Journal of Labor Research
https://doi.org/10.1007/s12122-022-09332-3

Regulation Enforcement

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Accepted: 22 March 2022

Abstract
This paper compares the effectiveness of two mechanisms of regulation enforcement: (1) the frequency of inspections and (2) penalties for violations. Threat effects of increased penalties and inspection rates, rather than corrective effects upon receiving an inspection or penalty, are the focus of analysis. Mining industry data from 2004–2009 are used to analyze the responses of mines to separate increases in inspections and citation penalties regarding regulations of safety standards. Mines did not improve safety in response to increased penalties at the ex-ante inspecting rates; however, mines significantly reduced accidents under increased inspections when implemented at those higher penalty rates. The identification strategy results in a local average treatment effect that implies increasing inspection rates from current levels would likely increase social welfare. Results are shown to be robust to bandwidth changes and model specification. The interpretation of the estimated local effect in the context of selection is analyzed. Robustness checks regarding selection exploit staffing changes and restrict to similar samples of treated and non-treated mines, justifying that results are representative.

Keywords Threat effects · Regulation enforcement · Worker safety · Compliance · Inspections · Mining

JEL Classification D04 · J08 · K23 · K42

Introduction

In a wide variety of settings, regulations and policies are imperfectly enforceable. Environmental emissions standards, self-reported filing of taxes, and enforcement of drunk driving laws, are a short list of settings in which an agent is requested to comply with well-defined standards, however enforcement of such standards is costly

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Published online: 13 April 2022

and imperfect. This paper uses data regarding safety regulations and accidents in the mining industry to compare the effectiveness of the two most prominent enforcement mechanisms: (1) the frequency of inspections and (2) the dollar value of penalties for violations. Mining is a meaningful industry to study regulation enforcement due to the significant risk to workers. Understanding mechanisms which effectively enforce safety specifically is also meaningful in light of the trade-off between economic growth and safety discussed by Jones (2016).

There are two channels whereby inspections and citations are hypothesized to affect behavior: (1) a threat effect, a response to the threat of being caught violating a standard or a response to the magnitude of the penalty associated with a citation and (2) a corrective effect, that agents may adjust behavior after being inspected or cited. It is often difficult to determine the mechanism which drives corrective effects (a short list of possible mechanisms includes learning, temporary abatement, and sunk-cost related fallacies). In contrast it is straightforward to understand the mechanism by which threats influence behavior. Because of this, the present paper focuses on threat effects. Despite our focus on threat effects, our empirical approach does not rigorously rule out corrective effects contemporaneously occurring and estimates ultimately could reflect both mechanisms.

Responses to the threat of inspections are identified by an increase in the propensity of the Mine Safety and Health Administration (MSHA) to inspect mines. In October, 2007 the MSHA announced the 100 Percent Plan, an effort to perform all mandated safety inspections (described in what follows), and subsequently increased average inspections. We view this policy as an exogenous shock to the threat of receiving a citation. It is shown that mines significantly reduced their propensity to have accidents in the wake of the announcement. To justify that the estimated safety improvements were caused by the increase in inspections, inspecting offices are marked by their change in inspecting rates around the announcement of the 100 Percent Plan. Safety improvements are only exhibited by mines for which the local office increased inspections by more than the median, implying the reduction in accidents was a response to the increase in inspections, rather than a response to other contemporaneous factors. Surface mines treated by the policy are estimated to have decreased average accidents per quarter by .146 between the announcement of the policy and December 2009, and underground mines are estimated to have decreased average accidents per quarter by .592. These are reductions in accidents of roughly 40% and 20% respectively (inspecting rates increased by about 40% and 10% respectively). Estimates are well-defined local effects for the treated population. Implications of selection into treatment are discussed in what follows. Treatment is shown to be driven greatly by increases in staffing of inspecting offices, which is exploited in an instrumental variable-style robustness check. Other robustness checks limit the sample to mines which were similar ex ante, also justifying results.

Regarding the threat effect of larger penalties, the Federal Mine Safety and Health Act of 1977 (Mine Act) established the issuance of citations for violations of the Mine Act. The MSHA announced increases to citation amounts in March 2007, taking effect in April 2007. Analysis indicates that mines did not adjust behavior in response to the increase in penalties at the ex ante inspection rates. It is difficult to rigorously confirm why this is so, although it is suggested that fines may act as payment for the right to commit violations in the style of Gneezy and Rustichini (2000). Alternatively, at local levels penalties may not be large enough to deter violations.

The results must be interpreted as local responses. i.e., we only estimate the effect of the increased inspecting rates when implemented at the increased monetary penalty rate. Analogously, we only estimate the effect of increased citation penalties at the ex ante, lower, inspecting rates. Our estimates are local effects, and should be interpreted as such. It would be unwise to use the results from this paper to make global conclusions regarding the effects of inspecting rates and penalties on safety.

We also acknowledge an alternative explanation that the response may be a corrective effect, namely, when more violations were given (due to increased inspecting rates), there were more corrections made by mines, and thus the safety improvement is a corrective response due to there being more violations inducing those corrective responses.

Related Literature

Implications of inspections on regulation enforcement have been studied in other contexts, notably with regards to tax filings. Dubin et al. (1990), Slemrod et al. (2001), and Kleven et al. (2011) among others, have shown that receiving an audit, and increases in audit rates, result in increases in personal tax reporting.[1]Makofske (2019) shows the importance of inspections being unanticipated on compliance among restaurants.[2] The primary contribution of the present paper is the comparison of responses to threats of citation amounts with responses to threats of inspections. In addition, this work considers a large industry in which inspections are frequent and routine, unlike tax filings. Estimates in this setting are more likely to be applicable when considering policies regarding enforcement of environmental regulations and industry standards.

In the context of environmental regulations, Telle (2008) attempts to quantify responses to threats of inspections through estimating the probability of an inspection. In Telle's context, the probability of an inspection relies on endogenous characteristics: risk class and previous compliance. The threat of inspections is endogenously determined. This paper provides estimates of threat effects in a context with exogenous inspection probability, and exploits an exogenous increase in inspections.[3]Duflo et al. (2018) exploit exogeneous variation in inspection frequently using an experiment in India. The analysis of the present paper exploits variation from an actual policy as opposed to variation in a controlled setting.

Pouliakas and Theodossiou (2013) provide a review of health and safety literature. In discussing the effectiveness of penalties and inspections, they state, "Empirical evidence tends to suggest that the estimated effects of (occupational safety

[1] In related research, Hansen (2015) uses a regression discontinuity to conclude that having blood alcohol content above the DUI threshold reduces recidivism by 17%.

[2] In a related paper, Makofske (2020) exploits a unique aspect of the restaurant grading scale to estimate corrective responses to a restaurant's hygeine score being downgraded.

[3] Other relevant research includes Hanna and Oliva (2010), who estimate corrective responses to inspections in the context of environmental regulation.

and health) inspections on safety are quite small or non-existent". They cite Shapiro (1999), who references a variety of papers that examine correlations between inspecting rates and safety, and violations and safety.[4] Slightly more recent research regarding effectiveness of workplace safety regulations include (1) Haviland et al. (2010), who show in manufacturing that inspections are negatively correlated with accidents in the short run, even for accidents that are not associated with violations, and (2) Kniesner and Leeth (2004), who use over 200 specifications of dynamic models to estimate the effect of regulations on safety for underground coal mines, concluding regulations have essentially no effect. These, and the studies cited by Shapiro, have focused on the corrective response of firms to being inspected or receiving a citation.[5] It is intuitive that forward looking agents would be minimally affected by a past event (unless it provided information). A contribution of this paper is to examine the safety response to an exogenous increase in the threat of receiving a violation. Estimates imply significant and meaningful safety improvements.[6]

In related work, health and safety in the context of compensating wage differentials has been well-researched, see Viscusi and Aldy (2003) for a review of estimates. Various sources have shown that workplace safety is a luxury good, that as non-labor income rises, workers choose safer jobs (Biddle and Zarkin 1988). Other relevant work includes Fishback and Kantor (1995), who show that costs of workplace safety are passed through to workers in the form of lower wages, and Drakopoulos and Theodossiou (2016), who show workers often underestimate job-associated risks. Other work has shown that workers prefer jobs with more amenities and lower wages in response to tax increases (Powell and Shan 2012). Powell (2012) shows safety is an amenity which is difficult to adjust in response to taxes, and finds large differences in the wage response of jobs to taxes based on their riskiness. This work contributes by comparing the effectiveness of policies designed to improve workplace safety.

In other regulation work, much has been learned regarding the effects of environmental regulations on productivity and firm behavior. Dechezleprêtre and Sato (2017) review the literature, showing environmental regulations have adverse effects on trade, employment, plant location, and productivity in the short run. It is also shown that such regulations induce innovation. Greenstone et al. (2012) show that air quality regulations cause a 2.6% decline in total factor productivity among manufacturing firms. Productivity implications of regulations are not analyzed in this paper for brevity. Other mining research includes Gowrisankaran et al.'s (2015) analysis of productivity responses to accidents among coal mines.

[4] Specific papers include: Viscusi (1992), Gray and Scholz (1993), Cooke and Gautschi (1981), Robertson and Keeve (1983), Scholz and Gray (1990), Smith (1979), McCaffrey (1983), Ruser and Smith (1991), Gray and Jones (1991), and Bartel and Thomas (1985).

[5] A slightly different strand of research regards discretion in enforcement and includes Jung and Makowsky (2014), who show that state agencies find fewer violations when unemployment is higher.

[6] In earlier versions of the present paper, corrective effects were estimated using regression with lagged violations as independent variables. Consistent with earlier literature, small, short-lived corrective effects were estimated.

In related work, Blundell et al. (2020) and Blundell (2020) estimate dynamic regulation enforcement in environmental settings. We do not pursue this estimation here due to the existence of policy shocks we exploit. Estimating a dynamic model in this setting is a possible avenue of further research.

This paper proceeds with background information, a description of the data, discussion of methodology, presentation of empirical results, and concludes.

Background

A natural question regarding the relevance of this paper is the size of the industry studied. According to the Bureau of Labor Statistics, the mining industry employed 731,000 individuals in January, 2016. The raw data used in this paper indicate there were 54,766 worker-days lost due to accidents in 2016. The average number of days lost per accident was 7.96. While mining accounts for a small fraction of U.S. employment, the findings of this work are meaningful beyond the context of reducing accidents in mining. The primary contribution is analysis of the general question regarding which methods best enforce regulations.

What follows draws from the MSHA-Handbook Series - *Citation and Order Writing Handbook for Coal Mines and Nonmetal Mines* and the *Metal and Nonmetal General Inspection Procedures Handbook*. The interested reader is referenced to these.

The Federal Coal Mine Health and Safety Act of 1969 (Coal Act) created the Mining Enforcement and Safety Administration, later renamed the MSHA. The Coal Act dramatically increased the safety and health standards of coal mines, and was later updated through the Mine Act to apply to all mines: coal, metal, and nonmetal. The Mine Act also established that inspectors would issue citations when it was believed a violation of the Mine Act had occurred. The Mine Improvement and New Emergency Response Act of 2006 (MINER Act) amended the Mine Act. The MINER Act included a variety of adjustments: creation of emergency response plans, changing reporting requirements for accidents, removing liability to individuals involved in rescue teams, and requiring the Secretary of Labor to modify the civil penalty criteria, eventually causing citation dollar amounts to increase in the following year (discussed in what follows).[7] An assumption of this paper is that the MINER Act's passage did not affect safety in mines. Required adjustments were with respect to accident response plans, rather than safety measures preventing

[7] Specifically the MINER Act consisted of the following: section 1 presented the name of the Act, section 2 addressed existence of emergency response plans, section 3 addressed liability for rescue operations, section 4 stated qualifications for mine rescue teams, section 5 required prompt notification of accidents, section 6 created the Office of Mine Safety and Health (designed to develop new safety technology), and section 7 addressed relationships with family members of miners which experienced an accident. Section 8 modified penalties, establishing a criteria for flagrant violations (reckless or repeated failure to make reasonable efforts to eliminate a known violation), and requiring that the Secretary of Labor promulgate new regulations with respect to penalties by the conclusion of the year. Section 9 regarded fine collections, and section 10 addressed the sealing of abandoned areas. Later sections regarded the Technical Study Panel (which provides recommendations with respect to the utilization of belt air and the composition and fire retardant properties), scholarships for Associate's degrees related to mining, and research for refuges in underground coal mines.

accidents or incentives to avoid accidents. Empirically it will be shown no kinks nor jumps in accidents per quarter occurred due to the passing of the MINER Act. It was ex ante hypothesized that the increase in citation rates resulting from the MINER Act would affect mine safety decisions, although estimation suggests a null effect.

