Workplace Safety and Worker Productivity: Evidence from the MINER Act

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Abstract

This study examines the effect of safety enforcement on workplace injuries and worker productivity in coal mines. The variation of safety enforcement comes from the introduction of "flagrant" violations in 2006, which may lead to a maximum of 0.22 million-dollar penalty per violation. Using an event-study model, the author finds after the issuance of a flagrant violation, the workplace injuries decreased significantly by 20% while the miner productivity decreased by 6%. The results suggest that the monetary value of the productivity loss is 1.3 times as the costs saved from fewer injuries, which highlights the costs of workplace safety regulations.

Keywords: Workplace Safety, Worker Productivity, MSHA, Coal Mining
JEL Codes: J28, J24, I18

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1. Introduction

The coal mining industry has one of the highest workplace injury rates and receives the most comprehensive regulations on working conditions. The extensive enforcement effort on working conditions may lead to better compliance with safety regulations and reduce workplace injuries. However, reducing workplace injuries may require workers to devote extra time or effort on precautions, which may decrease worker productivity. During the past two decades, the safety conditions in coal mines have improved consistently while miner productivity decreased (Figure 1). The increasing enforcement effort from the Mining Safety and Health Administration (MSHA) during this period may improve workplace safety and contribute to the decrease in worker productivity at the same time. This study evaluates how enforcement of safety regulations affects workplace safety and worker productivity in coal mines.

To examine the effect of safety enforcement, this study exploits the introduction of the high-penalty “flagrant” violation in the Mine Improvement and New Emergency Response Act (MINER Act) of 2006. A “flagrant” violation could lead to a maximum civil penalty of $220,000, substantially higher than the penalty for any other violations, ranging from $112 to $70,000 per violation. The theoretical framework of safety enforcement suggests that the employers determine the level of compliance by comparing the costs of complying with the regulations with the expected costs of non-compliance (Polinsky and Shavell, 2007). Thus, the issuance of a flagrant violation, which increases the employers’ expected costs of non-compliance, should lead to better compliance and fewer injuries.

The empirical analysis uses an event study model, which estimates the dynamic changes in workplace safety and worker productivity before and after the issuance of a flagrant violation. The analysis uses a panel dataset with rich information on all active coal mines in US, obtained from the Mine Data Retrieval System (MDRS). The dataset includes quarterly production and employment, logs of workplace injuries, and records on inspections, violations, and penalties. The empirical analysis uses data collapsed at mine-quarter level from 2000 to 2016.

This study provides new evidence on the effectiveness of safety enforcement. Inspections and the associated penalties are the primary tools that the governments use to enforce workplace safety standards. Previous research has studied the effect of enforcement in a wide range of industries and most find small and insignificant effect on workplace injuries (Kniesner and Leeth, 2014). The low financial penalty for noncompliance is one of the mostly cited reasons. In contrast, this study uses the issuance of flagrant violation as an exogenous shock on penalties, which costs up to 0.2 million dollars per violation, and finds such a substantial penalty reduced workplace injuries in coal mines significantly.

This study also contributes to the literature on the link between workplace safety and worker productivity. Consistent with the previous research (Gray, 1987; Boal, 2017; Gowrisankaran et al., 2019), the results of this study suggest a trade-off between workplace safety and worker productivity. The advantage of this study is to use MSHA enforcement as an exogenous shock on safety and estimate changes in injuries and productivity with panel data. Thus, the results are unlikely to be confounded by any unobserved differences across mines.

Lastly, this study adds to the literature on the economic costs of safety regulations. Regulations on safety and health are commonly cited as a major cause of the productivity decrease in coal mines (Darmstadter, 1997). According to the estimates from the event-study model, the productivity loss is approximately 1.3 times the benefits of injury reduction. The enforcement effort, aiming at improving workplace safety, have generated higher losses in worker productivity compared to the gains from fewer injuries.

2. Background

2.1. Public Enforcement of Regulations

Public enforcement is widely used to detect and sanction violations of laws and regulations. For example, the police detect crimes; tax auditors detect non-compliance of tax codes; and inspectors detect violations of safety, environmental, and health risks. Public enforcement has advantages over private enforcement as private parties may have limited knowledge on the identity of the violators and may find it costly to develop the technology needed to detect the violations (Polinsky and Shavell, 2007).

While the role of government agents in enforcing laws and regulations is obvious, the optimal form and level of enforcement becomes the focus of research on public enforcement. Based on the basic framework summarized in Polinsky and Shavell (2007), individuals commit harmful activities when the gain from not complying with the regulations is greater than the expected amount of penalty for non-compliance. An increase in the frequency of inspections or the amount of penalty per violation should increase the expected costs of non-compliance, thus improve the compliance level.

The empirical literature on the effectiveness of workplace safety enforcement examines firms' responses to changes in both the frequency of inspections and the amount of penalties. Most of the previous literature finds inspections by both the Occupational Safety and Health Administration (OSHA) and MSHA ineffective in improving workplace safety (Bartel and Thomas, 1985; McCaffrey, 1983; Ruser and Smith, 1991; Kniesner and Leeth, 2004).[1] The mostly cited reasons include the standards not addressing the various complex causes of the

[1] A few exceptions include Levine, Toffel, and Johnson (2012) and Li and Singleton (2018), which find enforcement reduced workplace injuries.

accidents across different industries and the penalties for the violations being too low to incentivize firms to comply (Kniesner and Leeth, 2014).[2] For example, Scholz and Gray (1990) estimated the effect of penalties from OSHA on workplace injury rate in manufacturing establishments. They found that the financial penalty, which was a few hundred dollars on average, had a small and insignificant effect on reducing injuries. In contrast, this study focuses on flagrant violations issued by MSHA in coal mines, where the causes of accidents are similar across mines and the increase in total penalties is substantial. According to the theoretical framework, firms are more likely to change their level of non-compliance facing a larger increase in penalty.

With enforcement of safety regulations, the change in social welfare equals the gain of individuals from non-compliance net the social costs of non-compliance and the costs of detecting the violations (Polinsky and Shavell, 2007). As an increase in the penalties for non-compliance is a costless transfer of money, the social welfare will only be affected when the individuals respond by changing the level of compliance. The net change in social welfare would be the gains from lower workplace injuries net the costs of complying with the regulations.

Most of the previous research finds inspections on workplace safety cost-ineffective (Morrall, 2003; Kniesner and Leeth, 2004; Hahn and Hird, 1991; and Crain and Crain, 2010). However, when analyzing the cost effectiveness of safety regulations, limited studies consider the potential impact on productivity.[3] Improving workplace safety may require workers to devote more effort to preventing injuries, leading to less effort on production and lower productivity. On

[2] The average penalties per violation of MSHA standard are $303 and $579 on the violation of OSHA standard based on author's calculation using the inspection records from 2000 to 2016.
[3] A few exceptions include Neumann and Nelson (1982), Gray (1987), and Gowrisankaran et al. (2019).

the other hand, if firms adopt new safety enhancing, which may also facilitate production, the productivity may increase.

2.2. MSHA Enforcement and the MINER Act of 2006

Coal mining has been historically one of the most dangerous industries. In 2007, the fatal injury rate in the mining sector was 24.8 cases per 100,000 full-time equivalent employees in the mining sector, more than five times as high as the 4.3 cases as the national average (BLS, 2010). The common hazards in coal mines include gas ignition, machinery accidents, and exposures to harmful gases, heat, and noise. In response to the high injury rate, this sector receives extensive regulations on workplace safety. The Mine Safety and Health Administration (MSHA), established after the Federal Mine Safety and Health Act of 1977, works to prevent death, illness, and injury from mining and promote safe and healthful workplaces for U.S. miners. MSHA is required to inspect each underground mine four times a year and each surface mine twice for occupational safety and health.

The most significant mine safety legislation since 1977 is the Mine Improvement and New Emergency Response Act (MINER Act) of 2006. The MINER Act was introduced shortly after an explosion at the Sago Mine in West Virginia in January 2006, during which twelve miners were killed. The MINER Act contains several provisions regarding emergency response plans, mine rescue teams, prompt notification of mine accidents, and enhanced civil penalties. While the first three provisions focus on improving the chance of survival for miners in fatal disasters, the enhanced civil penalties affect the regular operation of almost every coal mine. After the implementation of the MINER Act, the annual financial penalties assessed by MSHA increased substantially, from $23.2 million in 2006 to $112.3 million in 2008 (Figure 2).

