar year, it will have no historical data at the *yearly* level, but it will have historical data for three of the four *quarters* it was open. The number of union mines is computed by counting the mines that were unionized for any of the mine-quarters in the sample period. The total number of mines is computed by counting each mine in the sample, regardless of union status. Note that the confidential-fields versions of all models exclude any observations that lack information on confidential covariates.

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—my estimates could be biased. Unfortunately, demographic variables are unavailable at the mine level, making it difficult to verify the existence, let alone to estimate the magnitude, of such biases.<sup>25</sup> 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, that union miners are older than nonunion miners, and that the latter discrepancy has grown in recent decades.<sup>26</sup> Yet this age differential seems unlikely to explain much of the union safety effect, for two reasons. First, although the union–nonunion gap in the frequency of traumatic injuries expanded markedly during the 1990s, the gap in the proportions of young miners grew, if at all, only marginally during this period.<sup>27</sup> Second, although the negative correlation between unionization and mining fatalities intensified during the late 1990s, the union–nonunion gap in the prevalence of older miners, if anything, slightly widened.<sup>28</sup>

Several stakeholders suggested that unionized miners are more experienced than their nonunionized counterparts (although CPS data reveal no differences in median educational attainment<sup>29</sup>), and that total compensation including fringe benefits is higher at union mines, although both

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<sup>25</sup>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 data set excludes Kentucky and Pennsylvania, which contain 43% of all underground, bituminous mines in the United States, and data for West Virginia and Virginia—which contain an additional 46% of mines in our sample—are available only for 1997 onward. Additionally, since the Census Bureau and MSHA use different employer identifiers, merging these two data sets 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, March 3, 2011.)

<sup>26</sup>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. Historical CPS data, including the ORG data, are available at <http://www.nber.org/cps/>.

<sup>27</sup>In 1990 the CPS data 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.

<sup>28</sup>In 1990 the CPS data 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.

<sup>29</sup>The CPS data indicate that the median education level of both union and nonunion miners was a high school diploma or GED in 1990, 2000, and 2010, respectively.

disparities have diminished in recent decades. Unfortunately, no data are available with which to test the validity of either claim.<sup>30</sup>

In short, I cannot rule out the possibility that omitted variables have biased my analysis.<sup>31</sup> Nevertheless, the scant information available on disparities in miner demographics does not correlate particularly well with the trends observed in the data, suggesting that biases of this sort may not be a major concern.

If the observed relationship between unionization and mine safety is indeed causal, this raises a second important question: Why do my estimates differ so sharply from prior literature? Perhaps the union safety effect has always existed but has eluded detection because of the methodological shortcomings of and limited data used in prior work. Since complete data from the 1970s no longer exist, I cannot replicate these early studies. When I analyze my own data using a methodology similar to that of Appleton and Baker (1984), however, the results are qualitatively not unlike those reported here, casting doubt on the hypothesis that findings reported in early empirical scholarship were entirely spurious.<sup>32</sup> It is possible, then, that unions did not reduce mining hazards until decades after the Mine Act's passage. In other words, although my analysis is far from conclusive on this point, the union safety effect may be a relatively recent phenomenon.

If the latter hypothesis is correct, and unions had little impact on mine safety until just before the turn of the millinium, the question is why. Several possibilities should be considered. First, fluctuations over time in the stringency of MSHA 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.<sup>33</sup> Examining data from 1995–2009, Morantz (2012) finds that this

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<sup>30</sup>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. Because of 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 varied in recent years.

<sup>31</sup>If profitable mines are more (or less) likely to become unionized, profitability could also be an important source of omitted variable bias. Unfortunately, I cannot construct a credible proxy for mine profitability. On the revenue side of the equation, for example, the data provided by the EIA only include revenue from domestic sources, whereas sale of (typically metallurgical) coal abroad can be a critical and highly volatile source of revenue (see, for example, Rademacher and Braun 2011). Meanwhile, on the cost side, many factors that affect production—such as capital investments, labor costs per hour, use of subcontracting, receipt of federal subsidies—cannot be observed in the data; the only relevant information available is total hours worked. In an effort to at least partially mitigate this potential source of bias, I include a productivity measure (thousands of tons produced annually per full-time equivalent worker) in all specifications.

<sup>32</sup>See the Companion Website for a detailed description of my attempt to replicate Appleton and Baker's methodology using my own data set.