The MSHA is required to perform regular inspections at each underground mine four times a year and each surface mine twice a year. These frequencies are public information. Inspections are partitioned into three classifications in this paper, (1) regular inspections, (2) compliance follow-up inspections after violations have been issued, (3) all other inspections which include accident investigations, hazardous condition complaint investigations, and special inspections at extremely hazardous mines (e.g., those with large amounts of explosive gases). From 2004–2009, about 46% of all inspections were regular, and about 13% were compliance follow-up inspections. Inspections other than regular inspections usually address a specific subject or a limited area of a mine, while regular inspections are general. Inspectors are encouraged to vary their inspection routes and starting points from one regular inspection to another. Inspectors vary their inspection frequency as to the month of the quarter a mine is inspected.

If an inspector believes that a mine has committed a violation of the Mine Act, the inspector issues a citation to the mine operator. Each citation includes a reference to the provision of the Mine Act alleged to have been violated. Also recorded is the chapter and part of the Code of Federal Regulations (CFR) which was violated.

Each citation fixes a time for the abatement of the violation. If an inspector finds that a violation previously cited has not been abated and that the period of time for abatement should not be further extended, the investigator issues a withdrawal order for the cited equipment or area of the mine affected by the violation. Forced abatement is almost immediate. From 2004–2009, over 50% of citations required operators to abate the offense within a day, and the 95th percentile was 15 days.

Types of Violations

Each violation is marked by the part of the CFR which is violated. Since the passage of the MINER Act, most mining violations are from title 30, “Mineral Resources” however there are a trivial potion from title 42 “Medical Care and Examinations”. In the sample of analysis, the following parts of title 30 are violated: 40, 41, 44, 45, 46, 47, 48, 49, 50, 56, 57, 58, 62, 70, 71, 72, 75, 77, and 90. Parts 40–45 reference filing and administrative requirements, parts 46-49 reference education and training (i.e., new miner training), and part 50 regards reporting of employment, production, and accidents. Safety in metal and non-metal (but non-coal) mines is referenced in parts 56–58. Uniform health regulations are detailed in part 62. Coal mine safety and health is covered in parts 70–90.

Appendix Table 5 lists the name of each part of title 30 which is violated. A detailed explanation of all possible violations would add minimally. The interested reader is referenced to the CFR. A basic list of safety-related topics of violations is: fire prevention, air quality, use of scaffold, use of ladders, clear walkways, electric equipment, use of personal safety equipment, storage of materials and explosives, illumination, use of drilling equipment or other large machines, and ventilation.

100 Percent Plan

In October 2007 the MSHA announced the 100 Percent Plan, a goal to perform every mandated regular inspection during each calendar year (previously the MSHA had failed to perform all mandated inspections). The MSHA and various news releases indicate that the goals were achieved and all mandated regular inspections were completed. Data indicate that inspections increased following the announcement.

The MSHA cited various factors which contributed to the increase in inspections: "...the willingness and work ethic of dedicated career MSHA employees, the temporary reassignment of MSHA inspectors to areas where they were most needed, the provision for increased overtime for additional hours needed to complete inspections, and better oversight and tracking of inspections by the agency's district offices and headquarters. Nearly 190,000 hours of inspector overtime were logged during FY 2008." There are no records that inspecting procedures differed under this policy..

There was no concurrent legislation regarding mine safety, or major developments in safety technology. The MINER Act was passed in June 2006, a year prior to the 100 Percent Plan and increase in penalties. We acknowledge there may be lingering effects of its passage. There was a major contemporaneous accident, the Crandall Canyon Mine accident in August 2007 which occurred in Emery, Utah. This incident killed six miners and three rescue workers, receiving national attention. One could argue that other mines improved safety in response to such a major event. The improvements in safety following 2007 are long-term and show no reversion to pre-100 Percent Plan levels. Also, reductions in accidents are strongest for mines which were inspected by the offices where the inspecting rate increased the most. A response to an accident would presumably be exhibited by all mines. It is assumed that this incident is not the motivation behind improved safety.

Citation Amounts

Violations are assessed according to a formula that considers five factors: (1) history of previous violations, (2) size of the operator's business, (3) negligence by the operator, (4) gravity of the violation (likelihood of injuries), and (5) good faith in the operator trying to correct the violation promptly, which results in a 10% reduction (30% before the MINER Act). The five factors are determined from the inspector's findings, MSHA records, and information supplied by the operator. A sixth factor, the effect of the penalty on the operator's ability to stay in business, is considered when the operator submits information on the adverse effect of the penalty. The general method whereby fines are calculated is described below. The interested reader is referenced to CFR title 30, chapter 1, subchapter P, Part 11 and 72 FR 13591.

The history of previous violations affects penalties through two channels. (1) Operators who have 10 or more violations during the previous 15 months are assigned penalty points based on the total number of violations per inspection day. (2) Points are assigned for repeat violations of the same standard by an operator with at least six repeat violations in the previous 15 months, similarly assigned depending on the number of repeat violations per inspection day.

Points are assigned according to size as measured by tonnage of coal for coal mines, and labor hours for non-coal mines. Penalty points are assigned, increasing in severity, for each of the following categories: (1) Likelihood of injury, marked as one of the following: no likelihood, unlikely, reasonably, highly, and occurred; (2) the number of workers potentially affected; (3) the potential seriousness of injuries measured by potential days lost of work; (4) negligence, marked as one of the following: none, low, moderate, high, and reckless.

Given the total number of points, there is a mapping to the dollar value of the fine. The MINER Act did not change the core of the process whereby citation amounts are calculated, however did change both the number of points assigned for each characteristic, as well as the mapping from points to dollar values of fines. The Final Rule resulting from the MINER Act regarding citation increases, 72 FR 13591, did not take effect contemporaneously with the Act's passage. A proposed rule regarding the change in citations was made public on September 8, 2006. Six public hearings were made from September to October of 2006. After these hearings, revisions were made, and the final rules were announced on March 22, 2007, taking effect April 23, 2007. Most importantly, the changes were well-publicized and anticipated.

The changes resulting from the MINER Act greatly increased the average dollar value of citations. In an example published with the Final Rule, the average fine to a Peabody coal mine under previous legislation was $68, under the new legislation the average fine would have been $586. Formal estimation does not exploit specific changes in the rules, only that the new rule increased average citations (which is confirmed by the data).[8] Estimation proceeds in a reduced form manner regarding the threat of greater penalties. Because the estimation approach is reduced form and not structural, as previously explained, there is the potential that a portion of the estimated effect is a corrective response to more violations being penalized in addition to the response to the threat of increased inspection rates.

Types of Mines

There are three types of mines: surface, underground, and facility. In surface mining the earth is stripped back, mining ensues, and the overburden is put back in place after mining is complete. Underground mines access ore or coal either with a sloped decline, vertical shafts, or horizontal excavations into the side of a hill or mountain. Facility mines represent mill operations, preparation plants, or breaker plants. Underground mines are typically considered to be the most dangerous due to difficulties with ventilation, collapses, lighting, and entrapment. The vast majority of observations are of surface mines. In the data,

[8] The Final Rule acknowledges that a small portion of violations, about 5% of those occurring in 2005, would have received lower violations under the new rules.

73.63% of mines are surface, 20.03% are underground, and 6.34% are mining facilities.

Analysis separates underground and surface mines because the 100 Percent Plan had different implications on these mines. Facility mines are excluded due to small sample size and because inspections were minimally affected by the 100 Percent Plan.

Data

Data on inspections, accidents, violations, and fines, are publicly provided by the MSHA. Data are available at the violation-level, accident-level, inspection-level, and quarterly at the mine level for variables regarding employment and the current operator. Data regarding fines became available in 1995, although the sample is restricted to 2004–2009. Violations by the operator, accidents, and inspections are aggregated to the mine-quarter level. This data source has been used previously, notably by Stoker et al. (2005) in their analysis of productivity. Attention is restricted to observations with at least 3,000 employee hours in the quarter.[9]

Data on inspections includes the number of hours of the inspection and the components of the mine which were inspected (surface area, underground area, outby areas, refuse piles, shafts/slopes, dust samples, and air samples are some examples). Offices are assigned to inspect mines based on geographic location, and the inspector's name is not recorded in the data.

Descriptions of violations are detailed. Recorded variables include the part of the CFR which is violated, the likelihood of injury due to the violation, the potential number of persons affected, and the degree of negligence which resulted in the violation. Accident data are also detailed, including specifics of the injury which are not relevant to the methodology of this paper. For transparency, about 27% of injuries from 2004–2009 are marked as "No days away from work, no restricted activity". These are accidents such as non-severely twisted ankles and dislocated fingers. Of injuries which caused at least 1 day away from work, the median is 21 days and the 99th percentile is 330 days. Some examples of injuries are: falling off ladders and breaking bones, dropping a steel beam on one's foot, and muscle strains from lifting heavy objects. Mines are required to report accidents within 15 minutes of their occurrence, facing penalties for failure to do so. It is assumed accident reporting is representative.

Many mines are operated by more than one operator in their histories. In what follows, fixed effects are determined by the combination of the mine operator and mine.

[9] This restriction may induce sample selection bias by eliminating mines with very small labor forces. To the extent that we are estimating safety improvements, estimating the effect on mines with large labor forces is the subset of greatest interest and importance, even if estimates do not generalize to the full population.

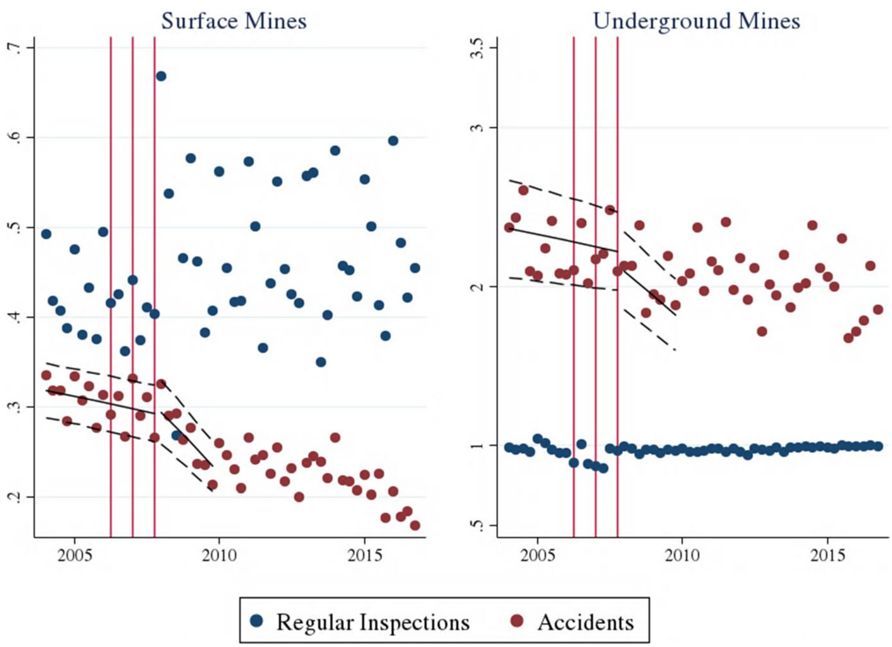

Fig. 1 Time trends in accidents and inspections. Plotted are the average number of accidents per mine-quarter and average number of regular inspections. The first vertical bar denotes June of 2006, when the MINER Act took effect. The second vertical bar denotes March of 2007, the announcement of increased penalty rates for citations caused by the MINER Act, taking effect in the following quarter. The third vertical bar denotes October of 2007, the announcement of the 100 Percent Plan to perform all mandated inspections, quarterly for underground mines, and twice per year for surface mines. Black lines denote fitted values and 95% confidence intervals for trends during the analysis time period, net of controls used in the specification of Table 2

Descriptive Statistics

Figure 1 displays the average number of accidents per quarter and regular inspections per quarter for surface and underground mines separately. From 2004 to October of 2007 there were minimal changes in average inspections and accidents per quarter for both surface and underground mines. This is unchanged by the MINER Act's passage in June of 2006, denoted by the first vertical bar, and the implementation of new citation amounts, denoted by the second vertical bar. The only deviation from a near-constant function for inspections is that the inspecting rate for underground mines began to dip in 2005 to around .9 per quarter. The third vertical bar denotes the announcement of the 100 Percent Plan, after which underground mines were inspected almost quarterly and the inspecting rate increases for surface mines. (As does the variance in regular inspections, with an increase in inspections specifically in the first quarter of each year, likely an effort early in each year to ensure compliance with standards). At this point, the rates of accidents in both surface and underground mines began declining. This decreasing linear trend in accidents