The substantial increase in financial penalties partly came from the introduction of "flagrant" violations. A flagrant violation is "a reckless or repeated failure to make reasonable efforts to eliminate a known violation of a mandatory health or safety standard that substantially and proximately caused, or reasonably could have been expected to cause, death or serious bodily injury." A unique feature of the flagrant violation is its high financial penalty. MSHA assesses the penalty of a violation based on the history of previous violations, the size of the business, any negligence by the operator, the gravity of the violation, and the operator's good faith in trying to correct the violation promptly. Normally violations may result in fines from $112 to $70,000. In contrast, a flagrant violation could result in a penalty of up to $220,000.

The flagrant violation regime, aiming at further improving the working conditions in mining, was challenged as the criteria of flagrant violations have no clear interpretation. MSHA does not provide definitions of "reckless failure", "repeated failure", "known violation", etc., making it difficult to predict whether a violation will be deemed as flagrant. The inspector has the initial power to issue flagrant violations, partly contributing to the large differences in the usage of flagrant violations across different MSHA districts. For example, MSHA district 4, including mines in southern West Virginia, issued 30% of the flagrant violations between 2006 and 2016, while only 10% of active coal mines are in this area. Although fatal accidents are obviously associated with severe violations of safety standards, most of the flagrant violations were issued during a regular inspection and only five percent were issued after a fatal accident. Overall, it is difficult for the mine operator to predict whether and when a flagrant violation will be issued, accompanied by a dramatic increase in penalties (Rubenstein and Blandford, 2009).

3. Empirical Strategy

The empirical objective of this study is to estimate the effect of a flagrant violation on workplace safety and worker productivity in coal mines. The identification strategy uses the issuance of flagrant violations, which are associated with substantial financial penalties. Figure 3 plots the quarterly total penalties of mines with flagrant violations, with period 0 indicating the quarter of a flagrant violation. While the quarterly penalty increased steadily in periods before the flagrant violation, in the quarter of the flagrant violation, the total penalty increased substantially. The initial assessment amount on average increased from $106,000 in the quarter before to $330,000 in the quarter of flagrant violation and the final assessment amount increased from 75,000 to $219,000. Overall, a flagrant violation is associated with an around two hundred percent increase in total quarterly financial penalty.

To estimate the effect of a flagrant violation on workplace safety and worker productivity, an event study model as follows is used:

$$Y_{it} = \sum_{\tau \neq -1} \beta_\tau D_{it}^{\tau} + \theta_i + \delta_t + \epsilon_{it}. \quad (1)$$

Y_{it} denotes the outcomes (for example, injury rate, and worker productivity) of a mine i in calendar quarter t. D_{it}^{τ} is a set of binary period indicators that equals 1 if an observation in quarter t in coal mine i is from τ quarter(s) from the quarter of the flagrant violation in mine i. The flagrant violations were issued during on-site inspections in various quarters from 2006 to 2017. For example, for an observation from one quarter after the year and quarter when the flagrant violation was issued in mine i, D_{it}^{1} equals to 1 and all other D_{it}^{τ} equals 0. The model omits period $\tau = -1$, the quarter right before the issuance of a flagrant violation. Thus, the coefficients of interests, β_τ, represents the dynamic change of the outcomes relative to the calendar quarter right before the flagrant violation. For parametric estimates, the calendar quarters after a flagrant violation are grouped into three categories: $0 \leq \tau \leq 7$, $8 \leq \tau \leq 15$, and $\tau \geq 16$, corresponding to one to two years after the flagrant violation, three to four years, and five years and after.

While the timing of flagrant violations differ from mine to mine, the model also includes calendar year by quarter fixed effects, δ_t. The calendar year by quarter fixed effects control any common shock to the industry in a given calendar year and quarter, such as the fluctuation of the price of coal and the increase in penalties for other types of violations in 2006. The model also includes mine fixed effects, θ_i, to control the time-invariant characteristics of each mine, such as the baseline technology, type (underground versus surface), quality of coal. With mine fixed effects, the estimates on workplace safety and worker productivity reflects within mine changes before and after a flagrant violation. The standard errors are clustered at the mine level.

The identification assumption of the event-study model is that the timing of a flagrant violation is not correlated with any unobserved determinants of workplace safety and worker productivity, except for those affected by the flagrant violation itself. The assumption is tested by examining the existence of any pre-trend in the outcomes. When τ is negative, the estimates of β_τ measure the changes in periods prior to the flagrant violation relative to the quarter right before, and provide a test on this assumption. Since it is difficult for the mine operators to predict the issuance of flagrant violations, the coefficients prior to the period are expected to be close to zero.

4. Data and Analysis Sample

The data of this study are combined from six datasets on coal mines, obtained from the Mine Data Retrieval System (MDRS), maintained by the Mine Safety and Health Administration

(MSHA). The datasets include the accident injuries data set, the quarterly employment/production data set, the inspection data set, the violation data set, the assessed violation data set, and mine addresses of record data set.

The accident injuries data set contains records on the accidents, injuries, and illnesses reported by mines. The mines report the time, location, severity of the injury, and the number of days away or restricted from work. Characteristics of the injured worker, such as age, gender, occupation, years of experience in the job, at a specific mine, and in mining sector are also recorded. The occupational illnesses (3.8% of all injuries and illnesses) are excluded from the analysis as they are mostly chronic ailment and difficult to determine the exact time of onset. Injuries due to natural causes, injuries involving non-employees, and injuries with missing classification code are also excluded (1.1% of all injuries and illnesses). The data set is collapsed at the mine-calendar quarter level. The key variable is the quarterly injury rate, defined as the number of injuries per 100 full-time equivalent employees in a quarter. The injury rate by different levels of severity are also calculated, including injuries involving fatal accidents and permanent disabilities; injuries with days away from work and/or restricted work activity, and mild injuries with no losses of workdays. .

The quarterly employment/production data set includes data on quarterly coal production, employee hours, and number of employees. The miner productivity is calculated as the number of short tons of coal produced divided by the total employment hours in a calendar quarter. The quarterly employment/production data set, combined with the mine addresses of record data set, which records the location and current status of the mines, is used to determine the operation status of the mines. A mine is defined as active in a calendar quarter if the current status is active and the number of employment hours is positive.

The inspection data set, the violation data set, and the assessed violation data set contain the records of the MSHA enforcement activities. The inspection data set includes the universe of inspections conducted by MSHA. The violation and assessed violation data set recorded the type of violation and the assessed amount of penalty, if any. All penalties are normalized to 2010 dollars values. These data sets are also collapsed at the mine-quarter level. The key variables include the quarterly number of inspections, violations, and amount of assessed penalties.

The data sets are combined using the unique mine id assigned by MSHA. The analysis period is from 2000 to 2016. The sample include only coal mines as metal/non-metal mines do not report total production. Coal mines with a fatal accident within one year before the flagrant violation are excluded. Fatal accidents are usually associated with extensive public attention and media coverage, which may affect the workplace safety and worker productivity directly (Gowrisankaran et al., 2019), regardless of the amount of financial penalties afterwards. For a coal mine with multiple citations of flagrant violations, only the first one is included. The observations with quarterly injury rates higher than 100 injuries per 100 full-time equivalent employees are excluded (0.5%). The final analysis sample includes 8,133 mine-quarter observations on 183 unique coal mines.

Figure 4, Panel A shows a map of active coal mines in the US as of 2006, the first year of Miner Act. Panel B shows the geographical locations of coal mines with flagrant violations. More than 80% of coal mines in the US are in Appalachian regions. The two states with the largest number of coal mines are Kentucky, accounting for 29% of the coal mines, and West Virginia, 23%. These two states also account for about 60% of the flagrant violations during the analysis period.

Table 1 presents the summary statistics of all coal mines and separately by mines with or without flagrant violations. The mines with flagrant violations had different characteristics compared to those without. Mines with flagrant violations had higher injury rates and received more inspections and penalties. The average quarterly injury rate of mines with flagrant violations is 6.66 cases per 100 employees, almost two times as the 3.38 cases in mines without flagrant violations. They are also larger, with the employment hours and total output around six times as those without flagrant violations. Seventy percent of the mines with flagrant violations are underground mines, which tends to be more dangerous than surface mines due to different production technologies. About three quarters of coal mines with flagrant violations are underground mines and the rest are surface mines and preparation or milling facilities.[4]

To test the robustness of the results, a comparison group is constructed by matching each mine with a flagrant violation to the closest mine that never received any flagrant violation. The mines are matched based on the longitude and latitude. Mines with the nearest matches farther than ten kilometers are excluded. Table 1, column 4 shows the characteristics of the comparison group. The comparison group has slightly higher injury rates and larger size of employment compared to any mines without any flagrant violations, which provides a closer comparison to mines with flagrant violations. The comparison group still has lower injury rates and smaller size of employment compared to mines with flagrant violations.