<sup>33</sup>Weil (1987) finds that union mines are more likely to designate employee representatives; to receive more frequent MSHA inspections of longer average duration; to be granted shorter periods in which to abate violations; to be granted fewer abatement extensions; to receive more citations per inspection; to

disparity has persisted along several dimensions.<sup>34</sup> If MSHA inspects union mines more intensively than nonunion mines—and if this differential has widened over time—it could help explain the observed trends. However, detailed comparison of the results presented here with those reported in Morantz (2012) casts doubt on this hypothesis. Whereas the “union safety effect” described in the Results section is strongest among large mines, the enforcement disparities reported in Morantz (2012) diminish sharply with mine size.

Second, unions may have shifted their institutional priorities in the 1990s, deliberately choosing to forfeit potential wage increases in exchange for enhanced workplace safety. CPS data do show some convergence in median (real) wages of union and nonunion miners since the early 2000s. There are several reasons, however, to doubt that UMWA leadership has pursued such a strategy.<sup>35</sup>

Finally and most important, it may have taken time for UMWA leadership to train a cadre of union members capable of effectively exercising their contractual and newfound statutory 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.”<sup>36</sup> The labor strife that characterized much of the 1970s (and to a lesser extent the 1980s) likely impeded the capacity of unions 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 Department of Health and Safety took more systematic measures to train its rank and file, such as the institution of local union training programs.<sup>37</sup> In short, changes in the leadership and institutional

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pay higher penalties per violation; and to be less successful in reducing penalty amounts through MSHA’s internal administrative appeals process than nonunion mines (pp. 120–85).

<sup>34</sup>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.

<sup>35</sup>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 claim 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, UMWA leadership find that young miners who 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 relatively 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 prevalence of inexperienced miners rather than enhanced congruence of pay scales. Unfortunately, the extreme paucity of miners surveyed for the CPS sample makes it difficult to conclusively resolve the issue.

<sup>36</sup>Telephone interview with Phil Smith, UMWA, May 28, 2010.

<sup>37</sup>Weil (1987: 200); Telephone interview with Michael Buckner, UMWA’s Director of Research from 1981–2005, on March 3, 2011.

focus of the UMWA during the 1970s and '80s that were intended to increase the union's long-term impact on mine safety may not have borne fruit until the 1990s.

### 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 passage of the Coal Act. 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 I use a variety of techniques to mitigate potential biases.

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 the 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 nontraumatic injuries, lending credence to claims that injury reporting practices differ significantly across union and nonunion mines.

Interestingly, the union safety effect on traumatic injuries seems to have escalated just before the turn of the millenium. 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 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.

## Appendix A

Table A.1. Characteristics of Underground, Bituminous Coal Mines: Sample Means

<i>Variable</i>	<i>Union mean</i>	<i>Nonunion mean</i>	<i>Variable</i>	<i>Union mean</i>	<i>Nonunion mean</i>
<b>Total sample size<sup>a</sup></b>			<b>Mine characteristics</b>		
Mine-quarters	5,807	34,501	Mine age (in years)	17.04	6.84
Mines <sup>b</sup>	356	2,455		(16.38)	(7.67)
<b>Injury rates (per annual FTE)</b>			Productivity	7.38	6.87
Nontraumatic injuries	0.0954	0.0712		(4.07)	(4.61)
	(0.1602)	(0.3395)	Percentage captive production	0.0702	0.0649
Total injuries	0.1309	0.1112		(0.2425)	(0.2788)
	(0.1878)	(0.3961)	Subsidiary indicator	0.2037	0.4027
Traumatic injuries	0.0356	0.0400		(0.4781)	(0.4046)
	(0.0850)	(0.1830)	Longwall indicator	0.3113	0.0399
Fatalities	0.0003	0.0011		(0.4630)	(0.1957)
	(0.0060)	(0.0535)	Subunits contained <sup>c</sup>		
<b>Mine and controller size measures</b>			<i>Surface</i>	0.8582	0.8254
Mine FTEs	193.36	57.73		(0.3487)	(0.3796)
	(207.11)	(86.68)	<i>Mill or prep plant</i>	0.2757	0.0434
Size quartile 1	15.98	12.05		(0.4469)	(0.2037)
	(23.74)	(9.47)	Mining method percentages		
Size quartile 2	31.57	28.21	<i>Conventional</i>	7.87	16.56
	(31.04)	(14.04)		(26.92)	(37.04)
Size quartile 3	64.38	50.81	<i>Continuous</i>	65.45	77.24
	(50.17)	(25.20)		(42.70)	(41.15)
Size quartile 4	330.76	166.34	<i>Longwall</i>	26.37	3.33
	(202.89)	(140.6624)		(38.84)	(16.25)
Mine employees	175,5273	51.25	<i>Shortwall</i>	0.18	0.01
	(181.12)	(72.82)		(3.75)	(1.08)
Mine tonnage	366,144	120,636	<b>Geological features</b>		
	(459,358)	(263,832)	Number of coal beds	1.0206	1.0019
Controller FTEs	1,451.81	632.69		(0.1593)	(0.1786)
	(1,910.59)	(1,146.56)	Mean coal bed thickness	1.0097	0.8976
Controller employees	1,292.98	542.75	(in yards)	(0.8820)	(0.7159)
	(1,673.56)	(980.04)	Recoverable reserves (in	20,623	7,019
Controller tonnage	3,115,829	1,307,115	millions of tons)	(32,875)	(28,223)
	(4,591,858)	(2,529,356)			

