Productivity, Safety, and Regulation in Coal Mining: Evidence from Disasters and Fatalities [*]

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Abstract

Coal mining is a dangerous occupation where costly fatalities and disasters may increase future accident costs. We use occurrences of deaths as shocks that affect the tradeoff between mineral output and safety. We find that government inspections and penalties increase after fatalities, and less-severe accident rates decrease by 10%. For mines in a disaster-affected state, less-severe accident rates decrease by 23%, and fatalities by 68%, saving up to \$2 per hour in accident costs, with limited evidence suggesting that mineral productivity falls by 7%, or \$14 per worker hour, and that the number of managers employed increases by 11%.

Keywords: Accidents, Mortality, Production Functions, Government inspections

JEL Classifications: D24, I18, J28, L72

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1 Introduction

Since 1900, over 100,000 workers have been killed in coal mines in the United States (Alford, 1980). Coal miners are exposed to a wide range of hazards including gas explosions, shifting rock, falls, and machinery and automotive accidents. Yet, as a result of government regulations, technological change, and a general emphasis on safety, coal mining fatalities have dropped dramatically over the twentieth century. Today, in any given mine, fatalities are now an unexpected and extraordinary event. Though fewer than before, coal mining deaths still occur in the United States: between 2000 and 2014, there have been 446 fatalities and five disasters – events with five or more deaths.[1] Injuries of all kinds are still commonplace in this sector.

The fact that safety remains an important concern in the coal mining industry suggests that it is appropriate to think of the industry as producing two joint outputs: extracted mineral and safety. The purpose of this paper is to estimate the joint production function for mineral and safety in the coal mining industry and to evaluate the role of regulation in affecting this tradeoff. Understanding the relationship between coal output, safety, and regulation is important for evaluating how productivity and safety might continue to increase in the coal-mining industry. The coal-mining industry employs over 90,000 workers in the United States (Energy Information Administration, 2014), underscoring the importance of this goal. In addition, understanding the tradeoff between productivity and safety might inform us about the potential sources of productivity increases in commodity extraction and manufacturing industries more generally, many of which are as or more dangerous than coal mining.[2] Finally, we are interested in how regulation affects safety and productivity. What is the marginal value of increased government enforcement activity? Do additional inspections and enforcement of regulations compromise productivity in the name of safety, enhance both safety and

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[1] Source: authors' calculation from Mine Safety and Health Administration data, ending at Q3:2014.

[2] Although coal mining was once one of the most dangerous occupations by fatality rate, it is no longer in the top 10. Occupations with higher or similar death rates include fishers (117.0 per 100,000 full time yearly worker equivalents), logging workers (127.8), roofers (40.5), and cement and concrete manufacturing (16.0). The rate for coal mining is 18.0. (Source: U.S. Bureau of Labor Statistics. *http://www.bls.gov/iif/oshwc/cfoi/cfoi_rates_2012hb.pdf.*) The large number of deaths in the coal mining industry reflects the large number of workers in the industry.

productivity, or simply have no effect on safety?

To analyze our research question, we make use of a panel dataset that records location, productivity, accidents, and regulatory inspections for coal mines throughout the U.S. The detailed data allow us to measure output much more precisely than in most industries, and to pinpoint potential factors that influence productivity, including the role of regulatory activity. Despite the uniquely detailed data, it would be problematic to answer our research question with a regression of a proxy of safety (such as accidents) on productivity. Unobserved factors, such as management quality or ease of coal extraction at a mine, might impact both the observed safety level and productivity. For instance, firms with higher management quality may achieve higher levels of both safety and productivity. Certain mines, such as surface mines, may allow for greater ease of coal extraction and also be inherently less dangerous than underground mines. Such factors would then result in an endogeneity bias.

We employ a different identification approach that does not rely on input choices being orthogonal to unobserved management quality. Instead, we identify the joint production function of coal output and safety by using disasters and fatalities as a source of quasi-experimental variation that affects the relative price of safety and productivity by increasing the cost of future accidents. Our identification strategy relies on the presumption that fatalities and disasters are tail events that are generally unexpected; certainly systems exist to reduce severe risks and no fatality would be allowed to occur if it could be foreseen by workers or management.

Why might a fatality or disaster change the relative price of safety to mineral output? We hypothesize that a fatality at a mine might increase the cost of future accidents through a variety of mechanisms. Most directly, a fatality at a mine might increase government regulatory inspections. This might then make the mine more likely to suffer penalties from safety violations, which would increase the price of safety relative to mineral output. Although regulation is one way in which fatalities might change the relative price of safety relative to mineral output, there are many other mechanisms. For instance, mines may become stigmatized by fatalities, which may harm their ability to attract labor or investment. Experiencing a fatality may also increase the psychic costs of risk exposure to both workers and management through fear or guilt. Finally, firms may have incomplete information about the safety levels of their mines and a fatality may be a signal that the mine is more dangerous than previously believed, implying that improving safety becomes a better investment following a fatality.

In contrast to single fatalities, mine disasters are generally followed by intense media exposure and public reprobation of those responsible for the disaster. For example, in the aftermath of the 2010 Upper Big Branch Mine disaster in Raleigh County, West Virginia, in a public eulogy to the fallen miners, President Obama remarked, “owners responsible for conditions in the Upper Big Branch Mine should be held accountable for decisions they made and preventive measures they failed to take” (Obama, 2010).

The publicity after the disaster was sufficient for Nike, Inc. to air a national television ad referencing the fallen miners (which was later pulled due to controversy).[3] Given the media exposure, we hypothesize that, relative to single fatalities, disasters are more likely to affect the cost of future accidents in the broader geographic area than just at the particular mine.

To formalize the production function of coal output and safety, and the effect of disasters and fatalities on this production function, we first develop a simple neoclassical model of the production of safety and mineral output. In our model, firms choose labor and safety inputs that, together with random draws, lead to a production level production for mineral output and accidents. The expected number of accidents per hour and mineral output are both monotonically decreasing functions of the chosen safety level implying that safety and mineral output are substitutes. Thus, this model hypothesizes a tradeoff between productivity and accident risk.

Within this simple economic framework, firms choose a level of safety that balances the marginal reduction in accident cost against the marginal reduction in productivity from an additional safety unit. We then assume that disasters and fatalities are very low probability shocks that increase the cost of future accidents. We show that given intuitively reasonable conditions on the interactions between labor and safety inputs and between safety input and

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[3] CBS (2010).

the cost of accidents, an increased cost of accidents leads to greater safety input, fewer workers, and hence less mineral production. Thus, the model predicts that mines react to a disaster or fatality by increasing safety at the cost of less mineral output per worker and fewer workers. These testable predictions form the basis for our empirical work: we examine whether mines reduce accident rates after a disaster or fatality, and if there exists an associated cost to productivity. We also directly test one set of mechanisms by which the cost of accidents might increase, by examining whether government enforcement activity increases after a disaster or fatality.

The model above assumes that mining companies behave rationally. We imagine firms walking a tightrope, attempting to maximize production while sensibly minimizing expected accidents given their production level. But in reality is this how firms actually behave? Do firms optimally choose mineral output and safety, or could other circumstances affect output? Surprising and robust evidence suggests that some industries have unrealized productivity. In his paper on iron ore producers, Schmitz (2005) finds that labor productivity doubled through changes in work practices. Foreign competition was the shock that spurred these new practices in the iron ore industry.[4] Similarly, it is possible in the aftermath of a fatality or disaster shock that an increased focus on safety could also spur productivity improvements in the coal mining sector. Supporting this view, occupational health and safety research has found that both productivity and safety could increase from managerial attention and training in underground mining (Fiedler et al., 1984), logging (Montorselli et al., 2010), and construction (Everett and Slocum, 1993). By testing the sign and magnitude of the impact of fatalities and disasters on productivity and safety, our empirical analysis provides a test of our simple neoclassical production function model.

Our empirical analysis proceeds as follows: we create a panel at the mine-quarter level that merges several publicly available Mine Safety and Health Administration (MSHA) datasets, including the *Accidents Injuries Dataset*, the *Employment/Production Data Set (Quarterly)*, the *Inspections Data Set*, and the *Violations Data Set*. Key variables in our data include mine location, coal production, hours worked, the number of fatalities and other accidents, and

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[4] Hendel and Spiegel (2014) also find large and not easily explainable productivity changes in Israeli steel mini-mills.

information on MSHA inspections and citations. Our regressions all use an event analysis framework. We regress dependent variables – such as productivity, accident rates, and MSHA inspections – on the occurrence of a fatality in the same mine or a disaster in the same state within the two previous years. In all regressions, we use mine and time fixed effects, and we cluster at the mine level. As a falsification exercise, all specifications also examine future fatalities or disasters within the two subsequent years. We also drop the five mines with a disaster from our sample.

We first examine "first stage" results of the impact of lagged fatalities at a mine on MSHA inspections. We find that MSHA inspections significantly increase during the quarter of the fatality, and that this increase is sustained for two years. The magnitudes are large, with a 11% increased inspection rate two years after the fatality. In contrast, the inspection hours and penalties only significantly increase for the first year after the fatality. Together, these results suggests that mines react to the increased MSHA inspections in the first year after a fatality by resolving problems that could lead to citations. Hence, the inspections become shorter and ultimately, the inspectors find no more to penalize than in the baseline. In almost all our regressions, we find that future fatalities had no statistically significant effect, suggesting the absence of pre-existing trends.

Having established at least one causal pathway by which fatalities might increase the cost of accidents, we turn to understanding the impact of fatalities on productivity and accidents. Here we find no evidence that fatalities decrease severe accident rates (defined as the rate of fatalities and permanent disabilities per hours worked) but find that they decrease less-severe accident rates (defined as the rate of all other accidents) by 10% two years after a fatality. There is also no evidence that productivity increased. Thus, the results indicate that the increased inspections and other effects from a fatality only affect less-severe accidents, but that they do this with no apparent negative effect on productivity.

We next consider disasters, and examine the effect of having a mine in the same state experience a disaster (omitting the mine with the disaster itself). Here, we find no evidence of increased MSHA regulatory scrutiny at other mines within the same state. However, we find that accidents drop significantly and by a large amount following a disaster. In particular, the rate of less-severe accidents per hours worked decreases by 23% and the rate of fatalities decreases by 68% two years after a disaster. We also find potential evidence that productivity went down, by 7% following a disaster, a result that is marginally significant (P=0.099). However, the pre-trends on productivity, while not statistically significant, are similar in magnitude, limiting the plausibility of any finding of a productivity decrease. Nonetheless, this evidence is supported by regressions using state-year-level data that the number of managers and supervisors at mines increases 11% two years after a disaster in a state, with no significant change in other workers.

It is useful to understand the cost savings that mines may incur from the drops in accident risk. An influential review article, Viscusi and Aldy (2003), finds the value of statistical life lies between $4 and $9 million using U.S. labor market estimates (which is close to our context). Using the midpoint value of $6.5 million (Viscusi and Aldy, 2003), we find that the reduction in risk of fatalities is worth $1.41 per hour worked. For less-severe accidents, a $30,000 estimate (National Safety Council, 2014) implies a cost savings of $0.24 per hour worked from the reduction in this type of accident. Hence, we believe that the total dollar cost savings to the firm from the decreased accidents following a mine disaster may be in the range of $1-$2 per hour worked. As a point of comparison, the 7% drop in productivity noted above, if real, would at the least imply a need to add 8% extra work hours to mine the same coal. At $25/hour, this represents an extra $2 in wages per current hour worked. However, labor costs are only a small part of the total costs of coal extraction. If lost production from enhanced safety could not be recouped with just labor input, the reduction in coal output would cost up to $14 per hour worked. Thus, the value of potential productivity losses here is not trivial.

The remainder of the paper is organized as follows: Section 2 provides background information on the industry and literature. Section 3 exposits our model and estimating framework. Section 4 discusses the data. Section 5 discuss results. Finally, Section 6 concludes.

2 Background

Coal mining is an important industry to study to answer questions regarding safety, productivity, and regulation. Tens of thousands of workers have been killed in the United States in the history of coal mining and many more have been injured and disabled. Figure 1 shows the U.S. death rate for coal coal miners from 1900-2013. During this long period, death rates for coal miners in the U.S. declined steadily so that they are now about 4% their 1900 level. Nonetheless, mining remains a dangerous occupation, with disasters such as in the Sago Mine (2006) and in Upper Big Branch (2010) killing 12 and 29 workers, respectively.