5. Results

5.1. Workplace Safety

[4] Facilities include preparation or milling plants that are not located on the same property as that mine, or process material from other mines (MSHA, 1996).

The theory of public enforcement predicts that a substantial increase in penalties, triggered by the citation of a flagrant violation, should lead to better compliance with the safety regulations. Figure 5 presents the graphical evidence on the effect of a flagrant violation on workplace injury rates. The graphs show the estimates of β_τ from equation 1, with the standard errors clustered at the mine level and the vertical bands reporting the 95% confidence interval. The workplace injury rate decreased from the third quarter after the issuance of a flagrant violation, and the decreasing trend persisted during the next eight quarters. The estimates of β_τ in periods prior to the flagrant violation are close to zero and statistically insignificant, suggesting that during the three-year period before the flagrant violation, the injury rate was not statistically different from the injury rate in the quarter right before the flagrant violation. This implies that the issuance of flagrant violations is not precipitated by any pre-existing increasing trend of workplace injuries.

Table 2, column 1 presents the estimates with the period indicators grouped into one to two years after a flagrant violation, three to fours years after, and five years and after. The injury rate decreased by 0.18 cases per 100 employees during the first two years after a flagrant violation, representing a 3 percent decrease compared to the average total case rate of 7.0 in the quarter right before the flagrant violation. The injury rate continues to decrease in the medium and long run. Between year three and year four after the flagrant violation, the injury rate decreased by 1.39 cases per 100 employees (20%) and by 1.44 cases year five and after (21%).

To examine the composition of the decrease in injury rates, the injuries are divided into three categories based on the level of severity, including fatal and permanent injuries, injuries with days away or restricted from work, and mild injuries with medical treatment but no losses of workdays. The graphical evidence is presented in Figure 5, Panel B-D. The results suggest that the decrease in workplace injuries mostly came from the decrease in injuries with days away or restricted from work, which dropped by 0.54 cases during the first two years after the flagrant violation and by 1.40 cases between year three and four (Table 2, column 3). The fatal and permanent injuries and mild injuries showed small and statistically insignificant changes both before and after the flagrant violation (Table 2, column 2 and 4).

One possible mechanism of the decrease in injuries is through reduced working intensity. Previous studies have shown that longer working hours and higher working intensity are associated with more workplace injuries and higher health risks (Ruhm, 2000; Hummels, Munch, and Xiang, 2016). In mines with flagrant violations, the average quarterly hour per worker is 562 hours, which is higher than a typical full-time worker (500 hours) and the average hours in mines without flagrant violations (515 hours). Thus, mines with flagrant violation may seek reducing workplace injuries through reducing hours of working. To test this hypothesis, Figure 6 shows the dynamic changes in average working hours per worker per quarter before and after a flagrant violation. The quarterly working hours decreased right after the issuance of a flagrant violation, and continued decreasing in the next twelve quarters. The estimates are presented in Table 3, column 1. During the first two years after a flagrant violation, the average hours decreased by 6 hours per worker per quarter and during year three and four, by 23 hours per worker per quarter, representing a 4% decrease compared to the average 562 hours per worker per quarter. The decrease in working hours might contribute to the decrease in injury rate after a flagrant violation.

The improvement in compliance of safety regulations is unlikely to be driven by the negative financial shock from the penalties. First, among mines with flagrant violations, the average quarterly production is 547 thousand short tons of coal. With the average price of coals as $56, an increase of $0.22 million penalties accounts for less than 1 percent of the quarterly revenue of coal mines. Second, the previous studies find that a negative financial shock increases injuries and reduces compliance of regulations (Cohn and Wardlaw. 2016; Earnhart and Segerson, 2012), which contradicts the results in this study that the injury rates decreased after a flagrant violation.

5.2. Miner Productivity

It is clear that flagrant violations were associated with a sizable and persistent decrease in workplace injuries in coal mines. Improving workplace safety may require workers to devote extra effort to preventing injuries, thus negatively affect worker productivity. Figure 7 presents graphical evidence on the effect of flagrant violations on worker productivity, defined as the number of short tons of coals produced per employment hour. The productivity decreased right from the issuance of a flagrant violation and the decreasing trend persisted over a three-year period. The estimated coefficients in periods before the flagrant violation are close to zero and statistically insignificant, which suggest that no pre-existing trend of productivity led up to the issuance of the flagrant violation. Table 3, column 2 presents the estimated coefficients. In the quarter of a flagrant violation, the productivity decreased by 0.25 short tons of coal per employment hour, representing a five percent decrease. Between year three and four, the productivity decreased by 0.32 tons of coal per hour (7%).

The introduction of flagrant violations led to better workplace safety conditions but lower worker productivity. Using the coefficients obtained from the event study model, I conducted a back-of-the-envelope calculation on the net benefits of a flagrant violation. To measure the value of reduced injuries, I use the estimates on the value of a statistical injury from Viscusi and Aldy

(2003). The median estimate of the value of a statistical injury is $69,393 per injury (2016$ value). In the medium run (three to four years) after the issuance of a flagrant violation, the quarterly workplace injury rates decreased by 1.39 cases per 100 full-time equivalent employees. This suggests a cost saving of $1.93 per employment hour ($69,393*1.39/50,000 hours per quarter for 100 full-time equivalent worker). The productivity loss, 0.32 ton per hour of labor input, amounted to $2.59 per hour ($25.75*0.32/3.18) given the average wage of miners being $25.75 per hour (BLS, 2017) and the average miner productivity being 3.18 short tons per hour. There might be additional costs on complying with regulations, such as training workers and updating technology and equipment. Thus, the losses from lower worker productivity were at least about 1.3 times the gains from improved workplace safety.

5.3. Auxiliary Analysis

The analysis on workplace safety and worker productivity above uses the event-study model with mine fixed effects, which estimates changes within mines before and after a flagrant violation. In addition to a structural change in workplace safety and worker productivity, the safety enforcement may affect overall safety and productivity in the industry through a compositional effect (Neumann and Nelson, 1982). For example, more dangerous mines or less productive mines may be affected disproportionally after a flagrant violation and more likely to exit the market. This may imply an improvement in overall safety and productivity in this industry.

While the estimates using the event study model includes all the mines receiving flagrant violations between 2006 and 2016, twenty-one percent of the mines closed within two years after the flagrant violation. Figure 8 presents the effect of flagrant violations on the operational status of mines. A coal mine is active in a corresponding quarter if the current status is active and the number of employment hours is positive. Conditional on being active in the previous quarter, the mine survival variable equals 1 if a mine is active in a calendar quarter and equals 0 otherwise. The likelihood of exit increased right after the flagrant violation and persisted over a three-year period. During the first two years after a flagrant violation, a mine is 3 percentage points more likely to exit the market (Table 3, column 3). The mine closures implied a total reduction of 277 injuries annually. The operational status showed small and insignificant changes in quarters before the flagrant violations.

To understand how the increasing mine exits might affect the aggregate trend of mine safety and productivity, the analysis sample is divided into mines with productivity above or below the median and mines with employment hours above or below the median, measured as of the quarter before a flagrant violation. The estimates are presented in Table 4. The increasing mine exits were predominantly driven by smaller and less productive mines.

Since the mines exiting the market might systematically differ from those that stayed active, the event-study model is also estimated with mines without any change in operational status within two years before and after the flagrant violation. The graphical evidence is in Figure 9. The results are similar to the estimates using the main analysis sample: workplace injury rate and worker productivity showed small and insignificant change before the flagrant violation and decreased persistently afterwards.