Notes: This table contains mean values for all underground, bituminous, active mine-quarters in each group; standard deviations are in parentheses. Each variable mean is calculated among all observations that contain information on that variable. See Appendix C for complete variable definitions.

<sup>a</sup> Total sample sizes represent counts (of mine-quarters and of mines, respectively) as opposed to mean values.

<sup>b</sup> Because a mine that was unionized for part of the sample period and nonunionized for part of the sample period is counted here as both a union mine and a nonunion mine, some mines are double counted for a total of 2,811 mines. There are 2,645 underground, bituminous coal mines with at least one active quarter from 1993–2010. The difference between these two numbers, 166, represents the number of mines that switched union status at some point during the sample period. Of these 166 mines, only 164 contain information on controller. Therefore, the sample size in the public-fields version of the fixed-effects models presented in Appendix Table A.3—focusing exclusively on mines that changed union status during the sample period—is 164.

<sup>c</sup> Only descriptive statistics for the surface and the mill or prep plant subunits are shown here. Other subunits include auger subunit; culm-refuse subunit; dredge subunit; independent shops or yard subunit; strip, quarry, or pit subunit; underground subunit; and other subunits.

Table A.2. Effect of Union Status on Injury Frequency: Expanded Covariate Report for Baseline, Public-Fields Specifications

Variable	Nontraumatic injury model	Total injury model	Traumatic injury model	Fatality model
<b>Union</b>	1.351*** (0.07)	1.148*** (0.05)	0.765*** (0.04)	0.346*** (0.13)
<b>Union x Size</b>	0.972 (0.02)	0.962* (0.02)	0.987 (0.02)	1.019 (0.03)
<b>Mine size</b>	0.877*** (0.02)	0.892*** (0.02)	0.921*** (0.03)	0.899*** (0.03)
<b>Log of controller size</b>	0.937*** (0.01)	0.986* (0.01)	1.063*** (0.01)	1.021 (0.06)
<b>Mine age</b>	0.999 (0.00)	0.999 (0.00)	0.998 (0.00)	1.007 (0.01)
<b>Productivity</b>	0.995 (0.00)	0.998 (0.00)	1.000 (0.00)	0.942*** (0.02)
<b>Lost-day injuries in previous year</b>	1.000*** (0.00)	1.000*** (0.00)	1.000*** (0.00)	1.000 (0.00)
<b>Penalty points in previous year</b>	1.000*** (0.00)	1.000*** (0.00)	1.000*** (0.00)	1.000*** (0.00)
<b>Longwall indicator</b>	0.887* (0.05)	0.873** (0.05)	0.882 (0.08)	1.572 (0.54)
<b>Mining subunit dummies<sup>a</sup></b>	Y	Y	Y	Y
<b>District fixed effects<sup>a</sup></b>	Y	Y	Y	Y
<b>Quarter/Year fixed effects<sup>a</sup></b>	Y	Y	Y	Y
<b>Number of observations</b>	38,890	38,890	38,890	11,045
<b>No. of union mines / No. of total mines</b>	355 / 2,635	355 / 2,635	355 / 2,635	352 / 2,568

Notes: Significance levels: \*\*\* 1%, \*\* 5%, \* 10%. Standard errors, clustered at the mine level, are shown in parentheses.