In the late nineteenth and early twentieth century, each miner worked in a "room," which is a small area of the mine that is individually allocated to a particular miner. A frequent cause of fatalities was a roof collapse in the miner's room (Fishback, 1992). The room's roof was progressively weakened by the process of coal extraction. Therefore, each miner had control over his or her safety, as miners spent their days literally demolishing the columns supporting the roofs over their heads. Pressure on the remaining coal increased as coal was removed, which actually made further mining easier (suggesting the opposite sign to the endogeneity between mineral output and safety noted in the introduction). As miners were paid piecerate, this "softening" was one reason miners valued obtaining the maximum possible coal from their room, even under conditions most would find terrifying.[5] Skilled miners could reasonably estimate when a roof was about to collapse, and dig the furthest, but it was never possible to avoid collapse with certainty. Each miner worked with the knowledge there was some low but real possibility that the roof would collapse, and some were killed when this in fact occurred.

These roof collapses are a vivid and unusually direct example of balancing productivity with safety. Although this hazard no longer exists, tradeoffs can be found virtually anywhere there is a risk of injury in a mine. For example, speed limits on trucks or other machinery can improve safety but slow production, and safety equipment such as gloves protect workers but reduce dexterity. Mine construction involves tradeoffs between speed and structural consid-

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[5] A vocabulary developed that described the various sounds the roof could make. The sound of a roof groaning under reduced support was known as the "roof working". Some sounds resembled crashing thunder. It is claimed experienced miners could detect a distinct sound that indicated imminent collapse (Brophy and Hall, 1964).

erations; miners still suffer fatalities from mine collapses. Finally, allowing for extra escape routes, rescue areas, and training reduces the time spent on coal extraction, but may reduce deaths in the events of a collapse.

In response to the dangers from mines, significant safety regulations have been enacted at the U.S. federal government level. The main regulatory changes are the creation of the Bureau of Mines in 1910, the Federal Coal Mine Safety Act of 1952, the Coal Mine Safety and Health Act of 1969,[6] the Occupational Safety and Health Act (OSHA) of 1971 (Alford, 1980), the Federal Mine Safety and Health Act of 1977 (which created the Mine Safety and Health Administration or MSHA) (Weeks and Fox, 1983), and, most recently, the Mine Improvement and New Emergency Response (MINER) Act of 2006. The MINER Act further advanced rules, outlined in the 1977 Act, pertaining to emergency response, emergency evaluation and notification, post-accident communications and tracking, mine rescue teams and their equipment, and sealing of abandoned areas of underground coal mines.

In many cases, these regulations were spurred by mine disasters. For instance, the 1952 act followed the 1951 Orient #1 explosion that killed over 100 miners, the 1969 act followed the 1968 Consol #9 disaster that resulted in 78 coal miner deaths, and the 1977 act followed the 1972 Sunshine Mine fire that killed 91 miners. Today, coal mines operate in a strict liability operating environment with mandated MSHA inspections – a minimum of 2 times per year for all surface mines and 4 times per year for all underground mines. Following inspections, the government can enforce regulations with punitive damages for statute violations that can range up to hundreds of thousands of dollars per violation.

A small literature has formalized the tradeoffs between safety, productivity, and regulation in coal mining and other sectors. To our knowledge, the first to do this for coal mining is Sider (1983), who specifies a model of coal mining with tradeoffs between safety and production, on which our model builds. Sider (1983) estimates a Cobb-Douglas production function for coal mines in Illinois that is motivated by his model. He did not estimate the reduction in safety stemming from regulations nor did he attempt to control for the endogeneity of safety

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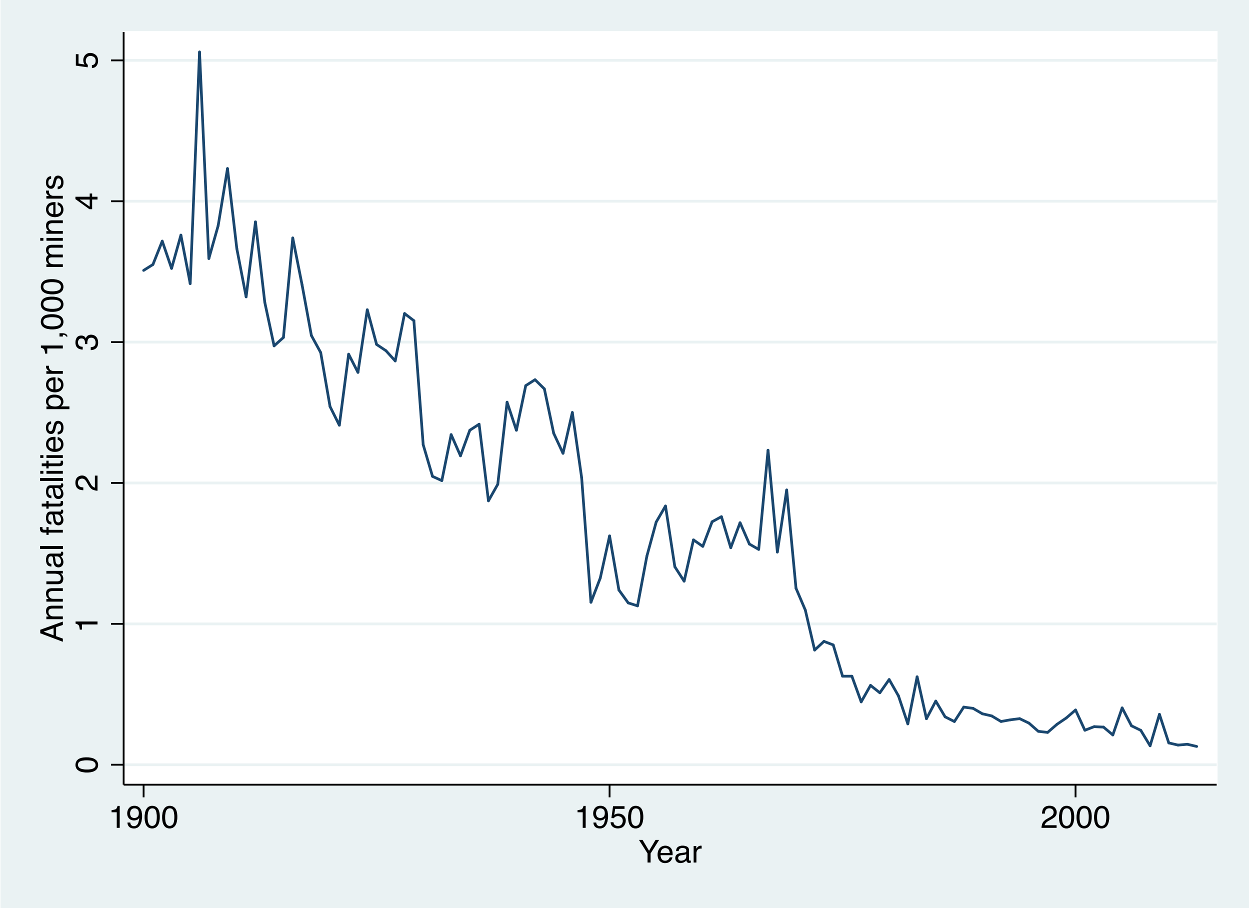
[6] See http://www.msha.gov/REGS/ACT/ACTTC.HTM.

Figure 1: Historical Coal Mining Fatalities in the United States.



Source: authors' calculations from http://www.msha.gov/stats/centurystats/coalstats.asp.

and production choices. Gray (1987), who considers all manufacturing sectors, estimates a production function that includes measures of regulations. He finds that safety regulations – such as OSHA inspections – contributed as much as 30% of the decline in productivity growth during the 1970s. Kniesner and Leeth (2004) examine whether MSHA enforcement activities reduce mine injuries and find very small effects.

At the same time, an empirical literature finds that productivity and safety may be improved simultaneously in a number of different sectors. Hausman (2014) finds that electricity market restructuring allowed nuclear power plants to operate both more safely and more efficiently. In a detailed evaluation of four Italian logging crews, Montorselli et al. (2010) find that the crew with formal safety training had both the best safety record and the highest productivity.

Fiedler et al. (1984) find that mine management safety programs simultaneously improve productivity and reduce accidents.

Finally, another literature seeks to understand what and who determines safety choices. Sawacha et al. (1999) analyze safety at construction sites, finding that incentive or bonus pay can lead to decreased safety. Similarly, Hensher et al. (1992) studied long-haul truck drivers and found that drivers respond to financial incentives by reducing safety. Both of these studies find that workers shift priorities when incentives change, thereby demonstrating that workers may have some control over the tradeoff between safety and productivity. Other studies show that management may also have control over safety and may respond to incentives concerning worker safety (Rittenberg and Manuel, 1987).

We believe that our study contributes to the general understanding of the determinants of productivity and safety through our novel identification strategy of using the random variation in mine disasters and mine fatalities. This allows us to estimate the tradeoff between productivity and safety in a way that controls for the endogeneity of safety and labor input choices.

3 Model and Estimation

3.1 Model

We present a simple neoclassical model of safety and productivity in mine operation and use the model to develop testable implications. In our model, profits are determined by the revenues from coal sales, the cost of the labor input, and the cost of accidents. The mine chooses a labor input of hours worked, x, and a safety input, s. Together, these choices lead to a stochastic occurrence of accidents and coal production. The mine is faced with – but does not choose – a cost of accidents, d, which is determined by the past occurrence of fatalities and disasters. A high cost of accidents implies that a given accident will cost the firm more.

We now turn to the details of the model. Let x and s both be non-negative and assume that a higher value indicates more hours worked or a higher safety input, respectively. Let the random vector $A(s)$ denote the occurrence of accidents per hour worked. We allow $A(s)$ to be vector valued, to account for multiple types of accidents. We expect that $s = 0$ would lead to a high expected number of accidents per hour and that a large s would lead to very few accidents. Denote the cost of accidents per hour as $C(A(s), d)$. Finally, we will want to directly consider the cost of any safety input and accident price d rather than the occurrence of accidents. Let the random variable $c(s, d) \equiv C(A(s), d)$.

Using this notation, we write the expected profit function for a mine as:

$$E[\pi(x, s|d)] = E[F(x, s) - wx - c(s, d)\, x]. \tag{1}$$

In (1), the first term, $F(x, s)$, is the net coal production expressed in dollars. In the second term, w is the wage and wx is the total wage bill. More generally, we might think of x as all factor inputs and wx as the costs for all factor inputs. Last, $c(s, d)\, x$ is the total accident cost, which is the per-unit cost of accidents multiplied by the number of hours worked.

We now specify assumptions regarding the impact of the inputs on profits in (1).

Assumption 1 *Impact of inputs on expected profits*

1. *Expected coal production* $E[F(x, s)]$ *is increasing in* x *and decreasing in* s;
2. *Expected accident cost* $E[c(s, d)]$ *is decreasing in* s *and increasing in* d.

We believe that Assumption 1 is intuitive. Part 1 of Assumption 1 implies that firms produce more coal if they employ more hours (conditioning on the safety input), and less coal if they use more safety input (conditioning on hours worked). Part 2 implies that expected per-hour accident cost is decreasing in the safety input s and increasing in the cost of accidents, d.

We next make assumptions on the second derivatives that we also believe are intuitive.

Assumption 2 *Impact of second derivatives of inputs on outputs*

1. *All functions are twice differentiable;*
2. $\partial^2 EF(x,s)/\partial x \partial s$ *is negative;*
3. $\partial^2 Ec(s,d)/\partial s \partial d$ *is negative.*

Part 1 of Assumption 2 is just for simplicity; we could alternately derive our results using lattices. Part 2 states that the marginal product of labor, in terms of mineral output, decreases in the chosen level of safety input. This result would be generated if, for instance, s were monotonic in the fraction of the time that workers spent on safety training, and workers allocated their time between safety training and coal extraction. In this case, with a higher s, an additional hour of labor would result in a lower fraction of an hour spent on coal production and hence in less coal. Part 3 implies that the marginal cost from increased accident risk (or equivalently, marginal benefit from increased safety input) is increasing as we increase the cost of accidents d. This would be generated if the cost of accidents were linear in d for instance.

Since we assume differentiability, we can write the first-order condition with respect to labor input as:

$$\frac{\partial E[\pi(x,s|d)]}{\partial x} = 0 \Rightarrow \frac{\partial E[F(x,s)]}{\partial x} - w - E[c(s,d)] = 0, \tag{2}$$

and with respect to safety as:

$$\frac{\partial E[\pi(x,s|d)]}{\partial s} = 0 \Rightarrow \frac{\partial E[F(x,s)]}{\partial s} - x\frac{\partial E[c(s,d)]}{\partial s} = 0. \tag{3}$$

Equation (2) states that firms set their marginal product of labor input with respect to mineral production equal to the wage plus the extra accident cost. It differs from a standard production FOC in the third term, which is the extra accident cost from the additional hour of work. Equation (3) states that firms set their safety input so that the cost of increasing safety at the margin in terms of reduced expected mineral output is equal to the benefit of safety at the margin in terms of decreased total expected accident costs.