The main results from the event study model assumes that no other shock existed during the same time as the flagrant violation. For example, MSHA might increase the usage of both the flagrant violations and other forms of enforcement in a district at the same time. To test this assumption, each mine with a flagrant violation is matched to the closest coal mine without any flagrant violation. Mines without a match within 10 km are excluded. The changes in safety and productivity are tested among the matched coal mines before and after a flagrant violation in a nearby mine. Presented in Figure 10, the injury rate and worker productivity show small and insignificant change before and after the flagrant violation, suggesting the main results are unlikely to be driven by any other local changes. The survival of mines in the comparison group also shows small and insignificant changes after the flagrant violation of a nearby mine. An alternative comparison group is constructed including only the closest matched coal mine owned by the same parent company. Mines without any match within 10 km that are owned by the same parent company are excluded. Consistent with the results in Figure 10, the mines in the alternative comparison group show small and statistically insignificant changes both before and after the flagrant violation of a nearby mine (Appendix Figure 1). The results stay consistent using the closet match mines of the same mine type. Since some mines with a flagrant violation do not have a matched mine in the comparison group, I estimate the baseline model using mines with a flagrant violation and a matched mine in the comparison group. Appendix Table 1 presents the estimates and they are similar to those in the main results (Table 2 and 3).

The event-study model uses the timing of the issuance of the flagrant violation, as it is associated with high penalty assessment, requirement on correcting the violations, enhanced enforcement activities, and higher penalty of future violations. The changes in enforcement and penalty incentivized the mines to improve workplace safety, even though the mine might not pay the penalty right after the issuance of a flagrant violation. On average, the lag between initial issuance of a flagrant violation and the final action is about 9 quarters. To test any dynamic changes around the timing of final action, I estimate the main regression model using the quarter of final action on a flagrant violation as period 0. The signs of the estimates are consistent with the main results and are statistically insignificant (Appendix Table 2).

To understand if the main results are driven by any specific groups of mines, I conducted several analysis on the heterogeneous effect. First, the main analysis sample include three types of coal mines, underground, surface, and facilities, which differ in risk level and production technology. Specifically, underground coal mines on average have higher injury rates and lower worker productivity. Appendix Table 3 presents the estimates separately by types of coals mines. The sign of the estimates are consistent across three types of mines: both injury rates and miner productivity decreased after a flagrant violation. The effect is most salient in underground mines, which account for about three quarters of mine with the flagrant violations. The estimates are less precise among surface mines and facilities, where the sample size is much smaller.

Second, while smaller mines are less likely to survive after a flagrant violation (Table 4), they also show larger decrease in injury rates. Appendix Table 4 shows estimates of the baseline model by mines with employment hours above and below median. The smaller mines experienced a larger decrease in injury rates and the decrease in productivity is of similar magnitude among larger and smaller mines.

Third, more than half of the flagrant violations were in mines in KY and WV. I estimated the baseline model separately for mines in KY and WV versus mines in other states. Mines in KY and WV showed a consistent decrease in both workplace injuries and worker productivity after a flagrant violation. The results in other states show a similar pattern, although the estimates are less precise (Appendix Table 5). The mines in KY and WV on average are smaller and are mostly underground coal mines. This is consistent with the results that smaller mines and underground mines show larger effect.

Lastly, while the flagrant violations are associated a median quarterly financial penalty of around 0.25 million dollars, the penalty mines received ranged from about 70,000 dollars to more than one million dollars. Appendix Table 6 presents the estimates of the baseline model separately for mines with penalty above and below median. For both groups, the injury rate and worker productivity decreased after flagrant violations. Mines receiving higher financial penalty showed larger decrease in injury rate while both groups showed a similar decrease in worker productivity. In summary, the effect of flagrant violations is more salient among, underground mines, small mines, and mines receiving higher penalty.

6. Conclusion

This study examines the effect of high-penalty flagrant violations on coal mine safety and miner productivity. The results highlight the trade-off between workplace safety and worker productivity: after a flagrant violation, the workplace injury rate decreased while the worker productivity decreased as well. The likelihood of a coal mine exiting the market increased by 3 percentage points within two years after the flagrant violation.

While public enforcement is widely used in regulating health and safety risks, most studies focus on its effectiveness in reducing the targeting risks and often overlook the potential costs on production losses and plant exits. This study finds that the value of the productivity loss is 30 percent higher than the gains from reduced injuries, suggesting that omitting the costs of productivity loss will substantially overestimating the benefits of safety regulations.

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Table 1. Summary Statistics

	All	Flagrant Violations	No Flagrant Violations	No Flagrant Violations, Closest Match
Inspections	2.451	8.773	1.912	3.204
	(4.266)	(9.840)	(2.793)	(5.681)
Penalties – Initial ($1,000)	6.818	56.633	2.573	5.497
	(54.423)	(181.932)	(12.814)	(21.735)
Penalties – Final ($1,000)	5.293	42.340	2.135	4.632
	(45.256)	(153.268)	(9.687)	(16.518)
Violations	9.317	46.845	6.119	11.861
	(22.867)	(54.912)	(13.426)	(24.309)
Injury Rate	3.634	6.663	3.375	4.935
	(9.727)	(9.510)	(9.702)	(11.271)
Injury Rate: Permanent	0.044	0.106	0.038	0.077
	(0.946)	(1.107)	(0.930)	(1.107)
Injury Rate: Days Loss	2.590	4.579	2.420	3.462
	(8.084)	(7.702)	(8.093)	(9.605)
Injury Rate: Mild	1.000	1.978	0.917	1.396
	(4.734)	(4.579)	(4.738)	(5.334)
Employment Hours (1,000)	22.899	94.594	16.788	31.723
	(49.334)	(113.285)	(32.744)	(68.570)
Quarterly Hours per Worker	519	562	515	558
	(182)	(129)	(185)	(151)
Coal (1,000 Short Tons)	130	547	95	201
	(801)	(2181)	(524)	(974)
Productivity	2.715	3.473	2.650	2.263
	(4.954)	(4.622)	(4.976)	(4.283)
Underground	0.274	0.718	0.236	0.336
	(0.446)	(0.450)	(0.424)	(0.472)
Surface	0.448	0.161	0.473	0.249
	(0.497)	(0.368)	(0.499)	(0.432)
Facility	0.278	0.121	0.291	0.415
	(0.448)	(0.326)	(0.454)	(0.493)
Observations	103,561	8,169	95,428	3,884

Note: Data are from the Mine Data Retrieval System (MDRS). Injury rates is measured as the average number of cases per 100 full-time equivalent employees. Productivity is measured as the number of short tons of coal per employment hour.

Table 2. The Effect of Flagrant Violations on Workplace Safety in Coal Mines

	Injury Rate	Injury Rate-Permanent	Injury Rate-Days away or Restricted	Injury Rate-Mild
Years 1 to 2	-0.182	0.030	-0.542	0.331
	(0.535)	(0.031)	(0.439)	(0.256)
Years 3 to 4	-1.388***	-0.018	-1.400***	0.029
	(0.487)	(0.024)	(0.400)	(0.228)
Years 5 and after	-1.440**	0.054	-1.391**	-0.103
	(0.717)	(0.040)	(0.573)	(0.329)
R2	0.058	0.013	0.051	0.022
N	8,133	8,133	8,133	8,133

Note: Data are from the Mine Data Retrieval System (MDRS). Injury rates is measured as the average number of cases per 100 full-time equivalent employees. Column 1 includes all workplace injuries; Column 2 injuries involving fatalities or permenant disabilities ; Column 3 injuries involving days away from work or work restrictions; Column 4 injuries with medical attention but no losses of work days. The model includes mine fixed effects and calendar quarter fixed effects. The standard errors are clustered at the mine level. ***, **, and * indicate statistical significance at the one, five, and ten percent levels, respectively.

Table 3. The Effect of Flagrant Violations on Working Hours, Worker Productivity, and Mine Survival in Coal Mines

	Hours per Worker	Productivity	Survival
Years 1 to 2	-0.006	-0.247**	-0.030***
	(0.007)	(0.101)	(0.010)
Years 3 to 4	-0.023**	-0.322**	-0.028**
	(0.009)	(0.132)	(0.012)
Years 5 and after	-0.003	-0.312	-0.043***
	(0.012)	(0.255)	(0.014)
R2	0.049	0.179	0.023
N	8,133	8,133	8,035

Note: Data are from the Mine Data Retrieval System (MDRS). Hours per worker is measured as the average hours per worker per quarter (in 1,000). Productivity is measured as the number of short tons of coal per employment hour. Survival is defined as staying active in the market in a given quarter conditional on being active in the previous quarter. The model includes mine fixed effects and calendar quarter fixed effects. The standard errors are clustered at the mine level. ***, **, and * indicate statistical significance at the one, five, and ten percent levels, respectively.