**Results presented:** The information presented in this table is identical to that presented in the Baseline/Public-Fields column of Table 2, but includes additional coefficient estimates. Each value represents the IRR (incidence rate ratio) coefficient on an independent variable in a negative binomial regression model. 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 1 represent predicted increases (e.g., a coefficient of 1.03 represents a 3% rise). Hours worked is the exposure term.

**Definitions:** A quarterly FTE is defined as 500 hours worked.

**Unit of observation:** The unit of observation is the mine-quarter for the nontraumatic, total, and traumatic injuries regressions. The unit of observation is the mine-year for fatality regressions.

**Dependent variables:** The dependent variables are counts of injuries of each type (specified in the top row) that occur underground. *Traumatic injuries* are defined to include 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 12 for more details on the definition on traumatic injuries.) The sum of traumatic and nontraumatic injuries makes up *total injuries*.

**Independent variables:** All models include the following regressors: union dummy, mine size (a continuous variable reflecting the mine's total number of FTEs), union x mine size, logged controller size (a continuous variable reflecting the controller's total number of FTEs), mine age, mine productivity, total lost-work injuries (in hundreds) during previous calendar year (for fatality models) or previous four quarters (for non-fatality models), total penalty points (in thousands) during previous calendar year (for fatality models) or previous four quarters (for non-fatality models), dummies indicating presence of each respective mine subunit, quarter/year dummies, district dummies, longwall indicator, and a constant term. See Appendix C for complete variable definitions. An expanded version of this table, including a complete covariate report, is available at <http://amorantz.stanford.edu/companions/union-coal-mine-safety/>.

**Sample:** The sample consists of underground bituminous coal mines from 1993–2010 with positive coal production, positive hours worked, and non-missing controller size data. Because the historical variables (lost-work injuries and penalty points) are summed up over the previous four *quarters* in the nontraumatic, total, and traumatic injuries regressions but are summed up over the previous *calendar year* in the fatality regressions, some mines excluded from the fatality models are included in the other models. For example, if a mine is open for all of only one calendar year, it will have no historical data at the *yearly* level, but it will have historical data for three of the four *quarters* it was open. The number of union mines is computed by counting the mines that were unionized for any of the mine-quarters in the sample period. The total number of mines is computed by counting each mine in the sample, regardless of union status. Note that the confidential-fields versions of all models exclude any observations that lack information on confidential covariates.

Table A.3. Fixed Effects Models

Specification	Baseline (Hours worked)		Employees		Tonnage	
	100 Quarterly FTEs		100 Employees		Millions of tons	
Version	Public- fields version	Confid.- fields version	Public- fields version	Confid.- fields version	Public- fields version	Confid.- fields version
<b>Nontraumatic injury model</b>	1.377*** (0.14)	1.098 (0.15)	1.387*** (0.14)	1.109 (0.15)	1.444*** (0.13)	1.110 (0.13)
<b>Total injury model</b>	1.208** (0.09)	1.061 (0.11)	1.206** (0.09)	1.072 (0.12)	1.259*** (0.09)	1.068 (0.09)
<b>Traumatic injury model</b>	0.896 (0.09)	1.039 (0.13)	0.882 (0.09)	1.062 (0.14)	0.968 (0.08)	1.036 (0.10)
Number of observations	4,075	1,558	4,075	1,558	4,075	1,558
No. of union mines / No. of total mines	164 / 164	79 / 79	164 / 164	79 / 79	164 / 164	79 / 79
<b>Fatality model</b>	0.381** (0.17)	<sup>a</sup>	0.386** (0.17)	<sup>a</sup>	0.423** (0.18)	<sup>a</sup>
Number of observations	1,082	412	1,082	412	1,082	412
No. of union mines / No. of total mines	151 / 151	71 / 71	151 / 151	71 / 71	151 / 151	71 / 71

Notes: Significance levels: \*\*\* 1%, \*\* 5%, \* 10%. Standard errors, clustered at the mine level, are shown in parentheses.

**Limitations of fixed effects model:** Only a small proportion of underground coal mines (6.2%) changed union status during the period examined (1993–2010), and those that did change status seem to be highly unrepresentative of the population as a whole (see footnote 19). Any analysis predicated on this idiosyncratic subgroup is likely to yield biased estimates of unionization's true effect, which is why I place this table in an appendix.