We now turn to our main result, which is that we will observe a decrease in mineral output and in expected accidents per hour (or equivalently, an increase in safety input) following a disaster or fatality. We define $x^*(d)$ and $s^*(d)$ to be the profit maximizing choices of labor and safety inputs respectively. Formally:

Proposition 1 $x^*(d)$ *is decreasing in* d *and* $s^*(d)$ *is increasing in* d.

Proof Assumptions 1 and 2 imply that:

$$\frac{\partial^2 \pi}{\partial x \partial d} = -\frac{\partial E[c(s,d)]}{\partial d} < 0,$$

$$\frac{\partial^2 \pi}{\partial x \partial s} = \frac{\partial^2 E[F(x,s)]}{\partial x \partial s} - \frac{\partial E[c(s,d)]}{\partial s} < 0,$$

and

$$\frac{\partial^2 \pi}{\partial s \partial d} = -x\frac{\partial^2 E[c(s,d)]}{\partial s \partial d} > 0.$$

Amir (2005) provides a simple proof of the monotonicity of optimal choices that is based on supermodularity as developed by Topkis (1978). For convenience, define $y = -x$ and $y^*(d) = -x^*(d)$. Then, the first condition of Amir (2005) Theorem 9 requires that the second derivatives of π with respect to y, s, and d all be positive, which we have shown. The second condition of the theorem is satisfied by our assumption that the choice set for x and s includes all non-negative real numbers, irrespective of a. Thus, by Amir Theorem 9, $s^*(d)$ and $y^*(d)$ are increasing in d, implying also that $x^*(d)$ is decreasing in d. ■

We believe that this result is intuitive. In a neoclassical model, firms choose safety levels to balance the accident cost with the production losses from safety. An unexpected fatality or disaster increases the cost of future accidents. This increases the firm's marginal benefits to improving safety, causing the firm to choose a greater safety input. The marginal productivity of labor in producing mineral output falls as a result, causing the firm to chooses less labor input. Together these effects result in a decrease in mineral output.

3.2 Estimation framework

Our model predicts that a fatality or disaster shock will lead to an increase in the optimal safety input s^* following a disaster or fatality. An increase in safety input in turn implies a decrease in the expected accidents per hours worked, $A(s^*)$. It also implies a decrease in the mineral output per worker, or productivity, conditioning on the number of hours worked. Finally, it implies a decrease in the number of hours worked.

Thus, we specify regressions that examine whether accidents per hour, productivity, and hours worked are affected by past mine disasters or fatalities. Specifically, we perform regressions at the mine-quarter level. Let i denote a mine and t denote a calendar quarter. We perform regressions of the form:

$$A_{it} = \alpha_i + \gamma_t + d_{it} + X_{it}\beta + \varepsilon_{it}, \tag{4}$$

where A_{it} are accident rates (or other dependent variables such as mineral production) per hours worked, α_i are mine fixed effects, γ_t are time (quarterly) fixed effects, d_{it} is the current cost of accidents (as determined by lagged fatalities and disasters), X_{it} represent other covariates such as hours worked, and ε_{it} include shocks to accidents rates. Besides accidents, we also perform similar regressions to (4) but using productivity and hours worked.

We allow for two types of regressions, based on d_{it} indicating either disasters or fatalities. For our regressions where d_{it} indicates disasters, we specify that the price of safety may change if there is a disaster located near the mine. The reason for this is because, as noted above, disasters are widely known and have intense media and political scrutiny. For our regressions where d_{it} indicates a fatality, we do not believe that there will be a wider change in the price of safety. Hence, we specify that the price of safety is likely to change only for the mine with the fatality itself. In all cases, we drop the five mines with a disaster, because other factors besides a change in the price of safety, such as physical damage, may be affecting their mineral output and safety choices. Noting that A_{it} is a vector, we estimate different versions of (4) with different types of accidents.

In (4), we include mine fixed effects because each mine produces with a different technology. For instance, we would expect underground mines to have more risks than surface mines, all else equal. By including mine fixed effects, we are controlling for the baseline risk at each mine in evaluating how past disasters and fatalities affect safety choices. Our estimates thus reflect the change in accidents after the disaster or fatality. Similarly, our covariates include time fixed effects because safety technologies and regulations have changed over time and because different input prices might cause mines to make different tradeoffs over time.

In addition to the regressions based on (4) we also specify first stage regressions that consider the mechanisms whereby a past disaster or fatality might increase the cost of future accidents. The central mechanism that we consider is regulation through MSHA. The format of these regressions is the same as (4) except that the dependent variable here indicates MSHA regulatory visits and enforcement.

Our regressions all include *future* fatalities or disasters. This inclusion forms a falsification test that would allow us to reject the causal interpretation of a disaster or fatality. For instance, if we observe that a future fatality significantly predicts higher accident risk, we might infer that the mine has undergone a period of low safety relative to its long-run average. We might then believe that the higher accident risk led to the fatality, rather than that the fatality changed the price of safety which led to differential accident risk, as we assume in our model. Thus, our model will tend to be more plausible to the extent that the future indicators are not significant predictors.

We cluster all our standard errors at the mine level to allow for ε_{it} to be serially correlated over time. We also weight all regressions by the mean hours worked at a mine, because mines with more hours worked may provide more information.

Finally, we include some regressions where the unit of observation is the state-year. These regressions use data on occupations within the mining sector that are only available at this level of aggregation. For these regressions, we cluster standard errors at the state level and weight regressions by the mean number of workers in the state.

4 Data

We obtain most of our data from the Mine Safety Health Administration (MSHA). We merge several datasets, all of which are available from the "Data Sets" area on the MSHA.gov website. The datasets report information on coal and metal mines. We keep from them exclusively records pertaining to coal mines. The *Employment/Production Data Set (Quarterly)* indicates the total coal production, the number of employees, U.S. state of location, and number of hours worked for all coal mines in the U.S. at the quarterly level from 2000 through the third quarter of 2014.

The *Accident Injuries Data Set* reports detailed information for all coal mining accidents in the U.S. From this database, we use the reported degree of injury. A fatality is a degree 1 injury, and an injury resulting in a permanent partial or total disability is a degree 2 injury. We classify accidents that result in degree 1 and 2 injuries as severe accidents. We classify injuries of degrees 3-6 as less-severe accidents. We exclude injuries of degrees 7-10, which include injuries from natural causes and injuries from non-employees.

The *Violations Data Set* reports the number of violations and financial penalties mines were assessed from MSHA inspectors during each quarter. The *Inspections Data Set* reports the number of inspections in a mine and the total hours each mine is inspected. Finally, the *Mines Data Set* provides latitude and longitude information for each mine.

Table 1 provides details on injury by degree during the period of our data. Fatalities are the most rare, with 446 observed over this period. Permanent disabilities occur slightly more often than fatalities, with 785 observed over the same period. Among the less-severe accidents, the most common are accidents with injuries that require days away from work only, with 42,122 observed, followed by ones that require no days away from work, but still require medical

Table 1: Summary of Accident Occurrences in Sample

Injury Degree	Accident Description	Severe Injury	Number Observed
1	Cases resulting in death	Yes	446
2	Cases with permanent total or partial disability	Yes	785
3	Cases with days away from work only	No	42,122
4	Cases with days away from work and restricted work	No	3,854
5	Cases with days of restricted work only	No	4,609
6	Cases without days away from work (but with medical treatment)	No	21,211

Note: sample period of accidents is is Q1:2000 through Q3:2014.

treatment, with 21,211 observed.

Figure 2 graphs fatalities and disasters over time during the period of our data.[7] We define a disaster as an accident with five or more fatalities. In this time period, all disasters are caused by the ignition of explosive gasses. We observe five disasters, two in the state of West Virginia, and one in each of Utah, Kentucky and Alabama. All disasters, including the mine and state in which they occurred, are noted on the figure.

We chose five as the threshold number of fatalities that defines a disaster as we thought that this number would represent a cutoff for generating more widespread attention. Note also from Figure 2 that four out of the five disasters that we observe have far more than five fatalities. Also, most non-disaster fatalities represent single fatalities. In particular, we observe 322 mine/months with 1 fatality, 25 mine/months with 2 fatalities, 2 mine/months with 3 fatalities, and none with 4 fatalities. We believe that this evidence shows that there is a sharp division between the disasters and the non-disaster fatalities.

Figure 3 graphs severe and less-severe accidents over time during the period of our data. We observe a downward trend in less-severe accidents over time. There is no clear trend for severe accidents.

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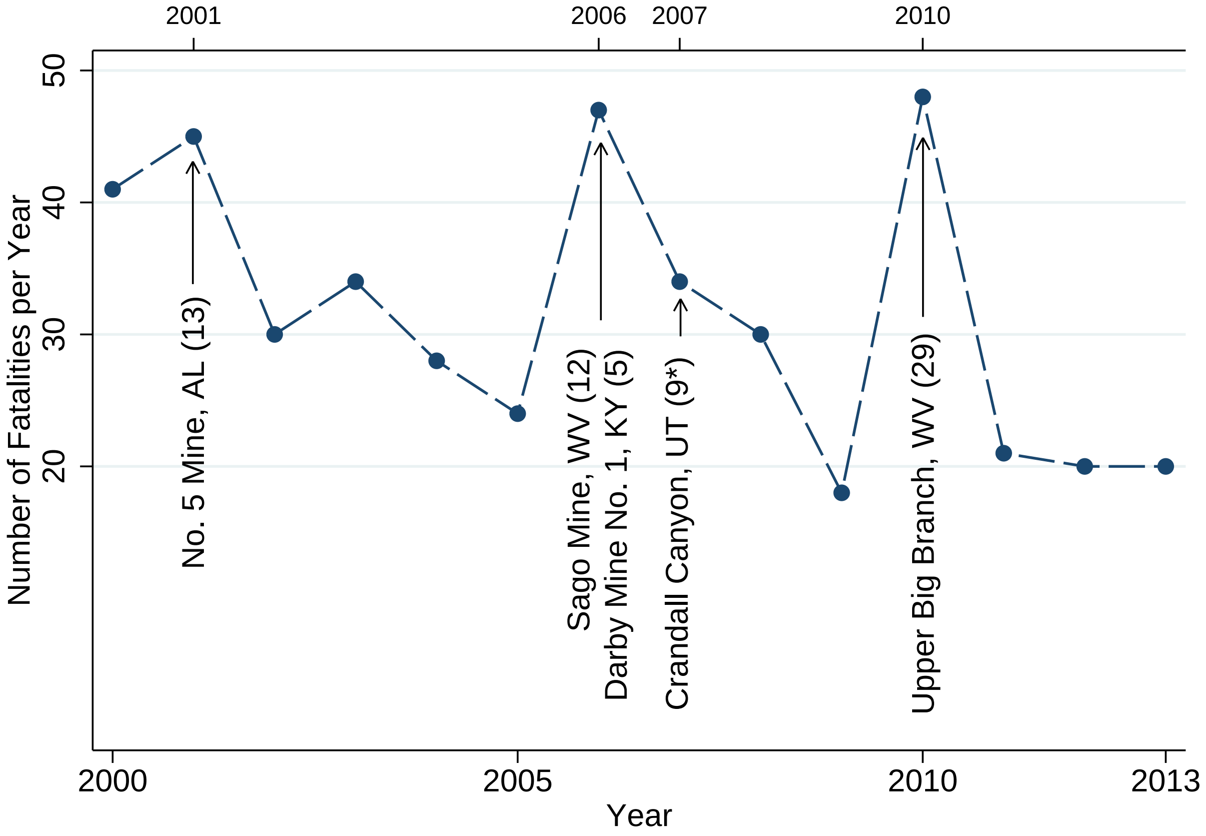
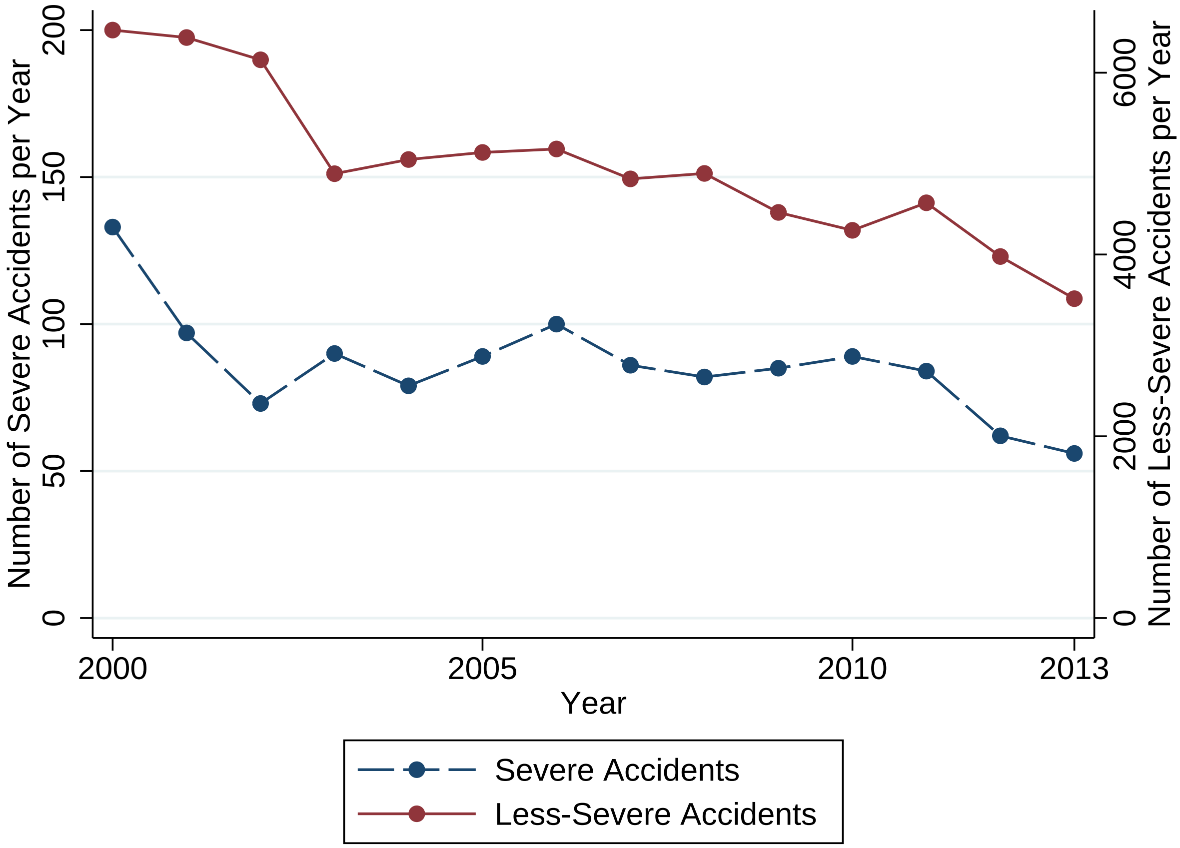
[7] We exclude 2014 from this figure as have only 3 quarters of data from 2014.