Table 4. The Effect of Flagrant Violations on Survival of Coal Mines, by Mine Characteristics

	High Productivity	Low Productivity	Large	Small
Years 1 to 2	-0.033**	-0.029**	-0.004	-0.053***
	(0.016)	(0.013)	(0.010)	(0.017)
Years 3 to 4	-0.023	-0.033*	-0.006	-0.047**
	(0.016)	(0.018)	(0.012)	(0.020)
Years 5 and after	-0.031	-0.054***	-0.022	-0.068**
	(0.022)	(0.019)	(0.014)	(0.026)
R2	0.032	0.034	0.027	0.039
N	4,036	3,999	4,302	3,733

Note: Data are from the Mine Data Retrieval System (MDRS). Column 1 and 2 includes mines with productivity above and below median. Column 3 and 4 includes mines with number of employment hours above and below median. The outcome is exiting the market in a given quarter conditional on active in the previous quarter. The model includes mine fixed effects and calendar quarter fixed effects. The standard errors are clustered at the mine level. ***, **, and * indicate statistical significance at the one, five, and ten percent levels, respectively.

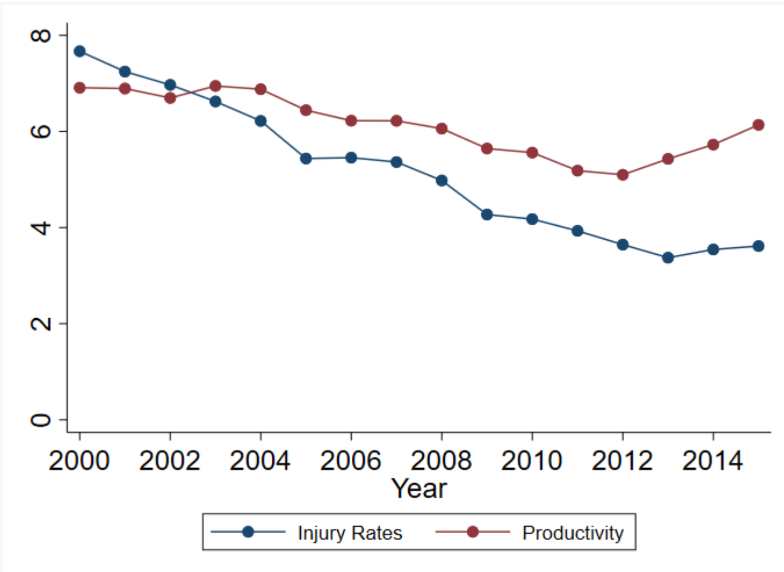


Figure 1. Injury Rates and Miner Productivity in Coal Mines, 2000-2015

Note: Data are from the Mine Data Retrieval System (MDRS), calculated by the author. Injury rate is measured as the average number of cases per 100 full-time equivalent employees. Productivity is measured as the number of short tons of coal produced per employment hour.

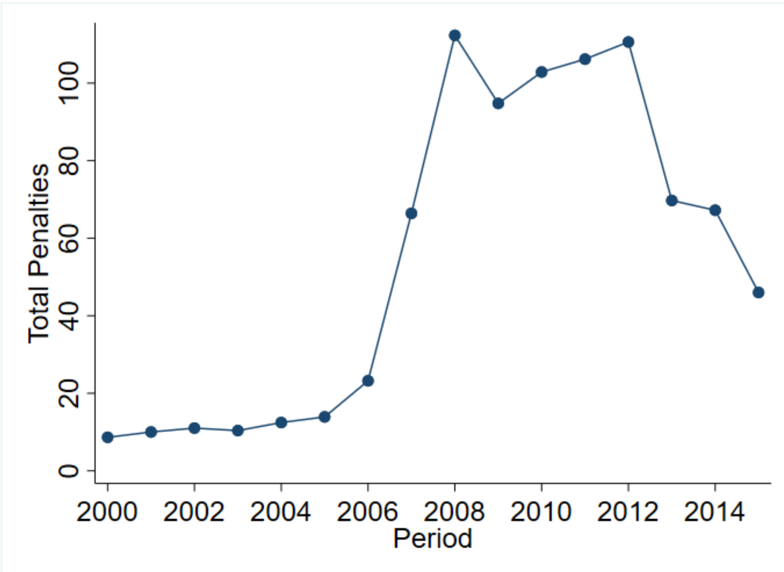


Figure 2. MSHA Initial Assessed Penalties on Coal Mines (in million $), 2000-2016

Note: Data are from the Mine Data Retrieval System (MDRS), calculated by the author.

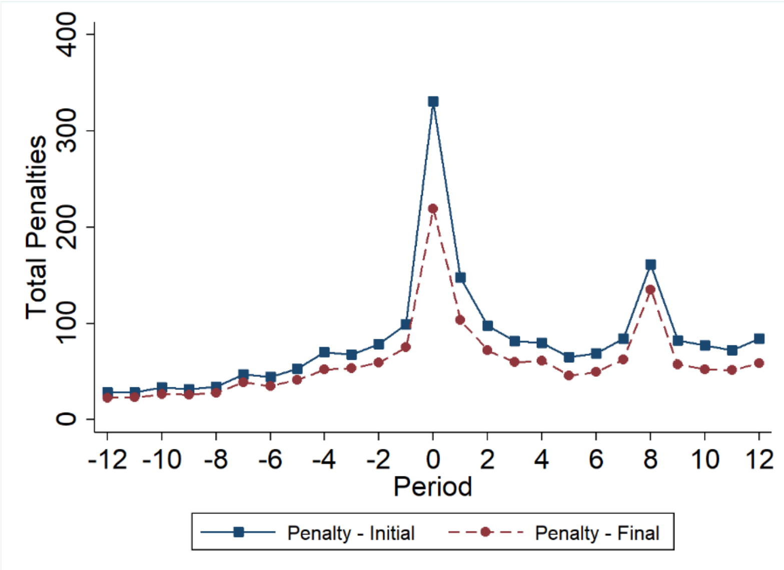
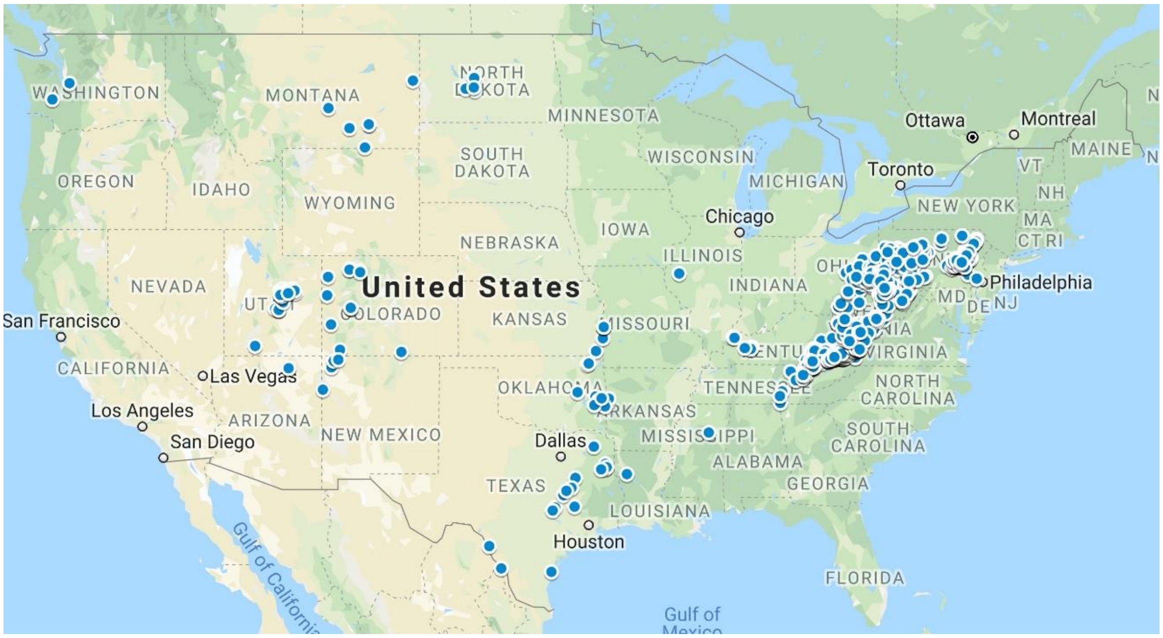
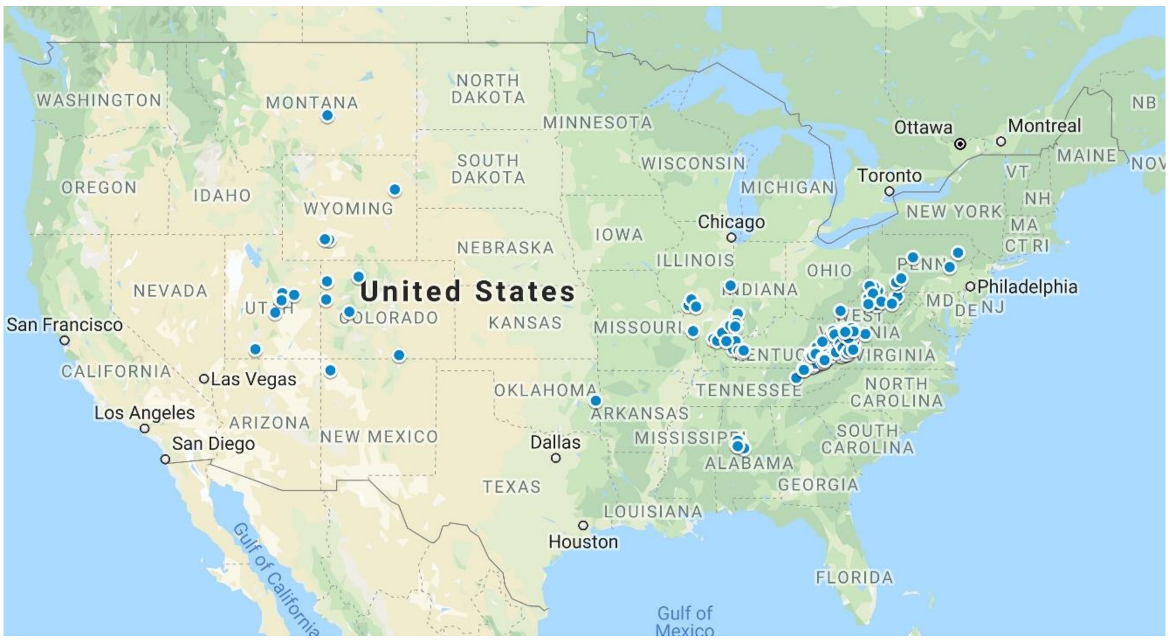