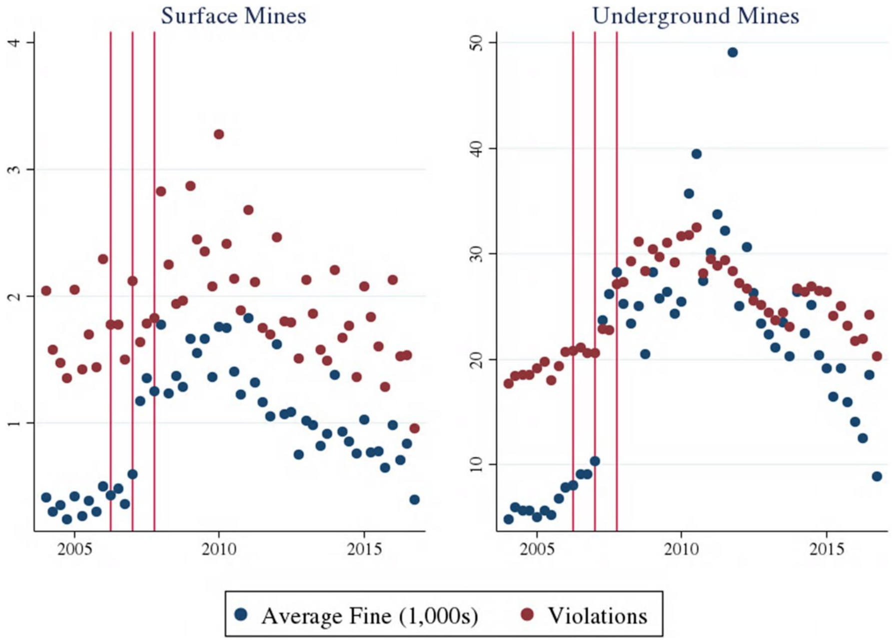

Fig. 2 Time trends in citations and violations. Plotted are the average number of violations per mine-quarter and average citation paid. The first vertical bar denotes June of 2006, when the MINER Act took effect. The second vertical bar denotes March of 2007, the announcement of increased penalty rates for citations caused by the MINER Act, taking effect in the following quarter. The third vertical bar denotes October of 2007, the announcement of the 100 Percent Plan to perform all mandated inspections, quarterly for underground mines, and twice per year for surface mines

continued until the fourth quarter of 2009. Appendix Fig. 6 presents the analogous figure with facility mines, showing a minimal increase in inspecting rates.

Figure 2 plots the average number of violations and the average citation paid by mines of each type. Violations increased with the implementation of the 100 Percent Plan, presumably due to increased inspecting rates, then declined as mines improved safety. Figure 2 also shows that citation amounts jumped meaningfully and discontinuously upward due to the implementation of new citation rules. Neither violations nor accidents kinked nor jumped in response to the jump in citation amounts.

Summary statistics of accidents, inspections, employment, and citations are presented in Table 1. The first three columns show average accidents per quarter for surface and underground mines separately, split by the time periods: before the average citation increase, between the policy changes, and after the announcement of the 100 Percent Plan until the end of 2009. For surface mines, average accidents per quarter are respectively .308, .290, and .268. For underground mines the averages are 2.232, 2.263, and 2.054. Citations jump upward after the implementation of the new formula.

To understand trends further, mines are partitioned to those "treated" and "untreated" by the policy change. A mine for which the local office increased the

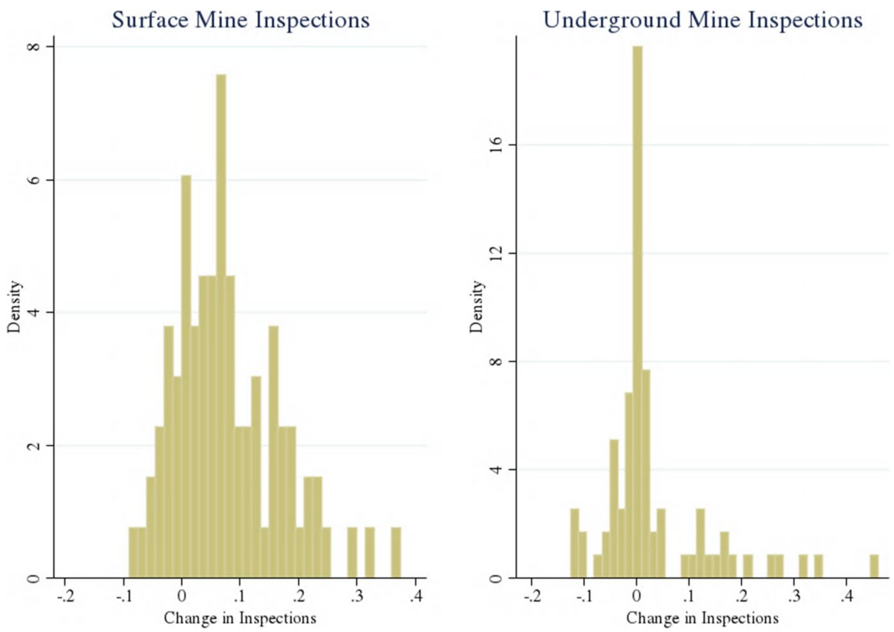

Fig. 3 Changes in the inspecting rate by inspecting offices. Observations are at the inspecting office level. Plotted is the increase in regular inspections per quarter from 2006-2007 to 2008-2009 for mines of the respective type

inspecting rate following the announcement of the 100 Percent Plan may be thought of as “treated” compared to mines for which the local inspecting office did not change behavior. Each mine is marked by the inspecting office that performed the most regular inspections during the years 2006–2009. The average inspections per quarter for all mines with the same inspecting office is calculated separately for 2008-2009, and for 2006-2007. Figure 3 displays histograms of the differences in these inspecting rates at the inspecting office level. At the mine-quarter observation level from 2004-2009, for surface mines the 25th percentile of the change in inspecting rates is .021, the median difference is .070, and the 75th percentile is .114. For underground mines the 25th percentile is -.008, the median is 0, and the 75th percentile is .042. The medians, .070 and 0, are respectively the cutoffs used to mark an office as “complying”. Mines for which the office complies are “treated”. Safety improvements are exhibited only by treated mines, and analysis separately estimates effects within each quartile. Larger effects are shown in the top quartile, justifying the claim that the reduction in accidents is a result of increased inspecting rates.

Treatment is defined at the office rather than mine level because average inspecting behavior of a local office is plausibly more representative of the threat of inspections. Also, increases in staffing of local offices will be shown to be a primary determinant of selection into treatment. Therefore, treatment is defined at the office level because this is effectively the level at which treatment is assigned.

Columns four through six of Table 1 restrict to treated mines. Columns seven through nine display summary statistics for all other mines. Treated surface mines

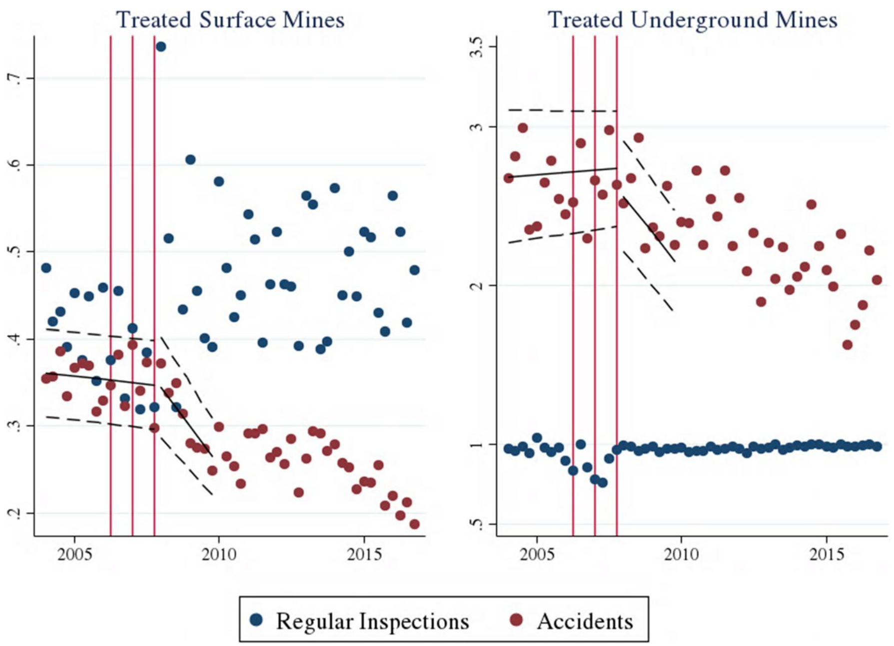

Fig. 4 Time trends in accidents and inspections in treated mines. Identical to Fig. 1, restricted to treated mines as defined in the text

reduced accidents per quarter from .367 to .348 to .318 over the respective time periods. Non-treated surface mines decreased accidents per quarter from .252 to .235 to .220. The respective percent reductions following the announcement of the 100 Percent Plan are $\frac{.348-.318}{.318} = 9.4\%$ and $\frac{.235-.220}{.220} = 6.8\%$. Figure 4 recreates Fig. 1, however restricted to treated mines. Treated mines had minimal pre-trends prior to the 100 Percent Plan, then accidents kinked strongly downward. Visually it appears the declining linear trend flattens by the end of 2009, and the fourth quarter of 2009 is used as the final time period when estimating the linear trend following the 100 Percent Plan. (Robustness checks vary the final time period of analysis). The plots for non-treated mines are shown in Fig. 5. The decease in accidents among non-treated mines following the 100 Percent Plan appears to be the result of a pre-trend, and this trend being unaffected by the policy.

For treated underground mines, average accidents per quarter are 2.611, 2.729, and 2.492 over the respective time periods. For untreated underground mines, average accidents for the three time periods are 1.745, 1.652, and 1.455. Percent reductions are 9.5% and 13.5%. Figures 4 and 5 show similar trends for underground mines as for surface mines. Treated underground mines had no trend in average accidents per quarter prior to the policy change, then accidents per quarter kinked downward after the 100 Percent Plan was announced. Accidents per quarter was trending downward in non-treated mines prior to the policy changes, and this trend was unchanged by the increase in citation amounts and 100 Percent Plan. As with

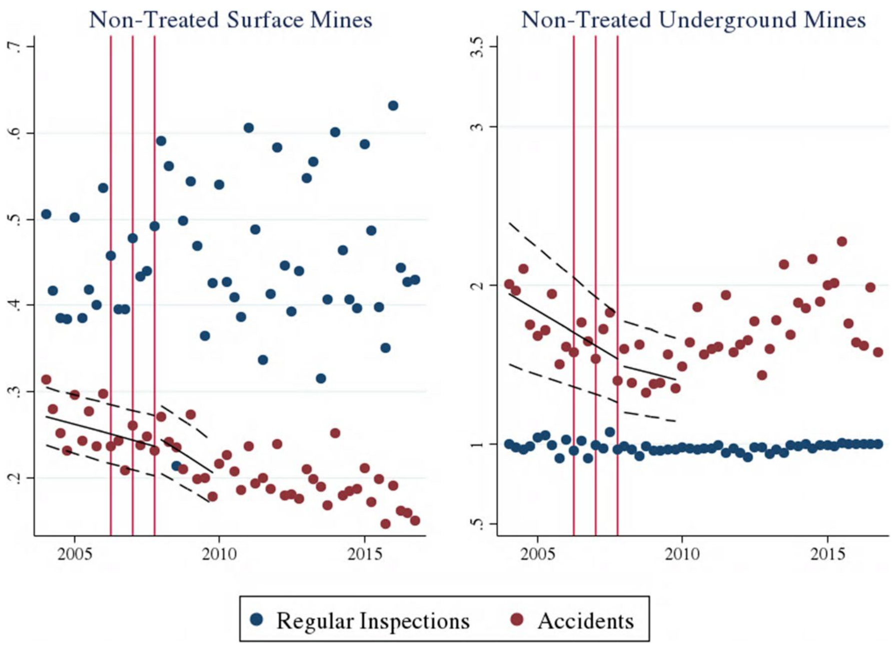

Fig. 5 Time trends in accidents and inspections in non-treated mines. Identical to Fig. 1, restricted to non-treated mines as defined in the text

surface mines, the downward trend in accidents among treated underground mines ended in the fourth quarter of 2009.

Importantly, the kink in accidents is only exhibited by treated mines, supporting the claim that safety improvements were a response to the threat of increased inspections. It is surprising that data imply mines minimally responded to the increase in citation amounts that is so prominently displayed in Fig. 2 and Table 1. Li (2020) showed that mine safety improved in response to the citation increase resulting from the MINER Act. Li's analysis focused only on flagrant violations, which are the most serious violations that have the greatest potential for injury and result in the largest fines, which can range into the hundreds of thousands of dollars. Our analysis differs in that we do not restrict based on severity of accidents or violations. Flagrant violations are a small fraction of total violations. Violations with reckless negligence (a component of the "flagrant" category) comprise 0.0789% of total violations. Li's work, which only studies coal mines, has 103,561 observations of which 8,169 are for mines which ever had a flagrant violation. The vast majority of mines never had a single flagrant violation. Although fines increased, an estimated null effect of average fines on safety is not unreasonable given that the average fine remained small due to the minuscule proportion of violations that are flagrant. Moreover, there is precedent for an effect to be visible only in a subset of a population (e.g., Card et al. 2009).