Figure 2: Fatalities and Disasters in Coal Mines



Note: number of deaths for each disaster reported in parentheses. *Of the nine fatalities associated with the Crandall Canyon disaster, three were rescue workers who were killed ten days subsequent to the initial collapse.

Figure 3: Severe and Less-Severe Accidents in Coal Mines



The production and accident databases are reported separately by each subunit within a mine. To create our estimation sample, we remove all observations that are in subunits that indicate office work instead of mining activity. We then collapse the data so that our unit of observation is a mine observed over a quarter. We define productivity as coal production measured in tons divided by person-hours of labor. Our data on MSHA violations and actions are reported at the mine-quarter level so we do not collapse these data.

Our analysis sample drops mines which produced no coal ever during our sample period. We also drop mine-quarter observations which reported fewer than 2,000 person hours, which is the equivalent of four full-time employees over the quarter. Last, as noted above, we exclude from our sample the five mines which experienced a disaster as these mines may be physically damaged by the disaster.

Our data extend from Q1:2000 through Q3:2014. Our regressors include lags and leads of disasters and fatalities up to two years. This limits our sample that uses fatalities to Q1:2002 through Q3:2012. However, because mine disasters are large, public event, we know when they occurred. The most recent mine disaster prior to our sample was in 1992, more than two years preceding our earliest data. Thus, for our regressions which include mine disasters as the main regressor, we can keep observations going back to Q1:2000.

Table 2 provides summary statistics on our estimation sample at the mine-quarter level. We include here all observations from Q1:2000 through Q3:2012, which corresponds to the sample with disasters as the main regressor; the sample with fatalities as the main regressor starts in Q1:2002. The mean hours worked is about 40,000, reflecting a mean mine size with a full-time equivalent of 80 workers. The largest mine is about 20 times this size. Mean coal production is about 270,000 tons per quarter. Mean productivity is 3.9 tons.[8]

Despite the high absolute numbers noted in Table 1, severe accidents are rare, with a rate of 0.5 per million hours worked. One million hours worked corresponds to 2,000 people working full-time over a quarter. Less-severe accidents occur an average of 27.8 times per million hours worked, suggesting that a larger mine with 1,000 workers would expect to have 13.9

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[8] MSHA (and our paper) use the short ton, which is equal to 2,000 pounds.

Table 2: Summary Statistics at Mine-Quarter Level

Variable	Mean	Std. Dev.	Mean Within Mine Std. Dev.	Min	Max
Coal production (thousands of tons)	271	1,221	86.3	0	31,354
Productivity (short tons per worker hour)	3.9	5.2	1.5	0	87
Hours worked (thousands)	40	64.7	13.2	2	882
Employees	69	113	21.3	2	1,661
Fatalities per million hours	0.2	5.0	1.0	0	467
Severe accidents per million hours	0.5	7.1	2.3	0	467
Less-severe accidents per million hours	28	61.3	44.4	0	2,238
MSHA inspections	3.5	5.7	2.0	0	58
MSHA inspection hours	166	272	87.1	0	8,526
MSHA penalties (thousands of $)	14	56.7	19.4	0	1,982
MSHA violations	17	30.6	11.7	0	470

Note: summary statistics are for estimation sample for specifications that have disasters as the main regressor. Sample period is Q1:2000 through Q3:2012. N=51,477. See text for details of sample construction and variable definitions.

such less-severe accidents each quarter. MSHA inspects mines 3.5 times per quarter on average spending an average of 166.2 hours on their inspections. They also assess penalties of $14,100 on average per mine-quarter, finding 16.8 violations on average.

For each reported statistic, the standard deviation is larger than the mean. This indicates that there is substantial variation in all the variables in our data. This variation reflects the diversity of mining operations in the United States, which vary in size from small mines employing a handful of workers to massive sites employing over a thousand workers. These operations likely have different rates of compliance with safety regulations.

Last, Table 2 provides information about within-mine variation by showing the mean of the within-mine standard deviations. This statistic is important because our identification of the response to exogenous shocks relies on within-mine variation given that we include mine fixed effects. As the table shows, there is also substantial within-mine variation for all of our variables of interest in our sample. For instance, the within-mine standard deviations in productivity has a mean of 1.5 tons per worker hour, compared to the unconditional standard deviation of 5.2. MSHA enforcement activity variables all have relatively large within-mine standard deviation. For instance, the within-mine standard deviation in the number of MSHA

Table 3: Summary Statistics for Coal Mining Occupations at State-Year Level

Worker Occupation	Observations	Mean	Std. Dev.	Min	Max
Miners	220	1,111	1,693	0	8,913
Managers	220	603	906	0	4,263
Other Workers	220	2,932	4,463	0	22,615
All	220	4,647	6,931	22	33,561

Note: data are obtained from IPUMS, extend from 2005 through 2013.

inspections per quarter has a mean of 2.0 compared to the unconditional standard deviation of 5.7.

In addition to MSHA data, we also obtained U.S. Census data from the Integrated Public Use Microdata Series (IPUMS, Ruggles et al., 2010). We use IPUMS data from the American Community Survey, which began in 2005. For our purposes, the IPUMS data list worker occupations for a sample of workers employed in the coal mining industry. These data allow us to understand variation in the effects of a disaster in a state by occupation. Unlike the MSHA data, which are at the mine-quarter level, the American Community Survey data are effectively only usable at the state-year level.

We extracted data from IPUMS for all employees who report coal mining as their occupation, using the 1990 industry code 41. We use the “occ1990” field as our measure of occupation. We split coal-mining workers into three occupations based on this field: coal miners, managers (defined as individuals whose occupation includes the word “manager” or “supervisor”), and other workers.

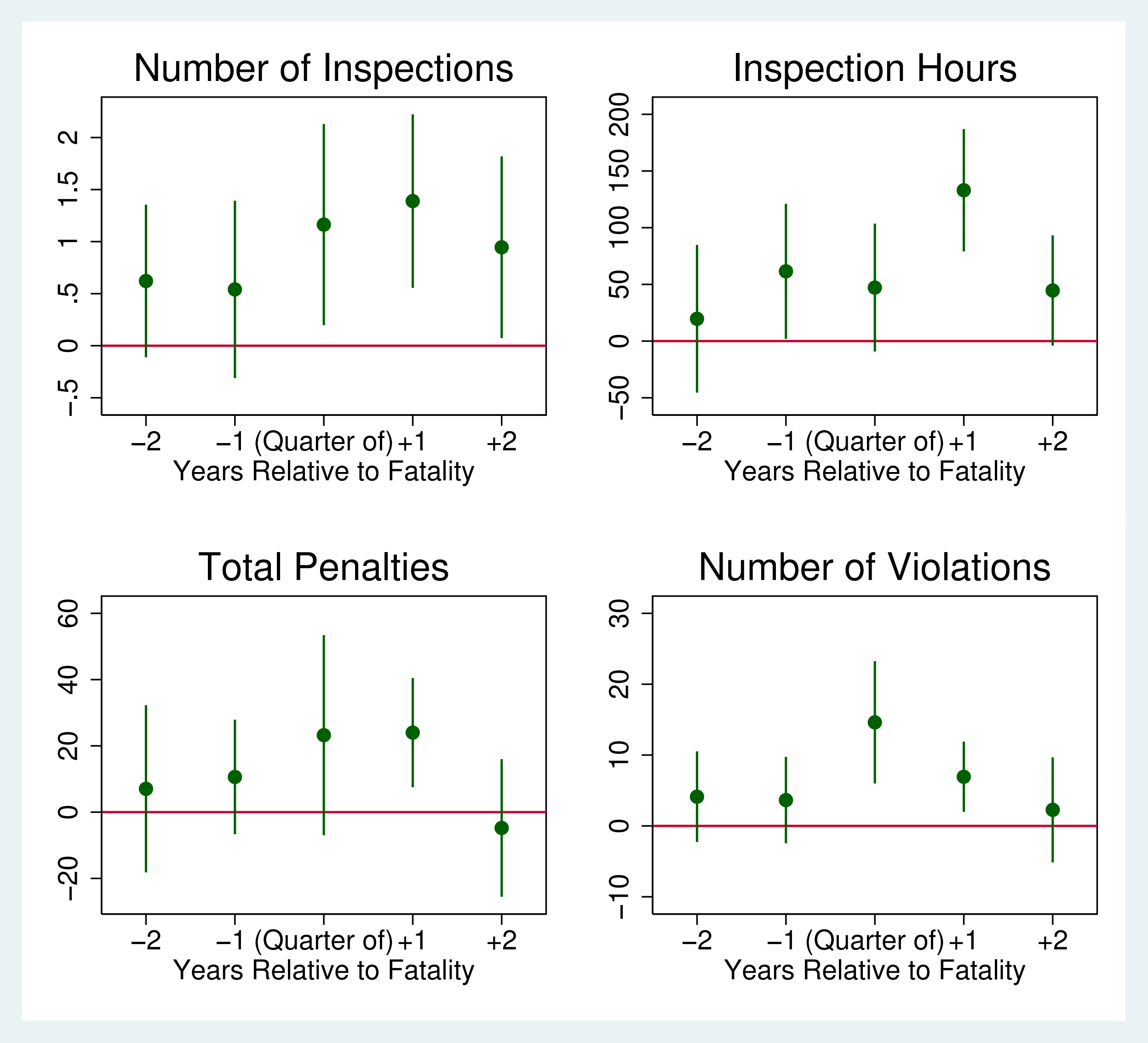
The IPUMS data include survey weights and we collapse the data to the state and year level using these weights. The data extend from 2005 through 2013, a shorter time period than our overall study period, thus limiting the power of this analysis.

Table 3 provides summary statistics on the IPUMS data. Our IPUMS data include 220 state-year observations, all of which have some workers in the coal mining industry. Miners comprise about 24% of the employees in this sector, managers 13%, and other occupations 63%.

5 Results

5.1 Effect of Mine Fatalities

Figure 4: Regressions of Fatalities on MSHA Activity



Each figure reports selected regressors from one regression. Dependent variables are indicated in the title. All regressions include mine fixed effects, quarterly fixed effects, and state dummies times hours worked and state dummies times employees (to control for economies of scale) as regressors and are weighted by mean hours worked at the mine. Standard errors are clustered at the mine level. Each line shows a 95% confidence interval.