Figure 3. The Effect of Flagrant Violations on Total Penalties in Coal Mines (in thousand $)

Note: Data are from the Mine Data Retrieval System (MDRS). Each period indicates a calendar quarter and period 0 indicates the quarter of the flagrant violation. The solid line presents the penalty from the initial assessment and the dash line presents the penalty from the final assessment.



Panel A. Active Coal Mines in 2006

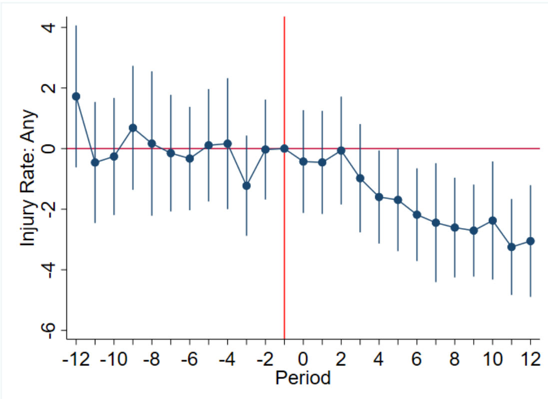


Panel B. Coal Mines with Flagrant Violations

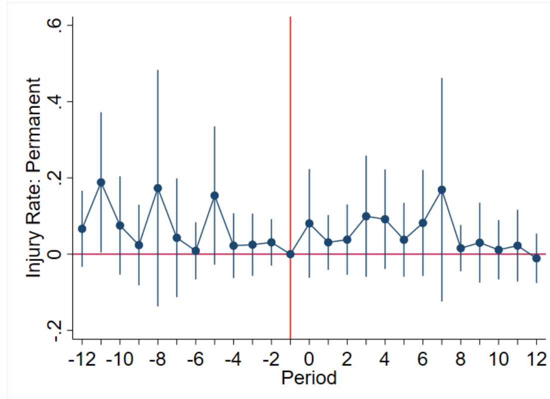
Figure 4. Locations of Coal Mines

Note: Data are from the Mine Data Retrieval System (MDRS).

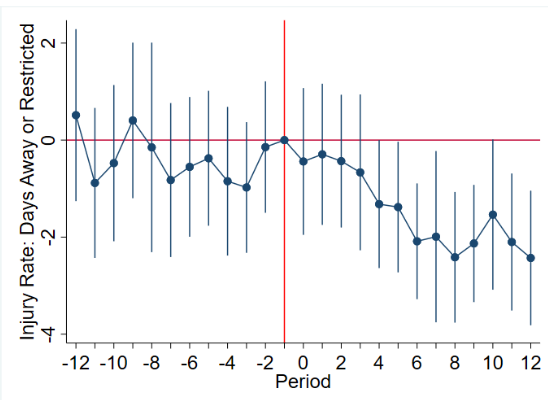
Panel A. Any Injuries



Panel B. Fatal or Permanent



Panel C. Days Away or Restricted



Panel D. Mild

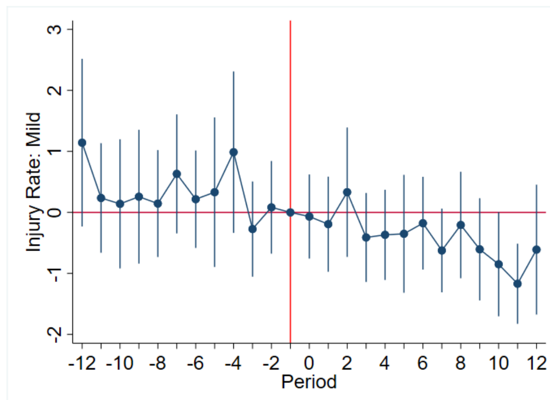


Figure 5. The Effect of Flagrant Violations on Injury Rates in Coal Mines

Note: Data are from the Mine Data Retrieval System (MDRS). Period 0 indicates the calendar quarter of the flagrant violation. Injury rates is measured as the average number of cases per 100 full-time equivalent employees. Panel A includes all workplace injuries; Panel B injuries involving fatalities or permenant disabilities; Panel C injuries involving days away from work or work restrictions; Panel D injuries with medical attention but no losses of work days. The dots show the estimates on the changes in dependent variable relative to period -1.The vertical lines show the 95% confidence intervals, with the standard error clustered at the mine level.

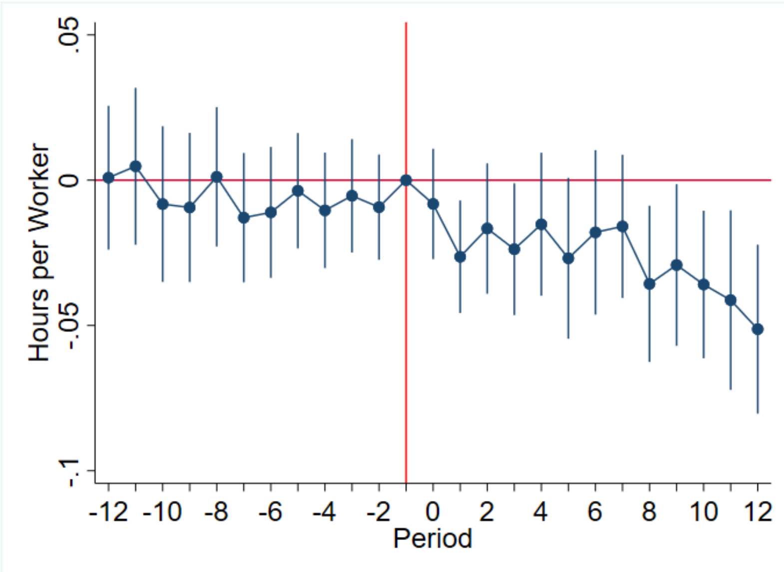


Figure 6. The Effect of Flagrant Violations on Hours per Worker in Coal Mines

Note: Data are from the Mine Data Retrieval System (MDRS). The outcome is the average working hours per worker per quarter (in 1,000). Period 0 indicates the calendar quarter of the flagrant violation. The dots show the estimates on the changes in dependent variable relative to period -1.The vertical lines show the 95% confidence intervals, with the standard error clustered at the mine level.