For both surface and underground varieties, treated mines had more accidents and higher employment prior to the policy changes. One may be concerned about regression to the mean.

Table 1 Summary stats - threat effects

	All data			Treated			Non-treated		
	Before	Mid	After	Before	Mid	After	Before	Mid	After
Surface									
Accidents	.308	.290	.268	.367	.348	.318	.252	.235	.220
	(1.082)	(1.274)	(1.139)	(1.325)	(1.630)	(1.435)	(.772)	(.784)	(.741)
Inspections	.422	.397	.467	.418	.343	.483	.426	.449	.451
	(.499)	(.494)	(.509)	(.500)	(.479)	(.509)	(.499)	(.502)	(.507)
Hours worked	15,700	15,722	15,982	18,135	18,294	18,698	13,327	13,226	13,331
	(36,288)	(41,331)	(44,068)	(43,476)	(50,957)	(54,009)	(27,324)	(28,874)	(31,242)
Citation ($100s)	386	1,256	1,479	473	1,649	1,860	301	874	1,108
	(2,624)	(10,089)	(14,323)	(3,193)	(13,325)	(18,449)	(1,910)	(5,290)	(8,538)
Violations	1.718	1.746	2.323	1.944	1.882	2.600	1.490	1.607	2.039
	(5.519)	(6.088)	(8.439)	(6.509)	(7.048)	(9.932)	(4.276)	(4.921)	(6.549)
N	63,729	15,602	35,867	31,457	7,684	17,718	32,272	7,918	18,149
Underground									
Accidents	2.232	2.263	2.054	2.611	2.729	2.492	1.745	1.652	1.455
	(3.929)	(3.893)	(3.567)	(4.503)	(4.564)	(4.150)	(2.966)	(2.658)	(2.436)
Inspections	.961	.935	.973	.938	.881	.977	.990	1.006	.967
	(.332)	(.364)	(.188)	(.356)	(.412)	(.181)	(.295)	(.272)	(.196)
Hours worked	45,174	46,955	49,826	49,641	51,573	54,400	39,432	40,892	43,555
	(68,651)	(70,733)	(75,417)	(72,257)	(74,833)	(78,977)	(63,265)	(64,504)	(69,778)
Citation ($100s)	6,971	26,000	24,817	7,431	28,903	28,298	6,380	22,189	20,045
	(27,878)	(73,866)	(61,024)	(30,765)	(81,875)	(66,051)	(23,646)	(61,641)	(53,013)
Violations	19.554	24.255	29.551	19.494	24.772	30.244	19.648	23.431	28.416
	(31.334)	(35.440)	(39.463)	(32.520)	(37.700)	(40.281)	(29.394)	(31.517)	(38.068)
N	7,617	1,841	4,917	4,284	1,045	2,843	3,333	796	2,074

Data are 2004 through 2009. “Before” is prior to the second quarter of 2007, “After” is following the fourth quarter of 2007, “Mid” is all other time periods. The fourth through sixth columns are restricted to mines for which the inspecting office increased inspections per quarter by .070 or more in 2008-2009 compared to the prior two years (0 for underground mines). The seventh through ninth columns are restricted to all other mines

i.e., treated mines were those that idiosyncratically had high accident rates prior to the 100 Percent Plan and the observed reduction is only regression to the mean. We find this unlikely as the patterns in Fig. 4 are inconsistent with this, and furthermore treated mines have larger labor forces (as seen in Table 1), thus it would be expected for them to have higher accident rates.

Possible selection concerns and implications on estimated effects are discussed in "Selection". Furthermore, a kink reflects a change in behavior over time, whereas a jump reflects a one-time change in behavior.

The announcement of the 100 Percent Plan does not cause a discontinuous change in accidents per quarter, but rather a kink. The lack of a discontinuous jump is not surprising, safety levels certainly have persistence. Discontinuous jumps would be a red flag that there may be changes in reporting methods or definitions of accidents. Because the change is smooth, it is assumed to be a result of mines improving safety.

This treatment approach divides mines based on the ex post behavior of the local inspecting office. We also performed analysis using an ex ante approach of whether a mine would anticipate more inspections than it had been receiving once the 100 Percent Plan was implemented, i.e., treatment is defined based on the difference between the ex ante inspection rate at a local office and the mandated inspection rate. Mines that had been inspected infrequently would expect more inspections than those that were already inspected often. Using this alternative treatment approach, mines are "treated" if the local office had not been inspecting frequently ex ante. We divide mines into quartiles as with the baseline treatment approach. We describe in "Results" that mines responded more strongly to actual changes in inspection frequency compared to expected changes, implying the response was to the realized inspection rates rather than expectations of such.

Methodology

Estimation uses the data for the time period 2004–2009 to estimate:

$$Acc_{it} = \beta_1 Cite_{it} + \beta_2 P_{it} + \beta_3 t + \beta_4 \tau_{1t} Cite_{it} + \beta_5 \tau_{2t} P_{it} + \alpha_i + \alpha_{\mathbb{T}} + \Gamma X_{it} + \varepsilon_{it}.$$

The outcome, Acc_{it}, is the number of accidents in the mine-quarter. The variable $Cite_{it}$ is an indicator for being later than the first quarter of 2007 but before 2008, P_{it} is an indicator for being in 2008 or later. The citation policy began in the quarter following the announcement (namely, the second quarter of 2007), and the 100 Percent Plan began with its announcement, however presumably mines had not yet reacted to the increased threat and a response would be observed in the following quarter (the first quarter of 2008). In the equation, t is centered such that the second quarter of 2007, the implementation of citation increases, is 0, τ_{1t} denotes time measured in years such that the first quarter of 2007 is 0, and τ_{2t} denotes time such that the fourth quarter of 2007 is 0.[10] Relevant coefficients estimate the change in the time trend that occurred between the policies, and after the 100 Percent Plan, respectively. Visually from Figs. 1, 4, and 5, it appears that higher order polynomials for time

[10] That is, fractional values can be realized, e.g., 0.25 denotes one quarter after the time period representing 0.

trends are unnecessary. The term α_i denotes a mine fixed effect and $\alpha_{\mathbb{T}}$ denotes quarter fixed effects to account for seasonality. Γ is a vector of coefficients for X_{it}, a controls vector.[11] This model simultaneously estimates jumps and kinks compared to the pre-policy time period for each policy change. The estimated effect of the citation policy change is insignificant and treated as a null effect. Analysis thus estimates the changes compared to the pre-trend caused by the 100 Percent Plan.

Charles et al. (2021) hypothesized two opposing effects of commodity prices - one in which price increases offset the financial burden of safety improvements, and another in which they increase the opportunity costs of focusing on safety over production. In unreported regressions, we included commodity prices as reported annually by the Energy Information Administration and United States Geological Survey, but coefficients for price were nearly always insignificant. Commodity price data are not available at quarterly intervals for many commodities produced by these mines, many of which are not traded on exchanges where prices are publicly reported. Moreover, commodity spot prices may provide little information about the price mine operators receive because mines may deal in futures contracts or other long-term obligations. For these reasons, as well as general insignificance, we do not report these regressions.

The equation is estimated while limiting the sample of mines according to the quartile of the change of the local inspecting office's inspections per quarter from 2008-2009 compared to 2006-2007. If estimated effects of the 100 Percent Plan are due to correlation of the 100 Percent Plan with an unobserved change, or because the response is a lag response to citation increases, then treated and non-treated mines should exhibit similar estimated coefficients. If instead the 100 Percent Plan only affects Acc_{it} through the increase in inspections, it is expected to see larger effects among mines for which local inspecting offices had larger increases in inspecting rates. To support our approach, we also estimate the same model, but with violations as the dependent variable instead of accidents. Although useful for comparison, our primary outcome of interest is worker safety. Accidents are our dependent variable of interest.

A limitation of this analysis is that only local responses to threats of citations and inspections are estimated. For both treated and non-treated mines, responses to the citation rate increase are estimated at ex ante inspecting rates and citation levels. For treated mines, the response to the increase in inspecting rates is estimated at given levels of inspecting rates and with the increased citation levels. It is difficult to draw conclusions about global responses, and only local effects are discussed.

[11] The vector X_{it} includes three lags of linear terms for regular inspections, compliance follow-up inspections, and other inspections, and third-degree polynomials for each of: three lags of the number of hours of non-regular inspections, three lags of the number of hours of regular inspections, employment in logs, and employment in levels.

Robustness

It is not assumed accidents are auto-correlated, however including lag accidents on the right side is a possible modeling choice. Doing so would raise an issue in the context of a fixed-effects estimator with a lagged dependent variable. Nickell (1981) shows that there is bias on the lagged dependent variable of order $\frac{1}{T}$. Other regressors will have coefficients that are biased as well. In appendix tables, the lag of accidents is included in the model, which is estimated with OLS as well as a systems GMM Blundell-Bond estimator (1998). Trends in coefficients of interest are unchanged.[12]

There is a judgment call regarding the bandwidth of time for which the post-100 Percent Plan linear trend is estimated. Primary analysis uses the bandwidth of the first quarter of 2008 through the fourth quarter of 2009. Time bandwidths contracting and expanding the final time period by 1 to 4 quarters were used to confirm results are representative, with implications on conclusions discussed in the results section.

Mines were geographically selected into treatment due to the behavior of local inspecting offices. In a similar vein, Table 1 indicates that treated mines had almost 50% more accidents per quarter prior to the policy changes. This selection issue is a distraction, however not a major concern. Fixed effects capture time-invariant determinants of selection. The empirical approach is to estimate whether there is a break in any pre-existing differences in the level or trend of outcomes around the time of the law's passage, resulting in an estimated local effect for the treated mines.

Robustness checks restrict analysis to subsamples for which treated and non-treated mines were more similar ex ante, both geographically and in terms of other observables. It will be shown that treatment was in large part determined by inspecting offices increasing their employment of inspectors. In another robustness check, staffing increases are used as an instrument for treatment. Furthermore, if understaffing and selection occurred at random, selection does not influence results. If selection was not random, then estimated treatment effects are a local treatment effect that is possibly not representative of an average treatment effect. Section "Selection" discusses how selection could influence the interpretation of estimates.

Assumptions

Leaving the selection issue aside for the moment, the critical assumptions of analysis are: (1) any improvements in safety in response to changes in citation amounts, and changes in inspecting rates, occurred immediately following implementation of the two policies and (2) no other factors contemporaneously occurred which induced mines to improve safety.

[12] Blundell-Bond estimates were computed using the xtdpdsys command in Stata using the one-step estimator that does not weight for cross correlations in residuals. Variables for lags of other inspections and lags of compliance follow-up inspections are assumed to be predetermined variables. No restrictions are imposed on the number of lags used for moments.

The public passage of the MINER Act, and the public announcement in September 2006 proposing new criteria for citations, justify the claim that impending policy changes to citation amounts were public information. Following public hearings regarding the proposal, the change in policy was announced in March 2007, a full month prior to taking effect. With this, the change in citation amounts was anticipated. Mines were, presumably, able to prepare any adjustments prior to the rule change or in immediate response to it. The announcement of the 100 Percent Plan in October, 2007 was a public announcement to which mines could immediately adjust safety. This assumption of immediate responses is critical in estimating effects of the two policies because they occurred in quick succession.

Results indicate a null effect of the increase in citations, and a reduction in accidents caused by the 100 Percent Plan. This reduction in accidents is only exhibited by mines which experienced larger increases in inspecting rates, justifying the assumption that the reduction in accidents is not caused by other factors.

Results

Table 2 shows estimates for the effects of the increase in average citations and the 100 Percent Plan on accidents per quarter. Discussion begins with surface mines. Column 1 restricts to mines for which the local office was in the top quartile of the change in inspections from 2008-2009 compared to 2006-2007 (.114 or higher). The only significant coefficient is the change in the time trend following the announcement of the 100 percent plan, representing a decline in accidents per quarter of .099 with each year. This suggests that mines increased safety under the threat of inspections at the heightened citation rate levels, however did not improve safety under the threat of increased citation rates at the ex ante, lower, inspection rates. These results support the hypothesized mechanism of a threat effect, however do not rule out the story of a corrective response to more frequently identified violations. These estimates are only of local, not global, responses. Column 2 restricts to mines for which the local office was in the second quartile of the change in inspections (between .070 and .114). Again only the linear term for the change in the time trend following the 100 Percent Plan is significant, however of smaller value, −.044. Column 3 pools all treated mines, with a coefficient of −.073 for the change in the time trend caused by the 100 Percent Plan, and no other significant coefficients.