Table 4: Regressions of Fatalities on MSHA Activity

	(1) Number of Inspections	(2) Inspection Hours	(3) Penalties (Thousands $)	(4) Number of Violations
Effect by Year				
Two Years Prior to Fatality	0.62*	19.7	7.04	4.13
	(0.37)	(33.2)	(12.9)	(3.26)
One Year Prior	0.54	61.5**	10.6	3.64
	(0.43)	(30.4)	(8.81)	(3.11)
Quarter of Fatality	1.16**	47.2	23.2	14.6***
	(0.49)	(28.8)	(15.4)	(4.40)
One Year After	1.39***	133.0***	24.0***	6.93***
	(0.43)	(27.5)	(8.41)	(2.53)
Two Years After	0.95**	44.6*	-4.77	2.27
	(0.45)	(24.8)	(10.6)	(3.78)
State×Hours Worked	Yes	Yes	Yes	Yes
State×Employees	Yes	Yes	Yes	Yes
N	43,377	43,377	43,377	43,377
R^2 Adj.	0.16	0.31	0.23	0.28

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Each column reports the results of one regression. Dependent variable is indicated in the column title. All regressions include mine fixed effects and quarterly fixed effects as regressors and are weighted by mean hours worked at the mine. Standard errors, reported in parentheses, are clustered at the mine level.

We start by examining the impact of mine fatalities on the mine itself. We first report on the “first stage” of the impact of MSHA enforcement activity. Here, we report results from a series of regressions that regress different MSHA enforcement actions on the presence of a current and lagged fatality at the mine. All regressions are at the mine-quarter level. We believe that the presence of a fatality represents a quasi-experimental source of variation. In order to partially test this hypothesis, all specifications also include *future* fatality measures as a falsification test. Because larger mines provide more information, we weight all regressions by the mean number of hours worked in that mine. We also include mine and quarter fixed effects and cluster standard errors at the mine level.

We report the same set of results in two ways. First, Figure 4 shows the coefficients on current, future, and lagged fatalities graphically, along with standard errors. Second, Table 4 shows the coefficients in table form. We present all results in this same manner.

We find that MSHA inspections, inspection hours, and the number of violations (though not penalties) increase significantly in the four quarters after a fatality at a mine. The magnitudes of the increases are large. For instance, the number of inspections increases by 1.5 in quarters 1-4 after the fatality, representing a 18% increase relative to the baseline at the affected mines at those time periods, while the number of cited violations increases by 6.2, representing a 16% increase.

Interestingly, in the period two years (5-8 quarters) after the fatality, the effects are somewhat different. While the number of inspections and inspection hours are still significantly higher than the baseline, the total penalties and number of violations both fall back to having much smaller coefficients that are statistically no different than the baseline. We believe that this may be caused by firms reacting to the fatality and the increased MSHA enforcement activity by increasing their safety input.

In contrast to the coefficients in the quarter of the fatality and following a fatality, the future presence of a fatality does not significantly affect MSHA enforcement activity, except for one variable in one year (inspection hours in the year before the fatality, with P=0.043).[9] Thus, the data do not seem to indicate the presence of a reverse causality story where common factors are driving both increased MSHA enforcement activity and more fatalities.

Having established that enforcement activity is a potential causal pathway by which fatalities might affect the relative price of safety and mineral output, we next seek to understand the impact of fatalities on productivity and measures of safety. Figure 5 and Table 5 present results that are analogous to Figure 4 and Table 4 respectively, regressing productivity and safety measures on current, future, and lagged fatalities. We include the same regressors as in the earlier specifications, except that our specifications with log hours as the dependent

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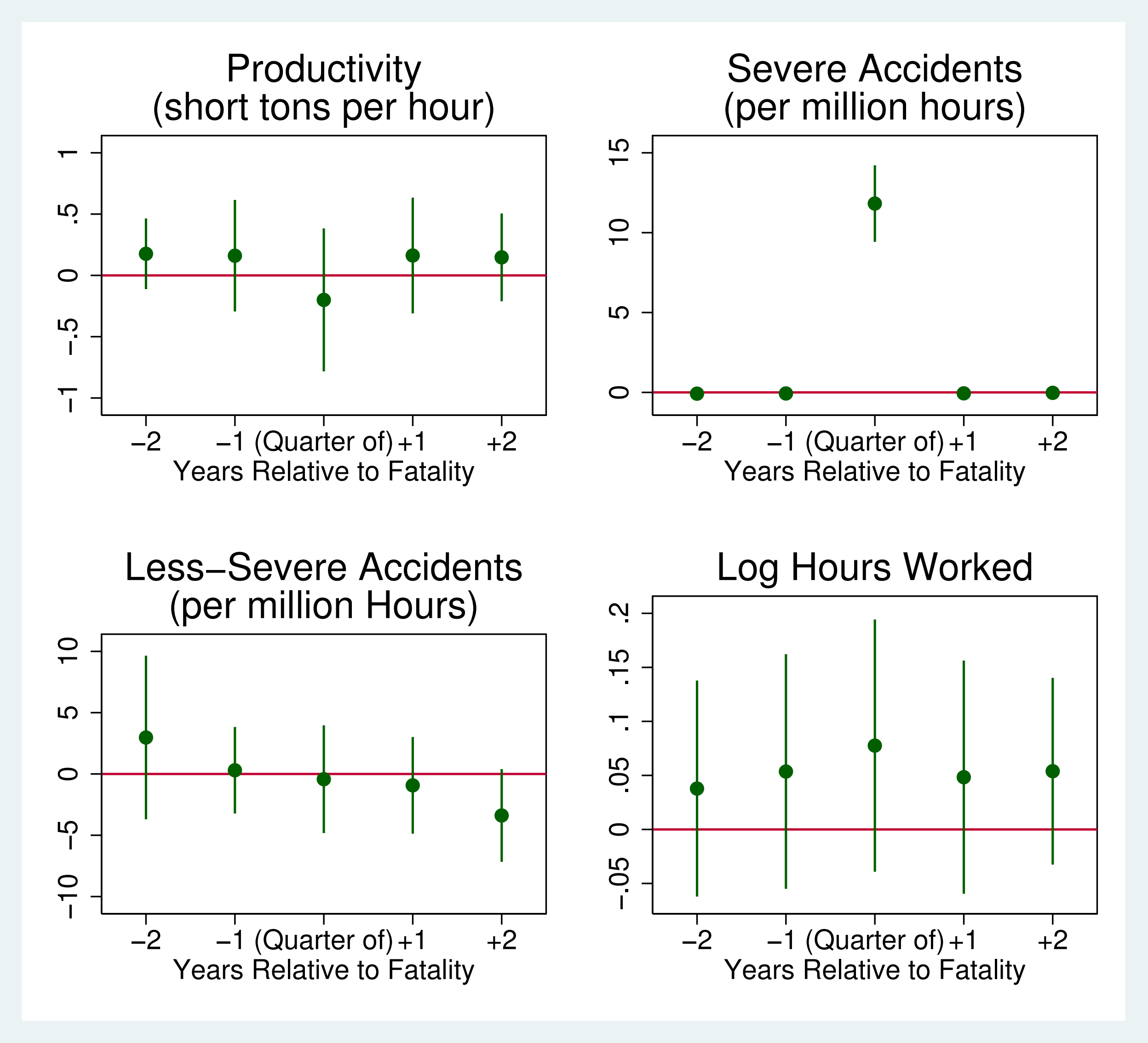
[9] Even in this case, the two dummies, on one and two years prior to the fatality, are not jointly significant (P=0.125).

variable exclude indicators for hours worked and employees.

Figure 5: Regressions of Fatalities on Productivity and Safety



Each figure reports selected regressors from one regression. Dependent variables are indicated in the title. All regressions include mine fixed effects, quarterly fixed effects as regressors and are weighted by mean hours worked at the mine. All regressions but log hours include state dummies times hours worked and state dummies times employees a regressors. Standard errors are clustered at the mine level. Each line shows a 95% confidence interval.

Here, we find that the rate of less-severe accidents per hour drop in quarters 5-8 (two years after) the fatality, with marginal significance (P=0.081). The drop is about 7% of the baseline value. The coefficient on severe accidents, though not significant, is also negative. None of the other coefficients on accidents are significant, except for the coefficient on accidents in the quarter of fatality, which is significantly positive and large, reflecting the fact that the fatality itself is a severe accident. We find no impact on productivity or log hours. We find no support for the reverse causality story.

Together, the results appear to support our hypothesis that mine fatalities are relatively rare events that shift the relative price of safety and mineral output for a mine through increased enforcement activity. The increased price of safety appears to cause mines to decrease their less-severe accidents by 7%. This does not appear to have any adverse impact of productivity, and indeed the point estimates on productivity and hours worked are positive.

5.2 Effect of Mine Disasters

We now present the effect of mine disasters, defined as five deaths or more at a mine. Recall that our sample includes five disasters (Figure 2). Because a disaster may permanently shut down or alter a mine, we are not as interested in the effect of a disaster on the mine itself. Rather, we are interested in understanding whether the disaster has an effect on mines in the nearby area although we also examine measures based on a fixed distance. As noted in the introduction, this may occur through media or regulatory attention or increased worker concern, among other factors. Our base results consider the impact of mines within the same state, where state is proxying for the nearby area. Of course, some of the impact of a mine disaster may be national, as evidenced by President Obama's speech noted in the introduction. Our estimation will capture national effects of the disaster through the time dummies and hence our estimate of the impact of the disaster will only capture the part of the effect that is local.

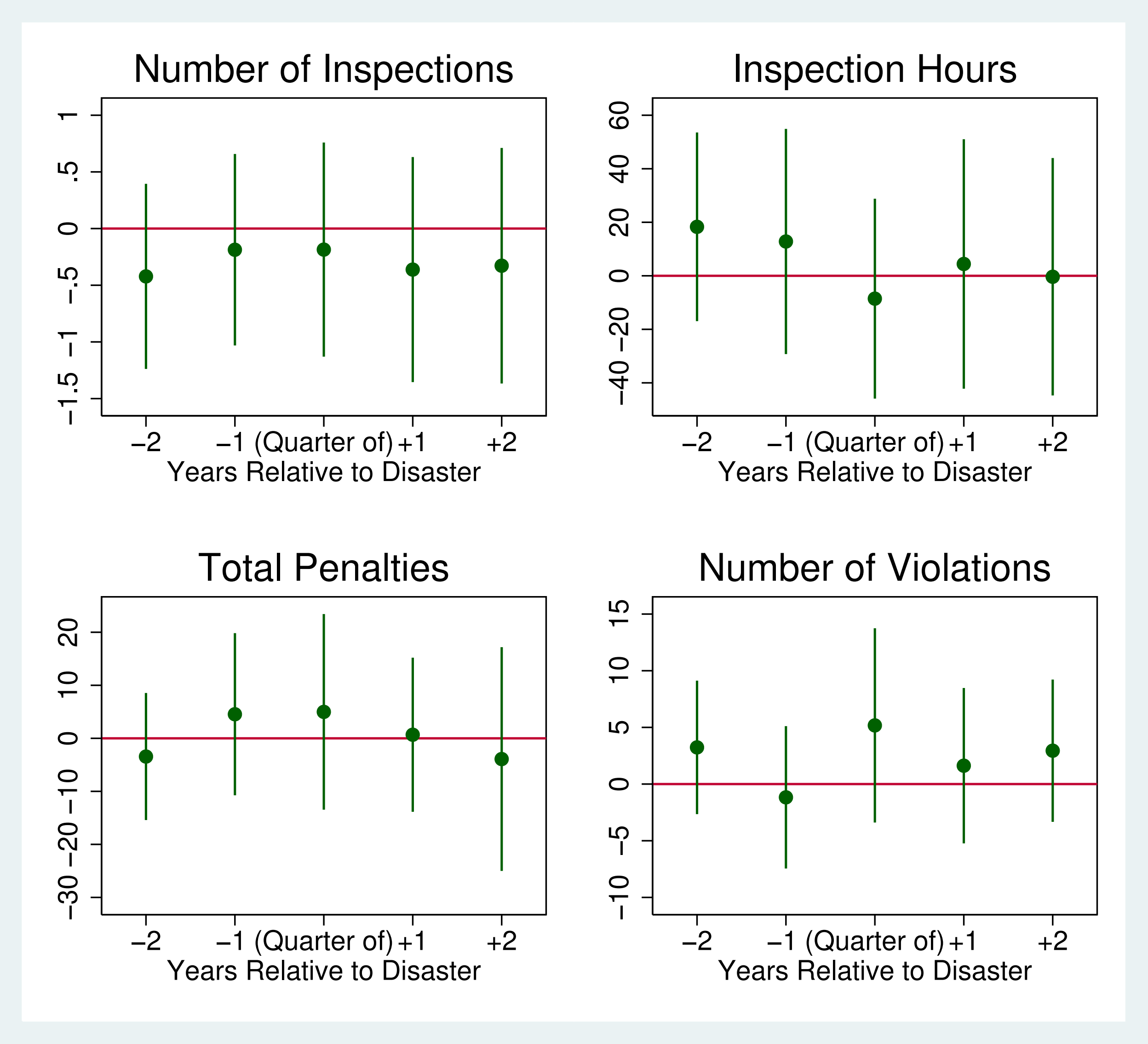
Figure 6 and Table 6 present evidence for the effects of disasters on MSHA enforcement activity. For each of the four enforcement variables, we find no pattern of significant variation in MSHA enforcement activity in mines following a mine disaster for mines in the same state

Table 5: Regressions of Fatalities on Productivity and Safety

	(1) Less-Severe Accidents (per million hours)	(2) Severe Accidents (per million hours)	(3) Productivity (short tons per hour)	(4) Log Worker Hours
Effect by Year				
Two Years Prior to Fatality	2.97	-0.077	0.18	0.038
	(3.40)	(0.089)	(0.15)	(0.051)
One Year Prior	0.30	-0.066	0.16	0.054
	(1.80)	(0.14)	(0.23)	(0.055)
Quarter of Fatality	-0.43	11.8***	-0.20	0.078
	(2.24)	(1.22)	(0.30)	(0.060)
One Year After	-0.93	-0.058	0.16	0.048
	(2.01)	(0.14)	(0.24)	(0.055)
Two Years After	-3.39*	-0.026	0.15	0.054
	(1.93)	(0.11)	(0.18)	(0.044)
State×Hours Worked	Yes	Yes	Yes	No
State×Employees	Yes	Yes	Yes	No
N	43,377	43,377	43,377	43,377
R^2 Adj.	0.05	0.09	0.27	0.03

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Each column reports the results of one regression. Dependent variable is indicated in the column title. All regressions include mine fixed effects and quarterly fixed effects as regressors and are weighted by mean hours worked at the mine. Standard errors, reported in parentheses, are clustered at the mine level.