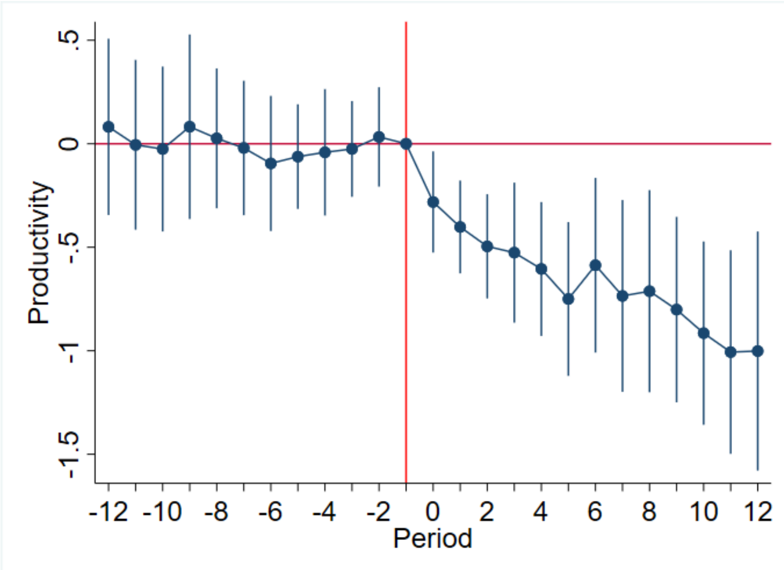


Figure 7. The Effect of Flagrant Violations on Worker Productivity in Coal Mines

Note: Data are from the Mine Data Retrieval System (MDRS). Period 0 indicates the calendar quarter of the flagrant violation. Productivity is measured as the number of short tons of coal per employment hour. The dots show the estimates on the changes in dependent variable relative to period -1.The vertical lines show the 95% confidence intervals, with the standard error clustered at the mine level.

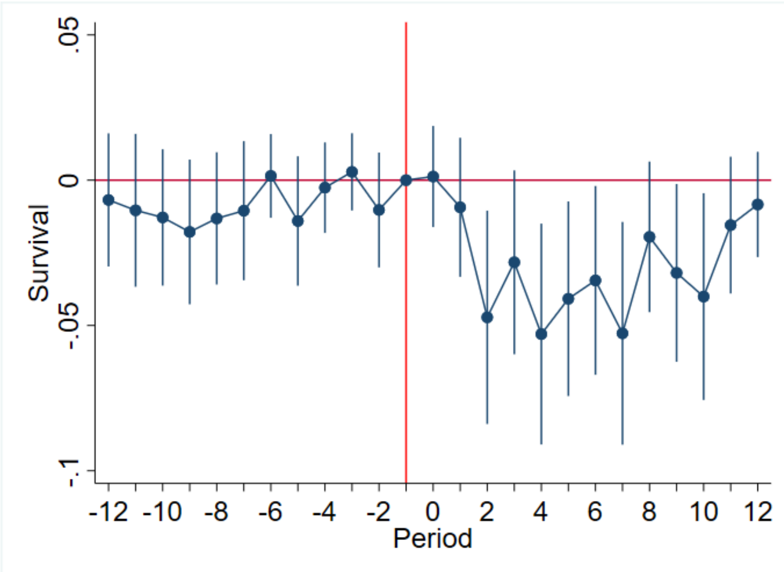
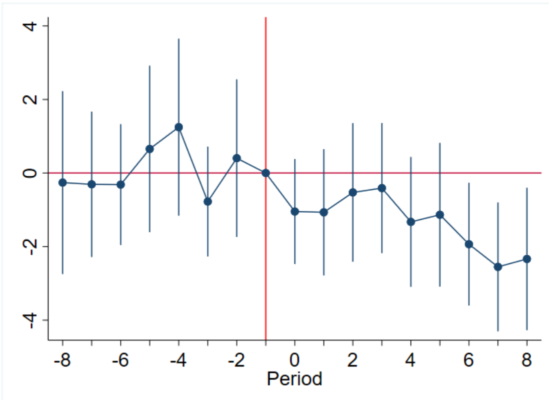


Figure 8. The Effect of Flagrant Violations on Operation Status of Coal Mines

Note: Data are from the Mine Data Retrieval System (MDRS). Period 0 indicates the calendar quarter of the flagrant violation. The dependent variable equals 1 if staying active in the market in a given quarter conditional on being active in the previous quarter. The dots show the estimates on the changes in dependent variable relative to period -1.The vertical lines show the 95% confidence intervals, with the standard error clustered at the mine level.

Panel A. Injury Rate



Panel B. Worker Productivity

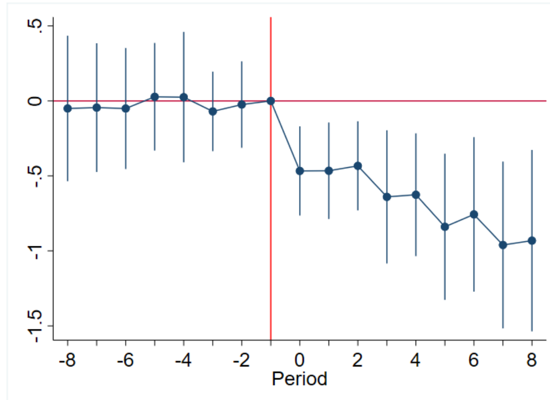


Figure 9. The Effect of Flagrant Violations on Safety and Productivity, Coal Mines Active during the Analysis Period

Note: Data are from the Mine Data Retrieval System (MDRS). Period 0 indicates the calendar quarter of the flagrant violation. Injury rates is measured as the average number of cases per 100 full-time equivalent employees. Productivity is measured as the number of short tons of coal per employment hour. The dots show the estimates on the changes in dependent variable relative to period -1.The vertical lines show the 95% confidence intervals, with the standard error clustered at the mine level.

Panel A. Injury Rate

Panel B. Worker Productivity

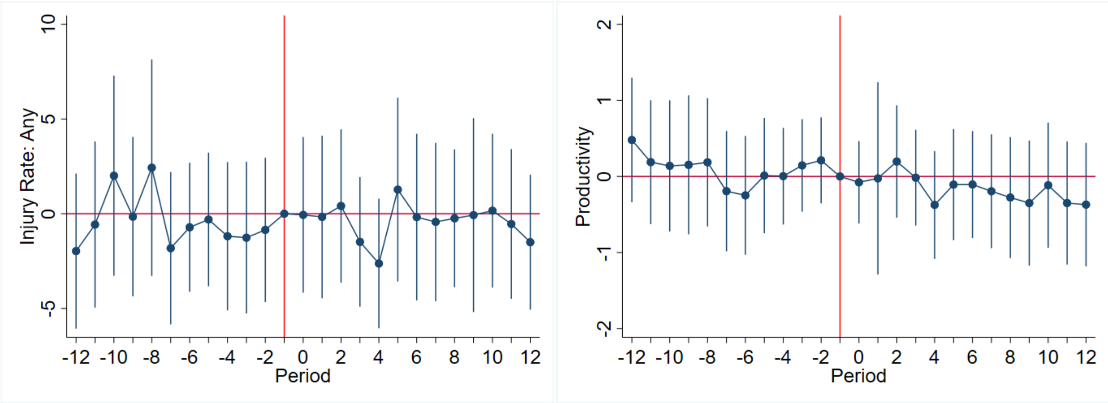


Figure 10. The Effect of Flagrant Violations on Safety and Productivity in Coal Mines, Comparison Group

Note: Data are from the Mine Data Retrieval System (MDRS). Period 0 indicates the calendar quarter of the flagrant violation. Injury rates is measured as the average number of cases per 100 full-time equivalent employees. Productivity is measured as the number of short tons of coal per employment hour. The dots show the estimates on the changes in dependent variable relative to period -1.The vertical lines show the 95% confidence intervals, with the standard error clustered at the mine level.