Column 4 restricts to mines for which the local office was below the median (.070) of changes in inspections. The pre-trend prior to the policy changes is significant, of value −.021. The change in the trend with the 100 Percent Plan is −.003 and insignificant. Insignificance remains even when splitting by mines for which the local office is in the bottom quartile (below .021) and the second lowest quartile (between .021 and .070) for the change in inspections.

Estimates regarding underground mines follow this pattern. When restricted to mines for which the local office was in the top quartile for the change in inspections (above .042), there is a change in the linear trend caused by the 100 Percent Plan. The coefficient estimate is −.376 and significant at the 10 percent level. For this specification there is a negative coefficient for the discontinuous jump caused

Table 2 Threat effect analysis: increases in citation amounts and inspections

	Accidents					
Percentile restriction	[75,100]	[50,75)	[50,100]	[0,50)	[25,50)	[0,25)
Panel A	Surface mines					
Time	− 0.001	0.009	0.005	− 0.021***	− 0.030***	− 0.013
	(0.011)	(0.011)	(0.008)	(0.006)	(0.007)	(0.009)
Time*Between policies	0.002	− 0.158	− 0.088	0.085*	0.069	0.095
	(0.060)	(0.097)	(0.058)	(0.045)	(0.053)	(0.072)
Time*Post 100 percent	− 0.099***	− 0.044**	− 0.073***	− 0.003	0.013	− 0.019
	(0.036)	(0.020)	(0.020)	(0.014)	(0.018)	(0.020)
Between policies	− 0.054	0.055	0.005	− 0.012	− 0.010	− 0.010
	(0.039)	(0.054)	(0.034)	(0.025)	(0.030)	(0.040)
Post 100 percent plan	0.009	− 0.031	− 0.015	0.039**	0.038	0.036
	(0.047)	(0.031)	(0.030)	(0.019)	(0.024)	(0.030)
N	22,056	22,698	44,754	42,063	21,000	21,063
Clusters	1,596	1,716	3,312	3,170	1,489	1,681
Panel B	Underground mines					
Time	0.064	− 0.076	− 0.023	− 0.084	− 0.000	− 0.127
	(0.109)	(0.068)	(0.056)	(0.066)	(0.067)	(0.090)
Time*Between policies	0.863	− 0.125	0.405	− 0.451	0.190	− 0.825
	(0.668)	(0.449)	(0.388)	(0.352)	(0.379)	(0.523)
Time*Post 100 percent	− 0.376*	− 0.271*	− 0.296**	0.012	0.007	0.014
	(0.218)	(0.142)	(0.120)	(0.124)	(0.168)	(0.154)
Between policies	− 0.485	0.081	− 0.211	0.354*	− 0.222	0.695**
	(0.428)	(0.282)	(0.249)	(0.193)	(0.208)	(0.284)
Post 100 percent plan	− 0.525*	0.159	− 0.128	0.028	− 0.341*	0.195
	(0.298)	(0.183)	(0.164)	(0.158)	(0.192)	(0.223)
N	2,961	3,789	6,750	4,883	1,894	2,989
Clusters	259	302	561	466	199	267

Restricted to 2004 to 2009. Columns are restricted to mines based on the percentile of the change in the main inspecting office's inspections per quarter in 2008-2009 compared to 2006-2007. Percentile restrictions are denoted in the column headings. Quartile breaks for surface mines are: .021, .070, and .114. Quartile breaks for underground mines are: −.008, 0, and .042. Unreported covariates described in the text. Standard errors clustered by mine-operator, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

by the 100 Percent plan, of value −.525, however significant only at the 10 percent level. This is treated as a null effect due to the analogous coefficient's insignificance when pooling treated mines, noting that this conservatively estimates the response of mines to the increase in inspections. Mines for which the local office is in the second quartile for the change in inspections (between 0 and .042) exhibit a smaller change in the linear trend caused by the 100 Percent Plan, −.271, again significant at the 10 percent level. When pooling treated mines, the coefficient for the change in the trend of accidents caused by the 100 Percent Plan is −.296, significant at the 5 percent level. No other coefficients are significantly different from 0. The aforementioned jump effect of the 100 Percent Plan is −.128 and insignificant. For non-treated mines, whether pooled or split by quartile (the break occurs at -.008), there are no significant responses to either policy. For the bottom quartile, there is a positive coefficient for the jump following the citation increase, .695. This is likely a freak-of-nature result caused by estimating the coefficient using only three observations for each mine.

Mines for which local inspecting offices increased the regular inspection rate by more than the median exhibited kinks in safety. The magnitude of the kink is greater for the subset of mines for which local offices were in the top quartile compared to the second quartile. It is posited that, locally, mines improve safety with increased inspecting rates; however do not respond to increases in average citations.

Regarding the division between surface and underground mines, it should be noted that coal mines are nearly evenly split between surface and underground mines, but mines producing metals and other minerals (metal/nonmetal mines) are nearly all surface mines. We estimated the same regressions, still separating underground and surface mines, however separating further by coal and metal/nonmetal mines. Results followed similar patterns. The difference in results between surface and underground mines holds when looking at coal and metal/nonmetal mines separately, thus addressing possible heterogeneous effects, selection bias, or Simpson's Paradox issues.

Overall Effect

Extrapolation is necessary to provide a point estimate of the overall effect of the 100 Percent Plan. The estimates presented in Table 2 assume the linear trend caused by the announcement of the 100 Percent plan lasted for two years.

Assuming linear trends caused by the 100 Percent Plan lasted for two years, estimates for the overall changes in accidents per quarter caused by the 100 Percent Plan are $2^{*}(-.073) = -.146$ for treated surface mines, and $2^{*}(-.296) = -.592$ for treated underground mines. By comparing these estimates with average accidents per quarter between policy changes (.348 and 2.729 respectively as shown in the fifth column of Table 1), the effects were improvements in safety of roughly 42.0% and 21.7% respectively. By inspection of Fig. 4, these estimates appear representative. Table 1 shows that average quarterly regular inspections increased by .140 and .096 for treated surface and underground mines respectively from between-policy levels of .343 and .881 to the time period after the announcement of the 100 Percent Plan (increases of 40.8% and 10.9% respectively). This implies massive safety responses to a small increase in inspecting rates.

When estimating the same model as in Table 2 except with violations as the dependent variable, we find a substantial increase in violations after the 100 Percent Plan was implemented. Results are in Table 3. This is expected. Increased inspections should result in more violations being identified. It also vindicates the 100

Table 3 Threat effect analysis: increases in violations

	Violations					
Percentile restriction	[75,100]	[50,75)	[50,100]	[0,50)	[25,50)	[0,25)
Panel A	Surface mines					
Time	0.030	0.096*	0.043	0.012	0.016	− 0.054
	(0.063)	(0.054)	(0.039)	(0.067)	(0.039)	(0.112)
Time*Between policies	1.593**	0.490	0.950**	1.296***	1.034***	1.381***
	(0.660)	(0.442)	(0.370)	(0.273)	(0.341)	(0.441)
Time*Post 100 percent	− 0.136	0.298*	0.094	0.171*	0.333***	0.099
	(0.137)	(0.167)	(0.112)	(0.096)	(0.101)	(0.151)
Between policies	− 1.000***	− 0.568**	− 0.714***	− 0.557***	− 0.680***	− 0.284
	(0.315)	(0.232)	(0.181)	(0.171)	(0.212)	(0.242)
Post 100 percent plan	1.428***	0.189	0.866***	0.450***	0.171	0.805***
	(0.248)	(0.166)	(0.155)	(0.160)	(0.139)	(0.298)
N	21,626	20,809	42,435	44,400	22,660	21,740
Clusters	1,614	1,503	3,117	3,367	1,637	1,730
Panel B	Underground mines					
Time	2.505***	0.102	1.394**	0.753	1.289	0.106
	(0.803)	(0.745)	(0.570)	(0.687)	(0.783)	(1.146)
Time*Between policies	17.177**	6.858	12.706***	6.923*	8.324	5.225
	(6.934)	(5.337)	(4.342)	(3.637)	(6.015)	(4.398)
Time*Post 100 percent	− 6.385***	− 0.605	− 4.179***	− 1.240	− 3.754**	2.221
	(2.240)	(2.027)	(1.461)	(1.353)	(1.758)	(2.014)
Between policies	− 8.556**	− 2.260	− 5.746**	− 1.028	− 0.865	− 0.796
	(3.374)	(2.828)	(2.294)	(2.177)	(3.493)	(2.746)
Post 100 percent plan	7.224***	2.648	5.178***	4.068**	3.640	4.501*
	(2.123)	(1.686)	(1.436)	(2.033)	(2.949)	(2.658)
N	3,058	2,562	5,620	6,013	2,932	3,081
Clusters	252	184	436	591	265	326

Restricted to 2004 to 2009. Columns are restricted to mines based on the percentile of the change in the main inspecting office's inspections per quarter in 2008-2009 compared to 2006-2007. Percentile restrictions are denoted in the column headings. Quartile breaks for surface mines are: .021, .070, and .114. Quartile breaks for underground mines are: −.008, 0, and .042. Unreported covariates described in the text. Standard errors clustered by mine-operator, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Percent Plan. This is a useful complement to our analysis, but our focus is on workplace safety. For our purposes, accidents are the more meaningful outcome variable.

Table 4 presents estimates of the overall effect while extending and contracting the final time period of estimation by 1 to 4 quarters. This varies from 1 to 3 years the time period for which time trends are assumed to be affected by the 100 Percent Plan. Estimated overall effects for surface mines range from −.075 to −.160, and all

Table 4 Robustness of analysis of threat effects - time window

	2008 Q4	2009 Q1	2009 Q2	2009 Q3	2009 Q4	2010 Q1	2010 Q2	2010 Q3	2010 Q4
	Surface mines								
Time*Post 100 percent plan	– 0.075*	– 0.104***	– 0.089***	– 0.089***	– 0.073***	– 0.055***	– 0.055***	– 0.058***	– 0.052***
	(0.044)	(0.036)	(0.027)	(0.023)	(0.020)	(0.016)	(0.015)	(0.014)	(0.013)
Post 100 percent plan	– 0.017	0.000	– 0.007	– 0.007	– 0.015	– 0.034	– 0.033	– 0.027	– 0.027
	(0.037)	(0.034)	(0.032)	(0.031)	(0.030)	(0.030)	(0.029)	(0.027)	(0.026)
Estimated effect	–.075	–.130	–.134	–.156	–.146	–.124	–.138	–.160	–.156
	Underground mines								
Time*Post 100 percent plan	– 0.362	– 0.354**	– 0.380***	– 0.368***	– 0.296**	– 0.224**	– 0.217**	– 0.236**	– 0.225***
	(0.237)	(0.171)	(0.135)	(0.134)	(0.120)	(0.107)	(0.096)	(0.092)	(0.086)
Post 100 percent plan	– 0.160	– 0.103	– 0.071	– 0.077	– 0.128	– 0.174	– 0.161	– 0.151	– 0.165
	(0.198)	(0.188)	(0.175)	(0.166)	(0.164)	(0.160)	(0.168)	(0.165)	(0.165)
Estimated effect	–.362	–.443	–.570	–.644	–.592	–.504	–.543	–.649	–.675

Reported are point estimates for two coefficients from the specification in the third column of Table 2, estimated with the final time period of the sample period changed as denoted in the column heading. "Estimated Effect" is calculated by multiplying the Time*Post 100 Percent Plan coefficient by the number of years past the beginning of 2008 the time period covers, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

but the estimate with the shortest time window is greater or equal in absolute value than .124. For underground mines estimated effects range from −.362 to −.675, and all but the two estimates with the shortest time windows are greater or equal in absolute value than .504. This exercise shows qualitative results are not cherry-picked by the time period chosen to estimate the linear trend following the 100 Percent Plan. It is difficult to confirm rigorously for how long the time trend caused by the 100 Percent Plan lasted. For a variety of plausible time windows however, qualitative results are unchanged.

Table 6 reports OLS and Blundell-Bond systems GMM estimates when including lag accidents as a covariate. Qualitative implications are unchanged.

Charles et al. (2021) consider varying forms of accident severity in analysis. In unreported estimation we observed that treated mines, relative to untreated mines, reduce severity of accidents as measured by the average work days lost.