Figure 6: Regressions of Disasters on MSHA Activity



Each figure reports selected regressors from one regression. Dependent variables are indicated in the title. All regressions include mine fixed effects, quarterly fixed effects, and state dummies times hours worked and state dummies times employees as regressors and are weighted by mean hours worked at the mine. Standard errors are clustered at the mine level. Each line shows a 95% confidence interval.

as the disaster. Thus, in the case of mine disasters, to the extent that disasters change the relative price of safety and mineral output, the causal pathway does not appear to be MSHA enforcement activity.

Table 6: Regressions of Disasters on MSHA Activity

	(1) Number of Inspections	(2) Inspection Hours	(3) Penalties (Thousands $)	(4) Number of Violations
Effect by Year				
Two Years Prior to Disaster	-0.42	18.3	-3.43	3.24
	(0.42)	(18.0)	(6.11)	(3.00)
One Year Prior	-0.19	12.8	4.54	-1.17
	(0.43)	(21.5)	(7.80)	(3.20)
Quarter of Disaster	-0.19	-8.54	4.99	5.18
	(0.48)	(19.0)	(9.41)	(4.37)
One Year After	-0.36	4.42	0.68	1.62
	(0.51)	(23.8)	(7.41)	(3.50)
Two Years After	-0.33	-0.36	-3.91	2.94
	(0.53)	(22.6)	(10.8)	(3.20)
State×Hours Worked	Yes	Yes	Yes	Yes
State×Employees	Yes	Yes	Yes	Yes
N	51,477	51,477	51,477	51,477
R^2 Adj.	0.18	0.34	0.25	0.31

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Each column reports the results of one regression. Dependent variable is indicated in the column title. All regressions include mine fixed effects and quarterly fixed effects as regressors and are weighted by mean hours worked at the mine. Standard errors, reported in parentheses, are clustered at the mine level.

We next turn to the effect of disasters on productivity and measures of safety. Figure 7 and Table 7 present these results. We find that the rates of fatalities and less-severe accidents per hour both drop steeply and significantly two years after a disaster in the state. The results are large with a coefficient of -0.22 on fatalities and -8.1 on less-severe accidents. These imply a drop of 68% in fatalities per hour worked and 23% in less-severe accidents per hour relative to the baseline at the affected mines at those time periods. As a caveat, the rates of these accidents were both negative preceding the disaster. However, the coefficients were generally much smaller and not statistically significant prior to the disaster. Even using the future rate as the baseline would imply a big drop in both severe and less-severe accidents from a disaster in the state. The impact of a disaster on severe accidents is not statistically significant but is similar in magnitude to the impact on fatalities.

Overall, we believe that there is strong evidence that a disaster in a state causes mines to increase safety inputs. Note also that the magnitude of the safety effects are much bigger than we find after a single fatality.

We find weaker evidence that mineral productivity drops following a disaster in the state: the coefficient in the year after the disaster is negative at -0.24 and marginally significant with $P = 0.098$. Moreover, even though future disasters do not significantly predict drops in productivity, the magnitude of the future coefficients is very similar (and actually slightly larger than) the -0.24 coefficient here. Although the model predicted that we should see a decrease in hours worked, we do not see any significant effect on hours worked following the disaster. Thus, there is at best very weak evidence that our rational model of a tradeoff between productivity and safety is an accurate description of safety behavior for coal mines.

Our results here focus on the effect of mine disasters on other mines in the same state. However, we have also examined other measures of closeness, such as mines located within 200 KM and 400 KM. These results, which we present in Appendix A, are very similar to our base results in Figure 7 and Table 7.

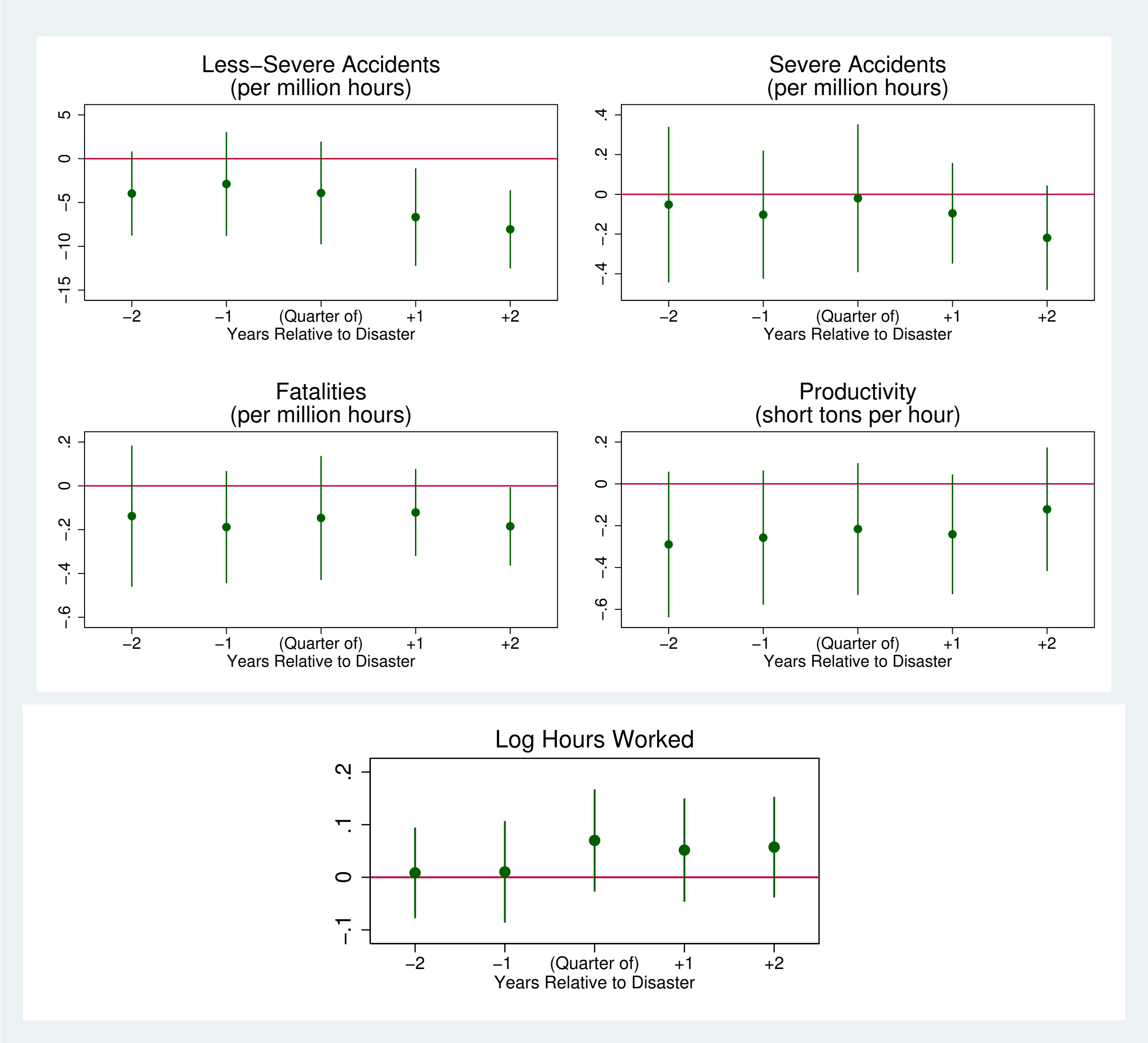
We also estimated specifications of the impact of disasters on productivity and safety with continuous measures of distance. Here, we present results that allow for a base effect of

Table 7: Regressions of Disasters on Productivity and Safety

	(1) Less-Severe Accidents (per million hours)	(2) Severe Accidents (per million hours)	(3) Fatalities (per million hours)	(4) Productivity (short tons per hour)	(5) Log Worker Hours
Effect by Year					
Two Years Prior to Disaster	-3.98	-0.052	-0.16	-0.29	0.0084
	(2.45)	(0.20)	(0.17)	(0.18)	(0.044)
One Year Prior	-2.89	-0.10	-0.19	-0.26	0.010
	(3.02)	(0.16)	(0.14)	(0.16)	(0.049)
Quarter of Disaster	-3.91	-0.020	-0.16	-0.22	0.070
	(2.98)	(0.19)	(0.16)	(0.16)	(0.049)
One Year After	-6.67**	-0.095	-0.14	-0.24*	0.052
	(2.84)	(0.13)	(0.11)	(0.15)	(0.050)
Two Years After	-8.06***	-0.22	-0.22**	-0.12	0.057
	(2.28)	(0.13)	(0.099)	(0.15)	(0.049)
State×Hours Worked	Yes	Yes	Yes	Yes	No
State×Employees	Yes	Yes	Yes	Yes	No
N	51,477	51,477	51,477	51,477	51,477
R^2 Adj.	0.04	0.00	0.00	0.31	0.03

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Each column reports the results of one regression. Dependent variable is indicated in the column title. All regressions include mine fixed effects and quarterly fixed effects as regressors and are weighted by mean hours worked at the mine. Standard errors, reported in parentheses, are clustered at the mine level.

Figure 7: Regressions of Disasters on Productivity and Safety



Each figure reports selected regressors from one regression. Dependent variables are indicated in the title. All regressions include mine fixed effects, quarterly fixed effects as regressors and are weighted by mean hours worked at the mine. All regressions but log hours include state dummies times hours worked and state dummies times employees a regressors. Standard errors are clustered at the mine level. Each line shows a 95% confidence interval.

being within 200 KM of a disaster and a term that interacts distance to the disaster with being within the 200 KM threshold. Table 8, which presents these results, shows base effects that confirm our results in Table 7: fatalities, severe accidents, and less-severe accidents all decrease after the disaster, but productivity and hours worked do not change significantly.

However, the distance effects also show some interesting differences. For both fatalities per hour worked and severe accidents per hour worked, the impact of the disaster is not significantly different the further one is from the disaster. But, the impact of the disaster on reducing less-severe accidents decays the further one is from the mine with the disaster. The decay effect is large, with a mine collocated at the disaster experiencing -9.15 fewer less-severe accidents two years after the disaster, but the effect being only -1.49 at 200 KM from the disaster. One possible explanation is that while mine owners face strong incentives to reduce fatalities and severe accidents in the wake of a disaster, they face lower incentives to reduce less-severe accidents. Instead, reductions in these relatively minor accidents are produced by face to face communication and word of mouth among non-executive employees across mines. Another explanation is that mines closer to the disaster are more likely to have in common the same types of equipment and procedures and are better able to share improved methods to reduce less-severe accidents.

Finally, we examine how disasters in a state change the composition of employees, using the American Community Survey data from IPUMS and regressions at the state-year level. Since our data here pertain only to 2005-13, they contain only four disasters. Moreover, we omit the falsification indicator for being two years before a disaster (but include the indicator for being one year before a disaster), as otherwise, we would be reduced to having two disasters in our sample.[10] We find that in the year of a disaster and the year following a disaster, there are fewer miners in the state of the disaster, but that this number rebounds to roughly the baseline level two years after the disaster. We also find that the number of other workers is significantly higher in the year and state of the disaster, but that this figure also is not significantly different than the baseline in the years following a disaster. In contrast, the number of managers increases by 252 two years after a disaster, which represents an 11% increase relative to the baseline at the affected states at those time periods. Unlike in the base regressions, the overall number of workers increases two years after a disaster in the state. The extra 1,679 workers represents an 8% increase relative to the baseline. Thus, it is

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[10] Also, unlike our base regressions, these regressions do not exclude the mine with the disaster.