**Results presented:** The table reports IRR (incidence rate ratio) coefficients on the union indicator variables in negative binomial regression models. 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 1 represent predicted increases (e.g., a coefficient of 1.03 represents a 3% rise). Hours worked is the exposure term.

**Definitions:** A quarterly FTE is defined as 500 hours worked.

**Unit of observation:** The unit of observation is the mine-quarter for the nontraumatic, total, and traumatic injuries regressions. The unit of observation is the mine-year for fatality regressions.

**Dependent variables:** The dependent variables are counts of injuries of each type (specified in the top row) that occur underground. *Traumatic injuries* are defined to include 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 12 for more details on the definition on traumatic injuries.) The sum of traumatic and nontraumatic injuries makes up *total injuries*.

**Independent variables:** All models include the following regressors: union dummy, mine size (a continuous variable whose units are specified in column header), union x mine size, logged controller size (a continuous variable whose units are specified in column header), mine age, mine productivity, total lost-work injuries (in hundreds) during previous calendar year (for fatality models) or previous four quarters (for non-fatality models), total penalty points (in thousands) during previous calendar year (for fatality models) or previous four quarters (for non-fatality models), dummies indicating presence of each respective mine subunit, quarter/year dummies, district dummies, and a constant term. Public-fields versions also include a longwall indicator. Confidential-fields versions also include the 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 C for complete variable definitions. An expanded version of this table, including a full covariate report, is available at <http://amorantz.stanford.edu/companions/union-coal-mine-safety/>.

**Sample:** The sample consists of underground, bituminous coal mines from 1993–2010 with positive coal production, positive hours worked, and non-missing controller size data that switched union status at some point during the sample period. The public-fields versions contain mine-quarters from 1993–2010, whereas the confidential-fields versions are restricted to 1998–2010. Because the historical variables (lost-work injuries and penalty points) are summed up over the previous four *quarters* in the nontraumatic, total, and traumatic injuries regressions but are summed up over the previous *calendar year* in the fatality regressions, some mines excluded from the fatality models are included in the other models. For example, if a mine is open for all of only one calendar year, it will have no historical data at the *yearly* level, but it will have historical data for three of the four *quarters* it was open. Note that the confidential-fields versions of all models exclude any observations that lack information on confidential covariates.

<sup>a</sup> Coefficients are not presented for this model because it did not yield valid estimates (i.e., the model failed to converge or the variance matrix was rank-zero).

## Appendix B Description of Model Specifications

The list below describes the three specifications and two versions that are included in Table 2.

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

**Employees specification:** 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 specification:** 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 version:** 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, mine productivity, number of lost-work injuries (in hundreds) in the previous calendar year (for fatality models) or previous four quarters (for non-fatality models), total penalty points (in thousands in the previous calendar year (for fatality models) or previous four quarters (for non-fatality models), a constant term, dummies indicating presence of each type of mine subunit, quarter/year dummies, district dummies, and a longwall indicator.

**Confidential-fields version:** 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, mine productivity, number of lost-work injuries (in hundreds) in the previous calendar year (for fatality models) or previous four quarters (for non-fatality models), total penalty points (in thousands) in the previous calendar year (for fatality models) or previous four quarters (for non-fatality models), a constant term, dummies indicating presence of each type of mine subunit, quarter/year 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 C Variable Dictionary

<i>Variable name</i>	<i>Variable definition</i>	<i>Source</i>
Nontraumatic 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 12)	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 in the previous calendar year (for fatality models) or previous four quarters (for non-fatality models), 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 calendar year (for fatality models) or previous four quarters (for non-fatality models)	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, e.g., "surface" and "mill or prep plant"	MSHA
Mean coal bed thickness	The mean thickness of all coal beds at the mine, in yards	EIA <sup>a</sup>
Mining method percentages	Proportion of underground operation that uses a given mining method, expressed as a 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 <sup>a</sup>
Percent captive production	Percentage of production for mine or parent company's own use	EIA <sup>a,b</sup>
Recoverable reserves	Estimated tonnage of remaining coal reserves	EIA <sup>a,b</sup>
Subsidiary indicator	1 if mine is a subsidiary of a larger firm, 0 otherwise	EIA <sup>a</sup>
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.

<sup>a</sup> These data fields were obtained on a confidential basis and are considered trade secrets by the companies that provided them.

<sup>b</sup> These data fields are unavailable prior to 1998.

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