Cost-Benefit Analysis

Firms make their own judgments about costs and benefits of injuries and fatalities. They may not include everything that workers wish to have included. From a firm's perspective, workers' compensation costs, lost production, insurance premiums, criminal penalties, and civil liability are all potential costs. Workers and their families are most affected by earnings potential, actual earnings, and quality of life. To quantify the benefits and costs of the 100 Percent Plan we use estimates from previous literature. Miller and Galbraith (1995) estimate, using 1990 dollars, the costs of workplace accidents while accounting for direct medical bills, loss of home production, legal fees, lost work days, and quality of life.[13] The cost of a fatality at work is estimated as $2,500,000. The average cost of a workplace injury that results in at least one day lost of work is estimated as $46,000. The average cost of an injury in which no days are lost is estimated as $650. From 2004–2007, .43% of accidents in surface mines, and .49% in underground mines, resulted in fatalities. Respectively 39.16% and 41.00% resulted in at least one day lost of work. Estimates for the average cost of an accident are: .0043*($2.5 Million) + .3916*($46,000) + (.6041)*$650 = $29,156 for surface mines and (.0049)*($2.5 Million) + .4100*($46,000) + (.5851)*$650 = $31,490 for underground mines.

It is estimated that surface mines decreased average accidents per quarter by .146 due to the increase in inspections, a value saved of .146*$29,156 = $4,257 per quarter. For underground mines the estimate is .592*$31,490 = $18,642. Average inspections per quarter increased by .140 and .096 for surface and underground mines respectively. An estimate for the dollar cost of additional inspections was not available through a Freedom of Information Act request. If the cost of an additional inspection is less than $4,257/.140 = $30,407 for surface mines and $18,642/.096 = $194,188 for underground mines, measured in 1990 dollars, the policy provided

[13] We are unaware of more recent work that estimates the costs of accidents while incorporating heterogeneity by accident severity. Miller and Galbraith's estimates are calculated using publicly available data. For example, average medical costs of accidents are calculated using the National Council on Compensation Insurance and the value of lost work is estimated using data on Workers Compensation insurance.

a net positive return in social value and, at the margin, increasing inspections would provide positive returns.[14]

An alternative approach is to estimate the statistical value of a human life. Viscusi and Aldy (2003) surveyed the literature on the value of a statistical life (VSL) and report on numerous studies that estimate VSL. The median estimate in their survey was $7 million in 2000, or $11.12 million in 2021 dollars. The survey of Viscusi and Aldy showed most estimates of the statistical value of a nonfatal injury ranging from $20,000 to $70,000, with a median of $43,992 in 2000. In 2021 dollars, the range is from $31,775 to $111,214, with a median of $69,893. To estimate the cost of an accident, we use the lower end of the range as our estimate for a minor injury and the higher end for a serious nonfatal injury. For a surface mine, the estimated cost of an accident is 0.0043*($11.12 million) + 0.3916*$111,214 + 0.6041*$31,775 = $110,563. For underground mines, the estimated cost is 0.0049*($11.12 million) + 0.4100*$111,214 + 0.5851*$31,775 = $118,677.

Selection

It is claimed that the reduction in accidents of treated mines is a response to the increase in inspections. It is also claimed that mines did not respond to the increase in average citations. Selection may influence the interpretation of results.

Similar to the present work, there are many papers which estimate responses to laws for which treatment is not randomly assigned; two examples are the introduction of medicare in 1965 and the imposition of mandatory medical insurance by Massachusetts in 2006 (see for example Finkelstein 2007, Miller 2012a, 2012b, and Kolstad and Kowalski 2012). In such econometric settings, fixed effects capture time-invariant determinants of selection, and the timing and direction of estimated responses imply that effects are a response to the change in policy. Selection regarding the types of agents which are treated may cause quantitative conclusions to be a local effect that does not represent an average treatment effect because treatment response may be heterogeneous. In a "worst-case" scenario, estimated effects are an upper bound on average treatment effects (if treated agents are those with largest average responses). In a "best-case" scenario, estimated effects are a lower bound (if treated agents are those with smallest average responses).

First, the determinants of selection are exploited. Through the Freedom of Information Act, the number of inspectors employed by each office in each year is gathered. Let ℓ_{k0} denote average employment in office, k, in 2006 and 2007, and let ℓ_{k1} denote average employment in office k in 2008 and 2009. For each office, let ι_{k0} denote the average number of quarterly regular inspections per mine in 2006 and 2007 and N_{k0} the mandated average (across surface and underground). The *shortage* of inspectors, S_k, prior to the 100 Percent Plan is $\frac{\ell_{k0}}{\iota_{k0}}(N_{k0} - \iota_{k0})$. The *reduction* in the

[14] This analysis ignores potential costs of reduced productivity due to improved safety. Output is only observable for coal mines. Preliminary analysis replicated Table 2 using two measures of production as outcomes: (1) log of coal output, (2) the ratio of the log of coal production to log employment. Treated and non-treated mines exhibit similar trends, generally of null effects, although in some cases treated mines exhibited improvements in productivity relative to non-treated mines.

shortage, R_k, is $\ell_{k1} - \ell_{k0}$. Let D_{kw} denote the change in average inspecting rates for mines of type w by office k between 2006-2007 and 2008-2009 (the variable defining treatment) and let d_{kw} denote the average inspecting rate from 2006-2007. The following is estimated separately for $w \in$ {Underground, Surface}:

$$D_{kw} = \beta_0 + \beta_1 S_k + \beta_2 R_k + \beta_3 d_{kw} + \varepsilon_k.$$

Predicted values from these regressions represent the predicted increase in the inspecting rate driven by the initial shortage of inspectors, and the reduction in that shortage. Results are shown in Table 7. The reduction in the shortage is a strong predictor of the treatment variable, and the initial shortage is never predictive. This implies a major determinant of treatment was the increase in staffing of inspecting offices. The specifications of Table 2 are estimated again, however instead data are split by quartile of the predicted values of the previous regressions. Results are in Table 8. Qualitative results for surface mines are somewhat attenuated, however follow similar trends. For underground mines the reduction in accidents is only exhibited by mines in the top quartile of the newly defined treatment. This differs from main results (which show effects in the top two quartiles) however is not a major concern. The purpose of this exercise is to show that qualitative trends are unchanged when isolating variation in treatment caused by staffing, which plausibly only affect safety through the increase in inspecting rates.

It is also reasonable to think that staffing and inspecting decisions were initially made while prioritizing the most dangerous mines, or mines which would be most responsive. If this is the case, then the increase in staffing would have occurred at mines for which the response to inspections is smallest. The estimated local effect would be a lower bound on the average treatment effect. As stated previously, the worst-case scenario is that estimates are an upper bound on average treatment effects. Focus now turns toward limiting samples of treated and untreated mines to those which are more similar ex ante.

Treatment is defined by inspecting offices' changes in inspecting behavior. This results in geographic selection. The number of treated and non-treated mines are graphed at the county level in Appendix Figs. 7 and 8.

For surface mines, geographic selection shown in Fig. 7 is apparent. Western states, namely Wyoming, Colorado, Utah, Arizona, Nevada, Oregon, and Idaho, and states in the South (Viginia, West Virginia, Kentucky, and states geographically south of these states) hold high populations of treated mines and minimal non-treated mines. States in the Midwest: Ohio, Michigan, Illinois, Minnesota, Iowa, Missouri, Kansas, Oklahoma, Nebraska, South Dakota, and North Dakota, along with some New England states, contain large quantities of non-treated mines.

For underground mines, Fig. 8 implies there is minimal geographic selection. Most such mines are in the area of West Virginia, the west part of Virginia, and eastern Kentucky, with both treated and non-treated mines being prevalent.

Geographic selection is only a mild concern. Minerals mined and mining practices certainly differ depending on location. This will only bias conclusions if geographically determined factors affected safety, or if the elasticity of accidents with respect to inspections or penalties differs between treatment and control regions. Furthermore, geographic selection appears minimal with respect to underground mines, implying that geographic selection does not drive results. To address geographic selection directly, Table 2 is replicated, restricted to states which have at least one treated mine and one non-treated mine of the relevant type. Results are in Appendix Table 9. If anything, estimates are larger on this subsample of treated mines, and remain insignificant for non-treated mines.

A potential concern is that treated mines were those which had more unsafe practices initially. One possible story is that, because of this, operators of treated mines were able to reduce accidents in response to the threat of increased citations, or potentially in response to having received a citation. If non-treated mines had already reduced unsafe practices as much as they feasibly could, they would be unable to meaningfully respond to the threat of increased citations. Such circumstances would result in similar estimates to those presented, however result from a response to citation increases, rather than a response to increases in inspections.

The first point made is that the timing of the kink in accidents per quarter coincides with the increase in inspections, rather than the announced and expected increase in citation amounts. However, as a robustness check, estimation for non-treated mines is restricted to mines which were more accident-prone and had more employees prior to the policy changes. Such mines are more similar to treated mines ex ante, and also presumably would have been more capable of responding to the incentives of increased citations, should operators have chosen to respond to these incentives.

Specifically, the fourth column of Table 2 is replicated while restricting to non-treated mines that averaged positive accidents per quarter prior to the change in citation amounts. Results are presented in Table 10. Column 2 further restricts to mines with 5 or more observations prior to the policy change, and column 3 restricts to mines with 15 or more observations prior to the policy change. Columns 4–6 restrict to mines that had total hours worked above the median prior to the policy changes (medians are 5,891 and 15,333 for surface and underground mines respectively), again columns 5 and 6 restrict to mines with at least 5 and 15 observations in the pre-policy period. Estimated coefficients of interest follow the same trends as shown in the fourth column of Table 2. These subsamples of non-treated surface mines averaged .433, .431, .448, .375, .376, and .395 accidents per quarter respectively, in fact more than the sample of treated surface mines (see Table 1). Average hours worked for these subsamples was higher as well. For underground mines, the average accidents per quarter were: 1.958, 2.008, 2.362, 2.701, 2.780, and 2.994. While often still slightly lower than the rate in treated mines, these subsamples of non-treated mines were more similar to treated mines in propensity to have accidents. Similarly, hours worked are often higher among these subsamples compared to hours worked in treated mines. These subsamples of non-treated mines presumably had accident levels which could be corrected, if mine operators were incentivized to do so. It appears such mines did not respond to either policy, and this justifies that selection does not drive results.

We also use an alternative treatment definition, specifically defining treatment based on quartiles for the difference between the ex ante inspection rate of a local office and the mandated inspection rate, representing the expected increase in inspections due to the 100 Percent Plan. Results are slightly different but show similar trends. Safety in surface mines increased because of these policies, but it was more pronounced at the second quartile than at the first and slightly attenuated (coefficients for the change in the time trend due to the 100 Percent Plan were − 0.046 for the top quartile and − 0.068 for the second quartile). The effect on underground mines is concentrated in the top quartile of the new treatment (coefficients were − 0.473 for the top quartile and 0.073 for the second quartile).

Results are more pronounced and of the expected pattern across the top two quartiles when using treatment based on mines that were inspected more (baseline treatment approach) as opposed to those that would have expected it more (alternative treatment approach). Possibly, some of these expectations were not met as there are differences between the treatment groups. Intuitively, mines likely observed changes in inspection rates as the 100 Percent Plan was implemented, and updated any expectations they had. As the safety improvements took time, mines likely responded to their updated beliefs regarding inspections.

An alternative explanation is that mine operators had some subjective idea that they would or would not be inspected more even after the policy was announced (e.g., mine operators may know if the local office would not implement the 100 Percent Plan). The differences in results between these two approaches show that actual inspections, not the announced threat of inspections, is more strongly correlated with compliance. Increasing fine amounts may do little in this regard given that mines act based on enforcement, and this is very different from an announced change.

Conclusion

It has been documented that mines significantly reduced accidents in response to increased inspections, however did not reduce accidents under the threat of increased penalties. It is suggested that the response to increased inspections is driven by the threat effect, while the lack of a response to citation penalties may result from penalties acting as "payment" for the right to commit a violation. At present levels, penalties are possibly not high enough to deter violations. We again acknowledge that increased inspections resulted in greater rates of identifying violations. This may have induced a corrective effect that is a component of our estimates.

An effort was made to address the possible selection issue. Despite this effort, one may wonder if selection drives results. If so, this does not invalidate the findings of this paper, however would indicate that the results only apply to the subset of the population which responds to threat effects, or the subset of a population which is most prone to commit violations. In most applications of threat effects, these are certainly large populations of interest. Regardless, the estimated local effect is at least an upper bound on the average treatment effect. If staffing decisions are made while prioritizing the most dangerous mines, then it is reasonable to believe that estimates are a lower bound.

Estimates are only of local responses to inspections and citation penalties. Despite this limitation, the results from this paper may allow for a better understanding of methods of regulation enforcement in other contexts such as environmental regulation and minimum wage compliance. This paper suggests that the strongest improvements in compliance result from responses to threats of monitoring and inspections.