Table 8: Regressions of Disasters on Productivity and Safety, With Distance Interactions

	(1) Less-Severe Accidents (per million hours)	(2) Severe Accidents (per million hours)	(3) Fatalities (per million hours)	(4) Productivity (short tons per hour)	(5) Log Worker Hours
Two Years Prior to Disaster					
Base	-2.85	-0.33	-0.39*	-0.34	-0.020
	(3.63)	(0.25)	(0.23)	(0.22)	(0.042)
Base × Distance (per 100km)	1.30	0.14	0.15**	0.050	-0.0082
	(2.59)	(0.12)	(0.073)	(0.091)	(0.033)
One Year Prior					
Base	-5.84	0.0092	-0.33	-0.16	-0.076
	(3.64)	(0.29)	(0.22)	(0.21)	(0.055)
Base × Distance (per 100km)	2.42	-0.31*	0.064	-0.029	0.019
	(2.20)	(0.19)	(0.074)	(0.093)	(0.040)
Quarter of Disaster					
Base	-3.46	0.077	-0.30	-0.11	-0.071
	(3.79)	(0.31)	(0.26)	(0.21)	(0.066)
Base × Distance (per 100km)	0.21	-0.20	0.16	-0.014	0.037
	(2.50)	(0.23)	(0.17)	(0.11)	(0.048)
One Year After					
Base	-7.08**	-0.34*	-0.35**	-0.060	-0.055
	(3.24)	(0.19)	(0.18)	(0.20)	(0.068)
Base × Distance (per 100km)	3.12*	-0.031	0.048	-0.085	0.0088
	(1.78)	(0.081)	(0.045)	(0.092)	(0.046)
Two Years After					
Base	-9.15***	-0.37*	-0.33**	0.060	-0.011
	(2.50)	(0.20)	(0.16)	(0.19)	(0.060)
Base × Distance (per 100km)	3.83**	0.019	0.086	-0.032	-0.027
	(1.80)	(0.11)	(0.063)	(0.076)	(0.037)
State× Hours Worked	Yes	Yes	Yes	Yes	No
State×Employees	Yes	Yes	Yes	Yes	No
N	51,477	51,477	51,477	51,477	51,477
R^2 Adj.	0.04	0.00	0.00	0.31	0.03

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Each column reports the results of one regression. The units of the Base × Distance regressor is in 100km. The dependent variable is indicated in the column title. All regressions include mine fixed effects and quarterly fixed effects as regressors and are weighted by mean hours worked at the mine. Standard errors, reported in parentheses, are clustered at the mine level.

Table 9: Regressions of Disasters on the Number of Employees by Occupation

	(1) All Workers	(2) Managers	(3) Miners	(4) Other Workers
One Year Prior to Disaster	-1315.2*	-102.9	-911.9	-300.4
	(742.8)	(387.2)	(626.3)	(949.2)
Year of Disaster	1642.3***	455.5**	-663.0	1849.8**
	(538.1)	(173.6)	(512.4)	(747.5)
One Year After	-763.5	-58.8	-954.2***	249.4
	(648.0)	(240.7)	(173.3)	(908.5)
Two Years After	1679.1***	252.0***	533.4	893.7
	(386.3)	(61.0)	(804.3)	(1035.1)
N	220	220	220	220
R^2 Adj.	0.51	0.26	0.33	0.27

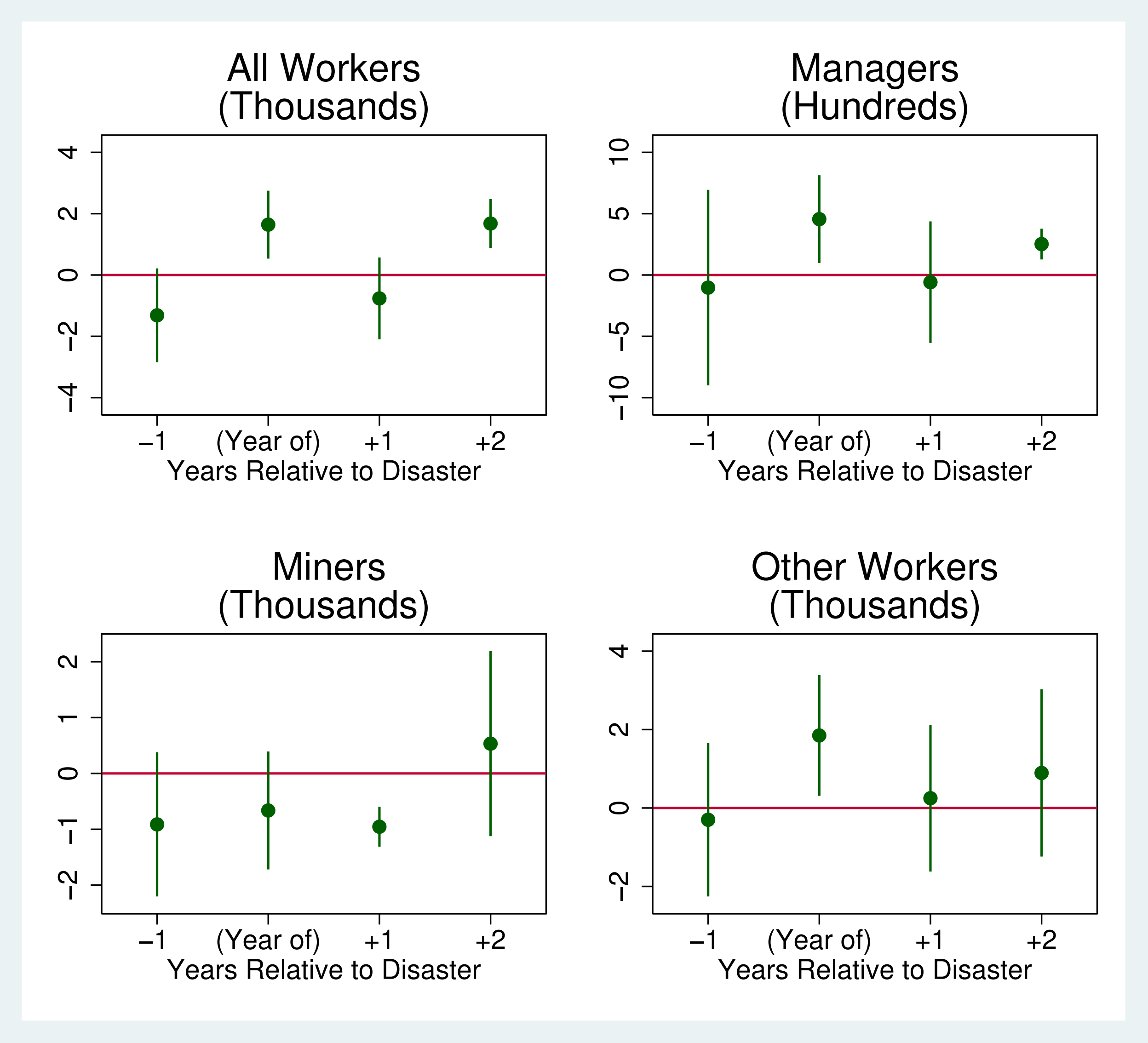
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Each column reports the results of one regression. The dependent variable is indicated in the column title. All regressions include state and year fixed effects as regressors and are weighted by the mean number of workers in the state. Standard errors, reported in parentheses, are clustered at the state level.

possible that firms employ more managers and supervisors two years after a disaster in their state with the goal of reducing accident risk. The hiring of additional personnel who do not produce coal would cause productivity decreases.

5.3 Dollar Magnitudes of Effects

We now turn to evaluating the dollar magnitudes of our effects. We first examine the dollar cost savings that mines may incur from the lowered the risk of fatality following a disaster in the state. There is a large literature on the value of a statistical life (VSL) that seeks to estimate the cost of fatalities. A number of papers in this literature use labor market data to estimate the wage premiums that workers earn from dangerous occupations such as mining, and divide the wage premiums by the probability of death. The fatality cost measured by these papers are costs borne by firms, who pay higher wages for dangerous occupations. An influential review article, Viscusi and Aldy (2003), finds that estimates of the VSL that use U.S. labor market data are between \$4 and \$9 million. Using their midpoint value of \$6.5

Figure 8: Regressions of Disasters on the Number of Employees, by Category



Each figure reports selected regressors from one regression. Dependent variables are indicated in the title. All regressions include state and year fixed effects and are weighted by the mean number of workers in the state. Standard errors are clustered at the state level. Each line shows a 95% confidence interval.

million, we find that the reduction in risk of fatalities two years after the disaster is worth $1.41 per hour worked.[11]

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[11] The VSL literature accounts for increased wage costs from accident risk but does not account for the direct cost of a large accident. This cost may be large: the National Safety Council estimates a workplace fatality to cost $1.4 million (National Safety Council, 2014), while BP paid over $8 million to each worker who died from the Deepwater Horizon oil-rig explosion (Dionne, 2011).

We next evaluate the cost savings from the lower risk of less-severe accidents following a disaster in the state. The National Safety Council estimates that the average cost of an accident which results in work absence is $30,000 (National Safety Council, 2014). Injuries resulting in work absence are our most common type of less-severe accidents (Table 1). This figure, together with our estimates above, imply a cost savings of $0.24 per hour worked from the reduction in less-severe accidents. Finally, the cost savings from the lower risk of less-severe accidents following a fatality in a mine are worth about $0.10 per hour worked.

These figures do not account for the reduced costs from fewer MSHA violations or from potential reductions in accidents with severe injuries other than fatalities. Indeed, Viscusi and Aldy (2003) state that permanent disabilities should be valued similarly to fatalities. Overall, we believe that $2 per hour worked is a reasonable estimate for the total dollar cost savings to the firm from the decreased accidents following a mine disaster in the state.

Although we do not believe that there is strong evidence of a productivity loss following a disaster, it is worth noting that the 0.024 drop in tons of coal per hour worked noted above, if real, would imply a 7% drop in productivity, implying the need to add an extra 8% work hours to mine the same coal. At $25/hour,[12] this represents an extra $2 in wages per current hour worked. Moreover, this may be a serious underestimate of the loss from the productivity drop. Coal sells for about $50/ton[13] and workers produce just under four tons of coal per hour on average (Table 2). Thus, to the extent that firms simply produce less following a disaster in the state rather than being able to hire more safety-related workers without capital costs, the reduction in coal productivity would cost the firm about $14 per hour worked. Thus, while we do not believe that our productivity numbers are conclusive, it is very possible that there are productivity losses following a disaster that cost the firm more than the savings from the increased safety using values of fatalities from the VSL literature.

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[12] $25 is close to the mean wage for the majority of workers that are being exposed to accident risk. BLS reports the three largest occupations and their wages to be "Construction and Extraction" with mean wage of $25.14, "Extraction Workers" with a mean wage of $25.10 and "Transportation and Material Moving Occupations" with a mean wage of $23.61. Virtually all other non-supervisor or non-management occupations have wages with a similar value. See Table NAICS 212100 in U.S. Bureau of Labor Statistics (2014).

[13] The average sales price of coal in 2013 was $37.24 per ton, but sales prices from underground mines were higher at $60.98, and in each state affected by a disaster, the average price of coal is generally higher than this average (Alabama $88, Kentucky $59, West Virginia $75, Utah $35. See Table 28 in Energy Information Administration (2015).)

6 Conclusion

Coal mining remains a dangerous occupation where firms and workers may be implicitly making tradeoffs between mineral production and safety. Mine regulation through MSHA is substantial in this sector, implying further that these tradeoffs may be determined by the extent of government regulation. This paper seeks to understand these tradeoffs. We hypothesize that a fatality at a coal mine increases the relative cost of a future accident and that a disaster at a coal mine has a broader impact, increasing the relative cost of a future accident in mines located near a disaster. We use fatalities and disasters as sources of quasi-experimental variation that allow us to trace out the production possibility set between mineral output and safety.

We find that fatalities cause a large increase in MSHA enforcement activity. This increase in enforcement activity appears to spur an increase in safety production, with less-severe accidents dropping 10% in the period two years after a fatality. Moreover, this drop in less-severe accidents is not accompanied by a drop in productivity, implying that firms and workers may be able to improve safety at the margin without incurring a drop in revenues from lower mineral production and that regulatory enforcement may be useful in causing this outcome.

In contrast, we find that disasters in the same state do not cause any change in MSHA enforcement activity. Yet, there is plenty of anecdotal evidence that a mine disaster causes media exposure and public pressure for safety. We find that following a mine disaster, there is a much larger drop in fatalities and less-severe accidents. The effect of less-severe accidents appears in mines local to the mine with the disaster while the effect on fatalities and severe accidents occurs as far as 200 KM away. There is also some marginal evidence that this drop may be accompanied by a drop in productivity. Finally, more managers and supervisors are employed in states with a disaster two years after the disaster.