Appendix

Appendix Table 1. The Effect of Flagrant Violations on Injury Rate and Productivity of Coal Mines, with a Comparison Group Mine

	Injury Rate	Productivity
Years 1 to 2	-0.216	-0.283***
	(0.563)	(0.096)
Years 3 to 4	-1.411***	-0.388***
	(0.497)	(0.128)
Years 5 and after	-1.492*	-0.281
	(0.772)	(0.227)
R2	0.063	0.219
N	7,152	

Note: Data are from the Mine Data Retrieval System (MDRS). The sample includes mines with a flagrant violation and a matched mine in the comparison group. Injury rates is measured as the average number of cases per 100 full-time equivalent employees. Productivity is measured as the number of short tons of coal per employment hour. The model includes mine fixed effects and calendar quarter fixed effects. The standard errors are clustered at the mine level. ***, **, and * indicate statistical significance at the one, five, and ten percent levels, respectively.

Appendix Table 2. The Effect of Flagrant Violations on Injury Rate and Productivity of Coal Mines, Final Action Date

	Injury Rate	Productivity
Years 1 to 2	-0.675	-0.309
	(0.792)	(0.195)
Years 3 to 4	-1.182	-0.336
	(1.104)	(0.338)
Years 5 and after	-0.557	-0.836
	(1.319)	(0.596)
R2	0.055	0.180
N	8,133	

Note: Data are from the Mine Data Retrieval System (MDRS). Period 0 is the quarter of the final action on the flagrant violation. Injury rates is measured as the average number of cases per 100 full-time equivalent employees. Productivity is measured as the number of short tons of coal per employment hour. The model includes mine fixed effects and calendar quarter fixed effects. The standard errors are clustered at the mine level. ***, **, and * indicate statistical significance at the one, five, and ten percent levels, respectively.

Appendix Table 3. The Effect of Flagrant Violations on Injury Rate and Productivity of Coal Mines, by Mine Type

	Underground		Surface		Facility	
	Injury Rate	Productivity	Injury Rate	Productivity	Injury Rate	Productivity
Years 1 to 2	-0.350	-0.277**	-0.587	-0.122	-1.373	0.114
	(0.682)	(0.123)	(0.734)	(0.290)	(0.125)	(0.236)
Years 3 to 4	-1.600**	-0.246	-0.091	-0.470	-2.809*	-0.585**
	(0.616)	(0.156)	(0.837)	(0.320)	(1.201)	(0.242)
Years 5 and after	-1.534*	-0.256	-0.132	-0.825	-2.278	-1.143*
	(0.923)	(0.291)	(1.048)	(0.884)	(1.321)	(0.595)
R2	0.067	0.137	0.067	0.324	0.134	0.351
N	5,841		1,311		981	

Note: Data are from the Mine Data Retrieval System (MDRS). Column 1 and 2 includes underground mines. Column 3 and 4 include surface mines. Column 5 and 6 include preparation or milling facilities. Injury rates is measured as the average number of cases per 100 full-time equivalent employees. Productivity is measured as the number of short tons of coal per employment hour. The model includes mine fixed effects and calendar quarter fixed effects. The standard errors are clustered at the mine level. ***, **, and * indicate statistical significance at the one, five, and ten percent levels, respectively.

Appendix Table 4. The Effect of Flagrant Violations on Injury Rate and Productivity of Coal Mines, by Mine Size

	Large		Small	
	Injury Rate	Productivity	Injury Rate	Productivity
Years 1 to 2	-0.116	-0.262*	-0.141	-0.236*
	(0.470)	(0.152)	(0.901)	(0.133)
Years 3 to 4	-0.990*	-0.374*	-1.565*	-0.311*
	(0.520)	(0.204)	(0.812)	(0.169)
Years 5 and after	-0.656	-0.270	-2.576*	-0.407
	(0.684)	(0.350)	(1.319)	(0.385)
R2	0.090	0.196	0.065	0.183
N	4,084		4,049	

Note: Data are from the Mine Data Retrieval System (MDRS). Column 1 and 2 includes mines with employment hours above median and column 3 and 4 includes those below median. Injury rates is measured as the average number of cases per 100 full-time equivalent employees. Productivity is measured as the number of short tons of coal per employment hour. The model includes mine fixed effects and calendar quarter fixed effects. The standard errors are clustered at the mine level. ***, **, and * indicate statistical significance at the one, five, and ten percent levels, respectively.

Appendix Table 5. The Effect of Flagrant Violations on Injury Rate and Productivity of Coal Mines, by Location

	KY and WV		Others	
	Injury Rate	Productivity	Injury Rate	Productivity
Years 1 to 2	-0.190	-0.275***	-0.113	-0.172
	(0.693)	(0.083)	(0.828)	(0.235)
Years 3 to 4	-1.573**	-0.289**	-1.029	-0.326
	(0.628)	(0.120)	(0.790)	(0.250)
Years 5 and after	-2.053*	-0.006	-0.749	-0.760
	(1.120)	(0.236)	(0.859)	(0.474)
R2	0.065	0.215	0.065	0.175
N	4,799		3,334	

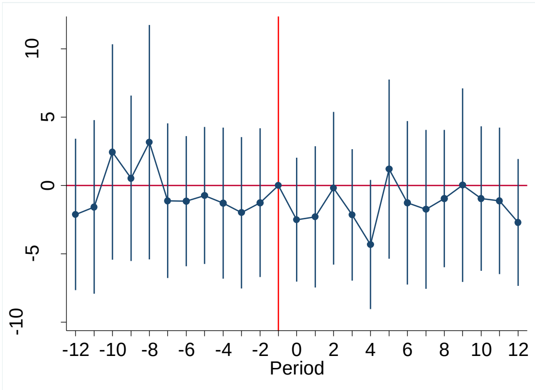
Note: Data are from the Mine Data Retrieval System (MDRS). Column 1 and 2 includes mines in Kentucky and West Virginia and column 3 and 4 includes mines in other states. Injury rates is measured as the average number of cases per 100 full-time equivalent employees. Productivity is measured as the number of short tons of coal per employment hour. The model includes mine fixed effects and calendar quarter fixed effects. The standard errors are clustered at the mine level. ***, **, and * indicate statistical significance at the one, five, and ten percent levels, respectively.

Appendix Table 6. The Effect of Flagrant Violations on Injury Rate and Productivity of Coal Mines, by Level of Penalty

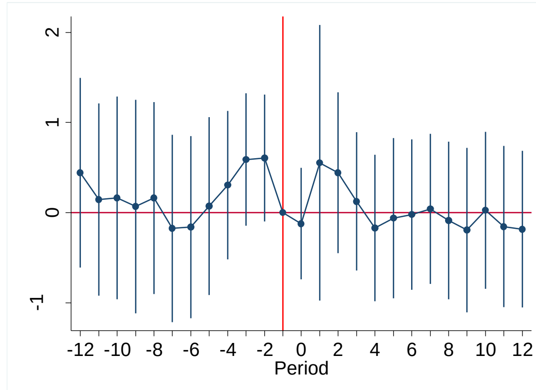
	Penalty above Median		Penalty below Median	
	Injury Rate	Productivity	Injury Rate	Productivity
Years 1 to 2	-0.359	-0.285*	-0.169	-0.227
	(1.502)	(0.146)	(0.575)	(0.137)
Years 3 to 4	-2.197**	-0.330*	-0.843	-0.319*
	(0.991)	(0.165)	(0.514)	(0.190)
Years 5 and after	-2.452*	-0.383	-0.559	-0.198
	(1.456)	(0.340)	(0.741)	(0.355)
R2	0.083	0.215	0.053	0.176
N	3,088		5,045	

Note: Data are from the Mine Data Retrieval System (MDRS). Column 1 and 2 includes mines with penalty above median during the quarter of flagrant violations and column 3 and 4 includes those below median. Injury rates is measured as the average number of cases per 100 full-time equivalent employees. Productivity is measured as the number of short tons of coal per employment hour. The model includes mine fixed effects and calendar quarter fixed effects. The standard errors are clustered at the mine level. ***, **, and * indicate statistical significance at the one, five, and ten percent levels, respectively.

Panel A. Injury Rate



Panel B. Worker Productivity



Appendix Figure 1. The Effect of Flagrant Violations on Safety and Productivity in Coal Mines, Alternative Comparison Group

Note: Data are from the Mine Data Retrieval System (MDRS). The sample includes the closet match to mines with flagrant violations and owned by the same parent company. Mines without any match within 10 km that are owned by the same parent company are excluded. Period 0 indicates the calendar quarter of the flagrant violation. Injury rates is measured as the average number of cases per 100 full-time equivalent employees. Productivity is measured as the number of short tons of coal per employment hour. The dots show the estimates on the changes in dependent variable relative to period -1.The vertical lines show the 95% confidence intervals, with the standard error clustered at the mine level.