Appendix

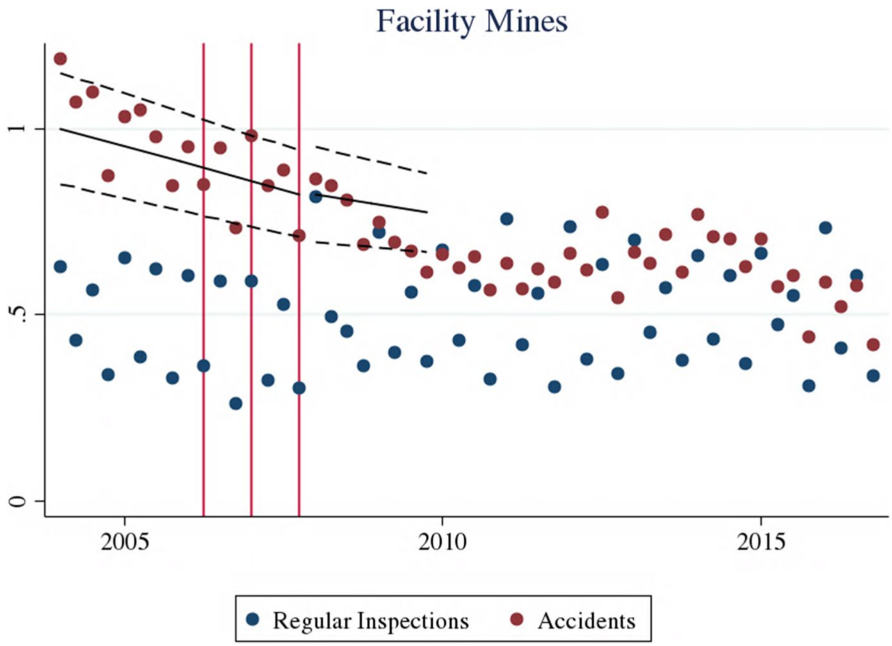

Fig. 6 Time trends in accidents and inspections: facility mines. Notes: Identical to Fig. 1 from the text, however restricted to mining facilities

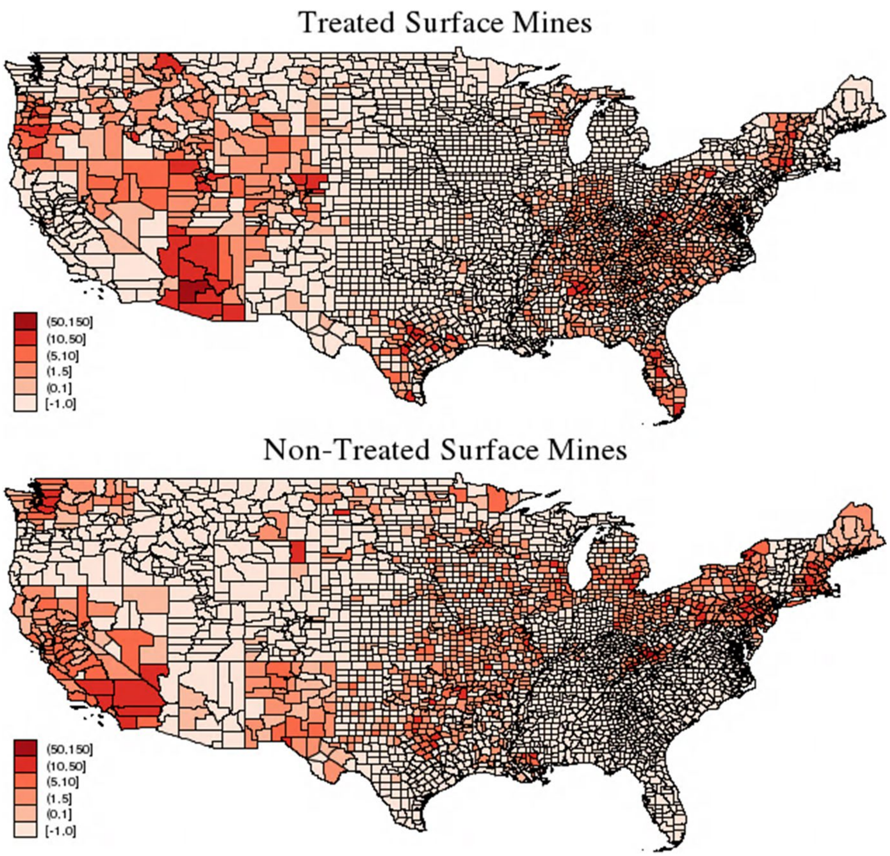

Fig. 7 Parts of the CFR violated. Notes: treatment is defined in the text. Plotted are the number of treated and non-treated mines at the county level

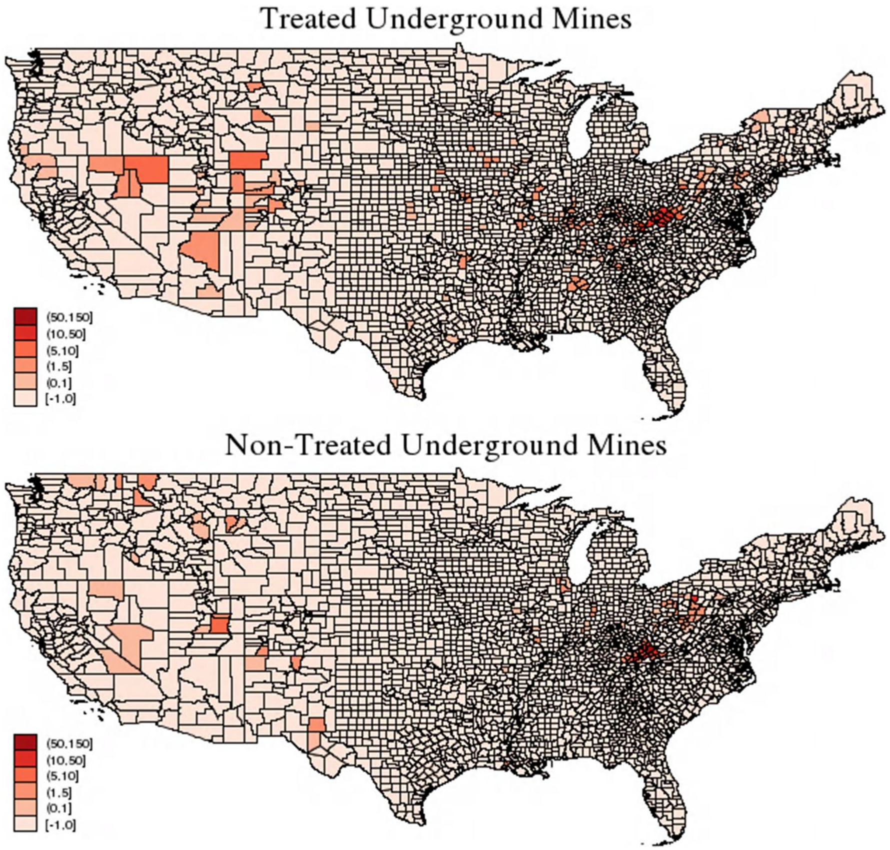

Fig. 8 Geographic selection into treatment: underground mines. Notes: treatment is defined in the text. Plotted are the number of treated and non-treated mines at the county level

Table 5 Parts of the CFR violated

Part	Name	N
40	Representative of miners	29
41	Notification of legal identity	1,406
44	Rules of practice for petitions for modification of mandatory safety standards	13
45	Independent contractors	366
46	Training and retraining of miners engaged in shell dredging...	8,766
47	Hazard communication	7,978
48	Training and retraining of miners	4,210
49	Mine rescue teams	342
50	Notification, investigation, reports, and records of accidents... and coal production	12,125
56	Safety and health standards - surface metal and nonmetal mines	279,480
57	Safety and health standards - underground metal and nonmetal mines	28,793
58	Health standards for metal and nonmetal mines	125
62	Occupational noise exposure	5,387
70	Mandatory health standards - underground coal mines	1,715
71	Mandatory health standards- surface areas of underground coal mines	1,576
72	Health standards for coal mines	3,704
75	Mandatory safety standards - underground coal mines	338,924
77	Mandatory safety standards- surface areas of underground coal mines	95,381
90	Mandatory health standards - coal miners who have evidence of... pneumoconiosis	47

Parts of Title 30 of the CFR Chapter I which are violated from 2004–2009

Table 6 Threat effect analysis with lag accidents

	Treated mines		Non-treated mines	
	OLS	Blundell Bond	OLS	Blundell Bond
Panel A	Surface mines			
Time	0.004	0.036***	− 0.020***	− 0.036***
	(0.007)	(0.008)	(0.006)	(0.006)
Time*Between policies	− 0.071	− 0.082	0.080*	0.041
	(0.057)	(0.057)	(0.044)	(0.044)
Time*Post 100 percent	− 0.060***	− 0.137***	− 0.001	− 0.039***
	(0.018)	(0.018)	(0.014)	(0.014)
Acc_{it-1}	0.138***	0.134***	0.070***	0.095***
	(0.031)	(0.005)	(0.021)	(0.005)
N	44,754	44,754	42,063	42,063
Clusters	3,312	3,312	3,170	3,170
Panel B	Underground mines			
Time	− 0.024	− 0.036	− 0.091	− 0.192***
	(0.051)	(0.059)	(0.059)	(0.056)
Time*Between policies	0.477	0.242	− 0.472	− 0.364
	(0.384)	(0.418)	(0.345)	(0.364)
Time*Post 100 percent	− 0.232**	− 0.245**	0.049	0.107
	(0.105)	(0.116)	(0.111)	(0.112)
Acc_{it-1}	0.125***	0.137***	0.131***	0.173***
	(0.033)	(0.012)	(0.026)	(0.014)
N	6,750	6,750	4,883	4,883
Clusters	561	561	466	466

The left, and right, two columns are respectively the specifications of columns 3 and 4 of Table 2, with the inclusion of lag accidents. Post variables are not reported only to save space. For Blundell-Bond, all three lags of compliance follow-up inspections and other inspections are treated as predetermined

Table 7 Determinants of selection into treatment

	Change in inspecting rate	
	Surface	Underground
Reduction in shortage	0.007**	0.010***
	(0.003)	(0.003)
Shortage of inspectors	− 0.003	0.007
	(0.003)	(0.008)
N	88	79
R-squared	0.487	0.447

Each observation is an inspecting office. The outcome variable is the change in inspections per quarter of mines of the relevant type from 2008-2009 compared to 2006-2007 (the variable defining treatment in Table 2). Independent variables are estimates for the number of inspectors needed to reach mandated targets in 2006-2007 and the reduction in this shortage by 2008-2009 (described in the text). Regressions include a linear term for average inspecting rates from 2006-2007. Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 8 Threat effect results using staffing-predicted treatment

	Accidents					
Percentile restriction	[75,100]	[50,75)	[50,100]	[0,50)	[25,50)	[0,25)
Panel A	Surface mines					
Time	− 0.004	0.014	0.002	− 0.019***	− 0.024***	− 0.018
	(0.009)	(0.012)	(0.008)	(0.006)	(0.007)	(0.012)
Time*Between policies	− 0.019	− 0.059	− 0.034	0.032	− 0.013	0.039
	(0.052)	(0.068)	(0.042)	(0.061)	(0.061)	(0.118)
Time*Post 100 percent	− 0.057***	− 0.052**	− 0.051***	− 0.024	− 0.013	− 0.022
	(0.019)	(0.026)	(0.015)	(0.017)	(0.018)	(0.027)
Between policies	− 0.029	− 0.009	− 0.021	0.012	0.038	0.014
	(0.033)	(0.044)	(0.028)	(0.033)	(0.037)	(0.059)
Post 100 percent plan	− 0.008	− 0.006	− 0.009	0.035	0.038*	0.030
	(0.028)	(0.032)	(0.022)	(0.027)	(0.021)	(0.054)
N	22,555	19,479	42,034	44,783	25,557	19,226
Clusters	1,647	1,473	3,120	3,362	1,898	1,464
Panel B	Underground mines					
Time	0.090	− 0.105	0.002	− 0.104	− 0.135	− 0.070
	(0.093)	(0.076)	(0.062)	(0.064)	(0.102)	(0.079)
Time*Between policies	0.812	0.375	0.573	− 0.586	− 0.259	− 0.770
	(0.588)	(0.512)	(0.356)	(0.406)	(0.645)	(0.509)
Time*Post 100 percent	− 0.539**	− 0.047	− 0.327**	− 0.070	0.064	− 0.175
	(0.222)	(0.146)	(0.137)	(0.112)	(0.178)	(0.131)
Between policies	− 0.651**	− 0.264	− 0.434*	0.542**	0.281	0.726**
	(0.308)	(0.329)	(0.224)	(0.234)	(0.304)	(0.328)
Post 100 percent plan	− 0.488	− 0.175	− 0.348**	0.210	0.175	0.246
	(0.321)	(0.172)	(0.172)	(0.168)	(0.248)	(0.210)
N	2,804	3,392	6,196	5,437	2,242	3,195
Clusters	241	324	565	462	204	258

Identical to Table 2, however split by quartiles of predicted values from regressions of Table 7