Overall, our results suggest that MSHA enforcement activity may be helpful in affecting safety at the margin but not as much in reducing severe accidents and deaths. Our site visits to mines reinforce these findings, with safety officers reporting that MSHA inspections focus on minor violations (such as open garbage can lids) rather than on systemic issues. In contrast, public pressure from mine disasters may be more useful in changing the culture of safety to increase safety production. Yet, this increase may also cause drops in mineral productivity.

Finally, it appears that coal mines are operating close to the frontier of the mineral output-safety production possibility set. We do not find evidence, such as in Schmitz (2005), Hausman (2014), or Hendel and Spiegel (2014), that coal mines are operating far from the frontier. It is possible that this is because the coal mining industry is more competitive than industries such as steel milling or iron ore processing, since it includes many firms and a sizable export market.

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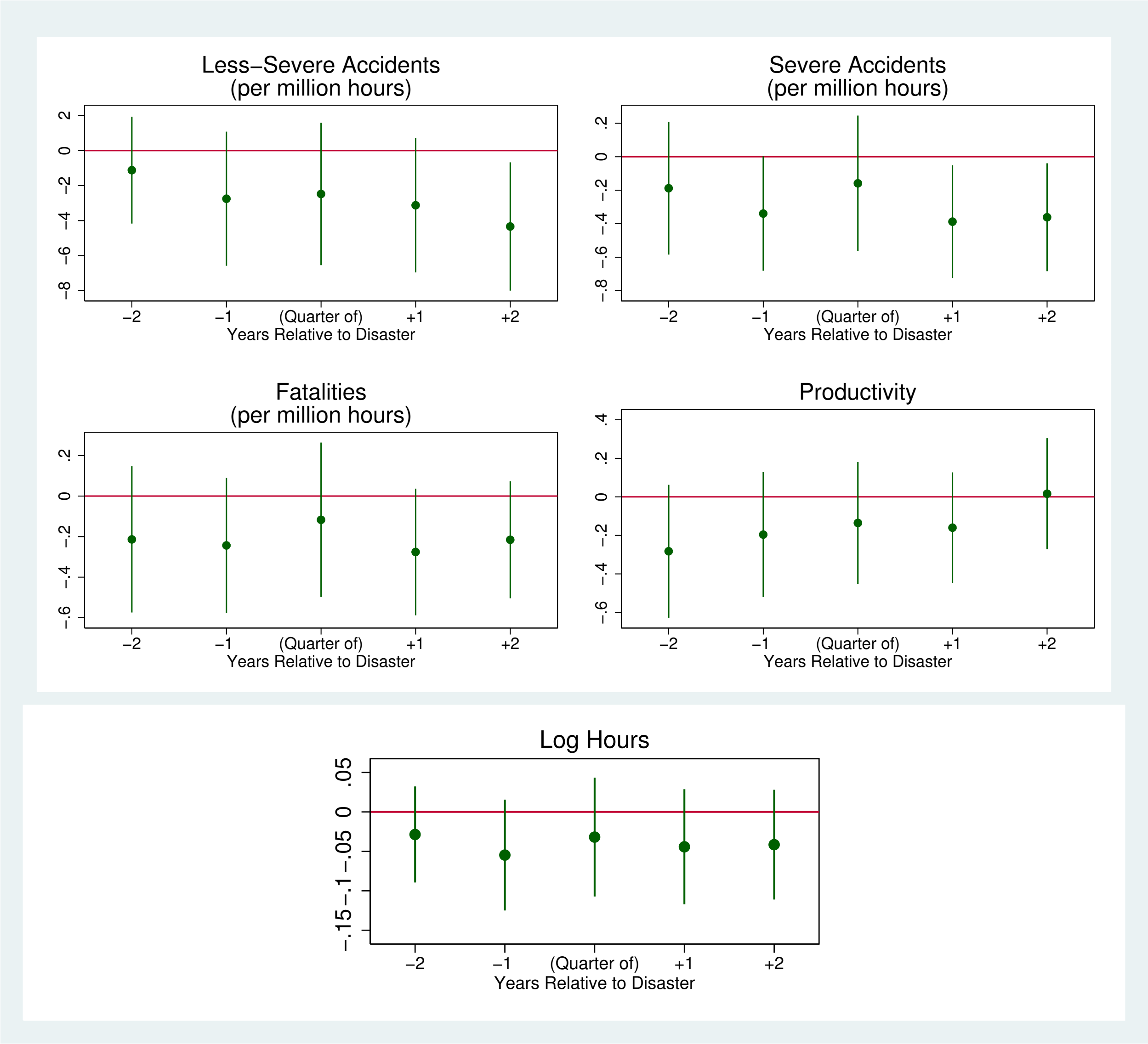
Appendix A Supplementary Regression Results

Table A1: Regressions of Disasters Within 200 KM on Productivity and Safety

	(1) Less-Severe Accidents (per million hours)	(2) Severe Accidents (per million hours)	(3) Fatalities (per million hours)	(4) Productivity	(5) Log Worker Hours
Effect by Year					
Two Years Prior to Disaster	-1.12	-0.19	-0.21	-0.28	-0.029
	(1.56)	(0.20)	(0.18)	(0.18)	(0.031)
One Year Prior	-2.75	-0.34*	-0.24	-0.20	-0.055
	(1.95)	(0.17)	(0.17)	(0.17)	(0.036)
Quarter of Disaster	-2.48	-0.16	-0.12	-0.14	-0.032
	(2.07)	(0.21)	(0.19)	(0.16)	(0.038)
One Year After	-3.12	-0.39**	-0.28*	-0.16	-0.044
	(1.96)	(0.17)	(0.16)	(0.15)	(0.037)
Two Years After	-4.34**	-0.36**	-0.22	0.016	-0.041
	(1.87)	(0.16)	(0.15)	(0.15)	(0.035)
State× Hours Worked	Yes	Yes	Yes	Yes	No
State×Employees	Yes	Yes	Yes	Yes	No
N	51,477	51,477	51,477	51,477	51,477
R^2 Adj.	0.04	0.00	0.00	0.31	0.03

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Each column reports the results of one regression. Dependent variable is indicated in the column title. All regressions include mine fixed effects and quarterly fixed effects as regressors and are weighted by mean hours worked at the mine. Standard errors, reported in parentheses, are clustered at the mine level.

Figure A1: Regressions of Disasters Within 200 KM on Productivity and Safety



Less–Severe Accidents (per million hours)

Severe Accidents (per million hours)

Fatalities (per million hours)

Productivity

Log Hours

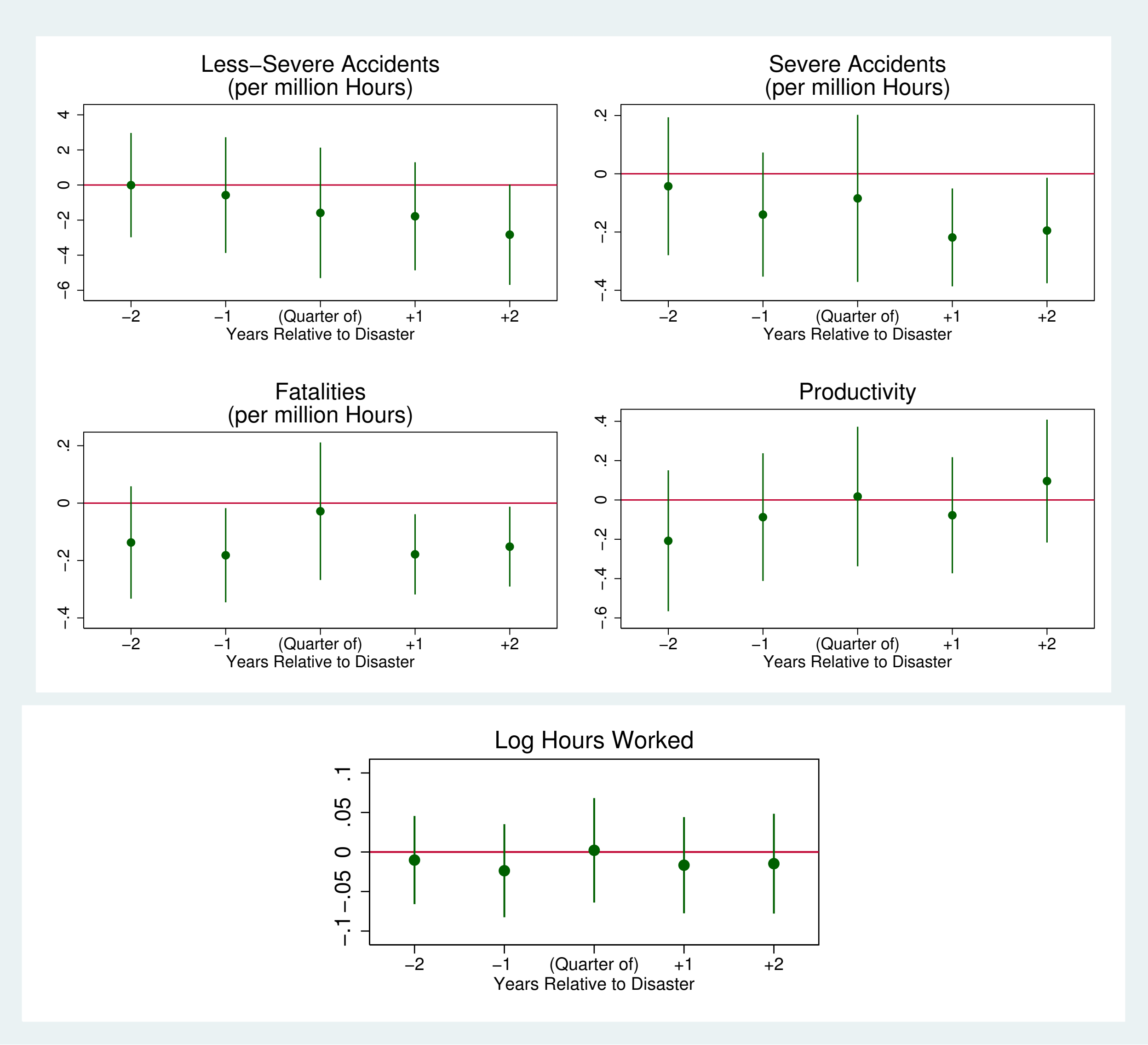
Each figure reports selected regressors from one regression. Dependent variables are indicated in the title. All regressions include mine fixed effects, quarterly fixed effects, and state dummies times hours worked and state dummies times employees (to control for economies of scale) as regressors and are weighted by mean hours worked at the mine. Standard errors are clustered at the mine level. Each line shows a 95% confidence interval.

Table A2: Regressions of Disasters Within 400 KM on Productivity and Safety

	(1) Less-Severe Accidents (per million hours)	(2) Severe Accidents (per million hours)	(3) Fatalities (per million hours)	(4) Productivity	(5) Log Worker Hours
Effect by Year					
Two Years Prior to Disaster	-0.0063	-0.043	-0.14	-0.21	-0.010
	(1.52)	(0.12)	(0.100)	(0.18)	(0.028)
One Year Prior	-0.58	-0.14	-0.18**	-0.087	-0.024
	(1.68)	(0.11)	(0.084)	(0.17)	(0.030)
Quarter of Disaster	-1.59	-0.084	-0.028	0.018	0.0022
	(1.90)	(0.15)	(0.12)	(0.18)	(0.034)
One Year After	-1.78	-0.22**	-0.18**	-0.078	-0.017
	(1.57)	(0.086)	(0.071)	(0.15)	(0.031)
Two Years After	-2.83*	-0.19**	-0.15**	0.096	-0.015
	(1.46)	(0.092)	(0.071)	(0.16)	(0.032)
State× Hours Worked	Yes	Yes	Yes	Yes	No
State×Employees	Yes	Yes	Yes	Yes	No
N	51,477	51,477	51,477	51,477	51,477
R^2 Adj.	0.04	0.00	0.00	0.31	0.03

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Each column reports the results of one regression. Dependent variable is indicated in the column title. All regressions include mine fixed effects and quarterly fixed effects as regressors and are weighted by mean hours worked at the mine. Standard errors, reported in parentheses, are clustered at the mine level.

Figure A2: Regressions of Disasters Within 400 KM on Productivity and Safety



Each figure reports selected regressors from one regression. Dependent variables are indicated in the title. All regressions include mine fixed effects, quarterly fixed effects, and state dummies times hours worked and state dummies times employees (to control for economies of scale) as regressors and are weighted by mean hours worked at the mine. Standard errors are clustered at the mine level. Each line shows a 95% confidence interval.