Table 9 Threat effect results limiting geographic selection

	Accidents					
Percentile restriction	[75,100]	[50,75)	[50,100]	[0,50)	[25,50)	[0,25)
Panel A	Surface mines					
Time	0.011	0.014	0.015	– 0.021***	– 0.032***	-0.012
	(0.020)	(0.012)	(0.010)	(0.006)	(0.008)	(0.010)
Time*Between policies	– 0.046	– 0.123	– 0.099	0.096**	0.089	0.095
	(0.105)	(0.111)	(0.081)	(0.048)	(0.057)	(0.076)
Time*Post 100 percent	– 0.197***	– 0.046**	– 0.101***	– 0.007	0.013	– 0.027
	(0.058)	(0.021)	(0.026)	(0.016)	(0.020)	(0.022)
Between policies	– 0.080	0.028	– 0.011	– 0.020	– 0.022	– 0.015
	(0.070)	(0.059)	(0.046)	(0.027)	(0.032)	(0.042)
Post 100 percent plan	0.032	– 0.040	– 0.019	0.041**	0.039	0.039
	(0.095)	(0.035)	(0.046)	(0.021)	(0.026)	(0.032)
N	10,272	18,146	28,418	38,408	18,674	19,734
Clusters	784	1,340	2,124	2,905	1,332	1,573
Panel B	Underground mines					
Time	0.061	– 0.159*	– 0.053	– 0.135*	– 0.034	– 0.204**
	(0.128)	(0.084)	(0.074)	(0.072)	(0.081)	(0.097)
Time*Between policies	0.777	0.052	0.569	– 0.244	0.362	– 0.595
	(0.762)	(0.560)	(0.487)	(0.360)	(0.387)	(0.545)
Time*Post 100 percent	– 0.534**	– 0.357**	– 0.446***	0.186	0.088	0.254*
	(0.265)	(0.181)	(0.162)	(0.129)	(0.187)	(0.152)
Between policies	– 0.394	– 0.049	– 0.332	0.263	– 0.253	0.620**
	(0.486)	(0.402)	(0.324)	(0.200)	(0.198)	(0.306)
Post 100 percent plan	– 0.500	0.204	– 0.177	– 0.056	– 0.270	0.084
	(0.325)	(0.255)	(0.210)	(0.169)	(0.198)	(0.246)
N	2,592	2,439	5,031	4,279	1,770	2,509
Clusters	239	211	450	424	191	233

Identical to Table 2, restricted to states with at least 1 treated mine and 1 non-treated mine. For surface mines **excluded** states are: Alaska, Alabama, Delaware, Florida, Georgia, Hawaii, Iowa, Maine, North Carolina, Nebraska, New Hampshire, New Jersey, Oregon, Rhode Island, South Carolina, Utah, and Vermont. For underground mines **included** states are Arkansas, California, Colorado, Illinois, Indiana, Kentucky, Maryland, Montana, Nevada, Pennsylvania, Texas, Utah, Virginia, and West Virginia

Table 10 Threat effects for non-treated mines: limited sample analysis

	Accidents					
Panel A	Surface mines					
Time*Between policies	0.131**	0.131**	0.098	0.115**	0.115**	0.089
	(0.065)	(0.065)	(0.064)	(0.058)	(0.058)	(0.058)
Time*Post 100 percent plan	– 0.003	– 0.001	– 0.007	– 0.002	– 0.001	– 0.005
	(0.020)	(0.020)	(0.021)	(0.018)	(0.018)	(0.019)
Between policies	– 0.041	– 0.040	– 0.027	– 0.015	– 0.014	– 0.006
	(0.036)	(0.036)	(0.037)	(0.032)	(0.032)	(0.033)
Post 100 percent plan	0.029	0.029	0.028	0.052**	0.052**	0.050*
	(0.028)	(0.028)	(0.029)	(0.025)	(0.025)	(0.026)
N	28,749	28,542	26,137	31,556	31,193	28,542
Clusters	1,959	1,887	1,588	2,119	1,997	1,677
Pre-period outcome mean	0.433	0.431	0.448	0.375	0.376	0.395
Pre-period mean employment	18,907	18,910	20,130	19,291	19,356	20,377
Panel B	Underground mines					
Time*Between policies	– 0.496	– 0.497	– 0.593	– 0.712	– 0.689	– 0.819
	(0.384)	(0.385)	(0.428)	(0.523)	(0.525)	(0.551)
Time*Post 100 percent plan	0.003	– 0.009	– 0.001	– 0.059	– 0.070	– 0.045
	(0.137)	(0.137)	(0.148)	(0.177)	(0.178)	(0.188)
Between policies	0.385*	0.374*	0.483**	0.489*	0.465*	0.593**
	(0.210)	(0.210)	(0.236)	(0.279)	(0.280)	(0.297)
Post 100 percent plan	0.011	0.001	– 0.007	0.040	0.029	0.025
	(0.169)	(0.169)	(0.191)	(0.235)	(0.235)	(0.251)
N	4,488	4,383	3,507	3,238	3,161	2,733
Clusters	412	368	256	296	265	212
Pre-period outcome mean	1.958	2.008	2.362	2.701	2.780	2.994
Pre-period mean employment	43,568	45,068	57,839	61,271	63,397	73,996

Identical to the fourth column of Table 2 with restrictions on the sample. Coefficients for the general time trend are excluded for brevity. The first three columns restrict to mines with positive accidents prior to the policy changes, columns 4 through 6 restrict to mines with above median employment prior to the policy changes. Columns 2 and 5 also restrict to mines with more than 5 observations prior to the policy changes. Columns 3 and 6 instead restrict to mines with more than 15 observations prior to the policy changes

Funding There is no funding to declare.

Data Availability Data are publicly available.

Code Availability The authors are quite willing to provide replication code.

Declarations

Conflict of Interests The authors declare no conflicts.

References

Bartel AP, Thomas LG (1985) Direct and indirect effects of regulation: A new look at OSHA's impact. J Law Econ 28(1):1–25

Biddle JE, Zarkin GA (1988) Worker preference and market compensation for job risk. Rev Econ Stat, 70(4):660–667

Blundell W (2020) When threats become credible: A natural experiment of environmental enforcement from Florida. J Environ Econ Manag 101:102288

Blundell R, Bond S (1998) Initial conditions and moment restrictions in dynamic panel data models. J Econ 87(1):115–143

Blundell W, Gowrisankaran G, Langer A (2020) Escalation of scrutiny: The gains from dynamic enforcement of environmental regulations. Am Econ Rev 110(8):2558–85

Card D, Dobkin C, Maestas N (2009) Does medicare save lives?. Q J Econ 124(2):597–636

Charles K, Johnson M, Stephens M, Lee D (2021) Demand conditions and worker safety: Evidence of price shocks in mining. J Labor Econ, forthcoming

Cooke WN, Gautschi FH (1981) OSHA, plant safety programs, and injury reduction. Ind Relat: A J Econ Soc 20(3):245–257

Dechezleprêtre A, Sato M (2017) The impacts of environmental regulations on competitiveness. Rev Environ Econ Policy 11(2):183–206

Drakopoulos SA, Theodossiou I (2016) Workers' risk underestimation and occupational health and safety regulation. Eur J Law Econ 41(3):641–656

Dubin JA, Graetz MJ, Wilde LL (1990) The effect of audit rates on the federal individual income tax, 1977-1986. Nat Tax J, 43(4):395–409

Duflo E, Greenstone M, Pande R, Ryan N (2018) The value of regulatory discretion: Estimates from environmental inspections in India. Econometrica 86(6):2123–2160

Finkelstein A (2007) The aggregate effects of health insurance: Evidence from the introduction of Medicare. Q J Econ 122(1):1–37

Fishback PV, Kantor SE (1995) Did workers pay for the passage of workers' compensation laws?. Q J Econ 110(3):713–742

Gneezy U, Rustichini A (2000) A fine is a price. J Leg Stud 29(1):1–17

Gowrisankaran G, He C, Lutz EA, Burgess JL (2015) Productivity, safety, and regulation in underground coal mining: Evidence from disasters and fatalities (No. w21129). National Bureau of Economic Research

Gray WB, Jones CA (1991) Longitudinal patterns of compliance with occupational safety and health administration health and safety regulations in the manufacturing sector. J Hum Resour 26(4):623–653
Gray WB, Scholz JT (1993) Does regulatory enforcement work? a panel analysis of OSHA enforcement. Law and Society Review 27:177–213
Greenstone M, List JA, Syverson C (2012) The effects of environmental regulation on the competitiveness of US manufacturing (No. w18392). National Bureau of Economic Research
Hanna RN, Oliva P (2010) The impact of inspections on plant-level air emissions. The BE Journal of Economic Analysis & Policy 10(1):Article 19
Hansen B (2015) Punishment and deterrence: Evidence from drunk driving. Am Econ Rev 105(4):1581–1617
Haviland A, Burns R, Gray W, Ruder T, Mendeloff J (2010) What kinds of injuries do OSHA inspections prevent?. J Saf Res 41(4):339–345
Jones C (2016) Life and growth. J Polit Econ 124(2):539–578
Jung J, Makowsky MD (2014) The determinants of federal and state enforcement of workplace safety regulations: OSHA inspections 1990–2010. J Regul Econ 45(1):1–33
Kleven HJ, Knudsen MB, Kreiner CT, Pedersen S, Saez E (2011) Unwilling or unable to cheat? Evidence from a tax audit experiment in Denmark. Econometrica 79(3):651–692
Kniesner TJ, Leeth JD (2004) Data mining mining data: MSHA enforcement efforts, underground coal mine safety, and new health policy implications. Journal of Risk and Uncertainty 29(2):83–111
Kolstad JT, Kowalski AE (2012) The impact of health care reform on hospital and preventive care: evidence from Massachusetts. J Public Econ 96 (11-12):909–929
Li L (2020) Workplace safety and worker productivity: evidence from the MINER Act. ILR Review, forthcoming
Makofske MP (2019) Inspection regimes and regulatory compliance: How important is the element of surprise?. Econ Lett 177:30–34
Makofske MP (2020) Disclosure policies in inspection programs: The role of specific deterrence. Econ Lett 196:109533
McCaffrey DP (1983) An assessment of OSHA's recent effects on injury rates. J Human Res 18(1):131–146
Miller S (2012a) The effect of insurance on emergency room visits: an analysis of the 2006 Massachusetts health reform. J Public Econ 96(11-12):893–908
Miller S (2012b) The impact of the Massachusetts health care reform on health care use among children. Am Econ Rev 102(3):502–07
Miller TR, Galbraith M (1995) Estimating the costs of occupational injury in the United States. Accident Analysis & Prevention 27(6):741–747
Nickell S (1981) Biases in dynamic models with fixed effects. Econometrica: Journal of the Econometric Society 49(6):1417–1426
Pouliakas K, Theodossiou I (2013) The economics of health and safety at work: an interdiciplinary review of the theory and policy. J Econ Surv 27(1):167–208
Powell D (2012) Compensating differentials and income taxes are the wages of dangerous jobs more responsive to tax changes than the wages of safe jobs?. J Hum Resour 47(4):1023–1054
Powell D, Shan H (2012) Income taxes, compensating differentials, and occupational choice: How taxes distort the wage-amenity decision. American Econ J: Econ Policy 4(1):224–47
Robertson LS, Keeve JP (1983) Worker injuries: The effects of workers' compensation and OSHA inspections. J Health Polit, Policy Law 8 (3):581–597
Ruser JW, Smith RS (1991) Reestimating Osha's effects: have the data changed?. J Hum Resour 26(2):212–235
Scholz JT, Gray WB (1990) OSHA Enforcement and workplace injuries: a behavioral approach to risk assessment. J Risk Uncertain 3(3):283–305
Shapiro SA (1999) Occupational safety and health regulation. In: Bouckaert B, Geest GD (eds) Encyclopedia of Law and Economics, Edward Elgar Publishing and University of Ghent. Available at http://encyclo.findlaw.com (Last Accessed 28 January 2010)
Slemrod J, Blumenthal M, Christian C (2001) Taxpayer response to an increased probability of audit: evidence from a controlled experiment in Minnesota. J Pub Econ 79(3):455–483
Smith RS (1979) The impact of OSHA inspections on manufacturing injury rates. J Hum Resour 14(2):145–170

Stoker TM, Berndt ER, Ellerman AD, Schennach SM (2005) Panel data analysis of US coal productivity. J Econ 127(2):131–164

Telle K (2008) The threat of regulatory environmental inspection: impact on plant performance. J Regul Econ 35(2):154–178

Viscusi WK (1992) Fatal tradeoffs: Public and private responsibilities for risk. Oxford University Press, Oxford

Viscusi WK, Aldy JE (2003) The value of a statistical life: a critical review of market estimates throughout the world. J Risk Uncertain 27(1):5–76