Productivity, Safety, and Regulation in Underground Coal Mining: Evidence from Disasters and Fatalities

Gautam Gowrisankaran, Charles He, Eric A. Lutz, Jefferey L. Burgess

University of Arizona, HEC Montreal, and NBER

Amazon.com

University of Arizona

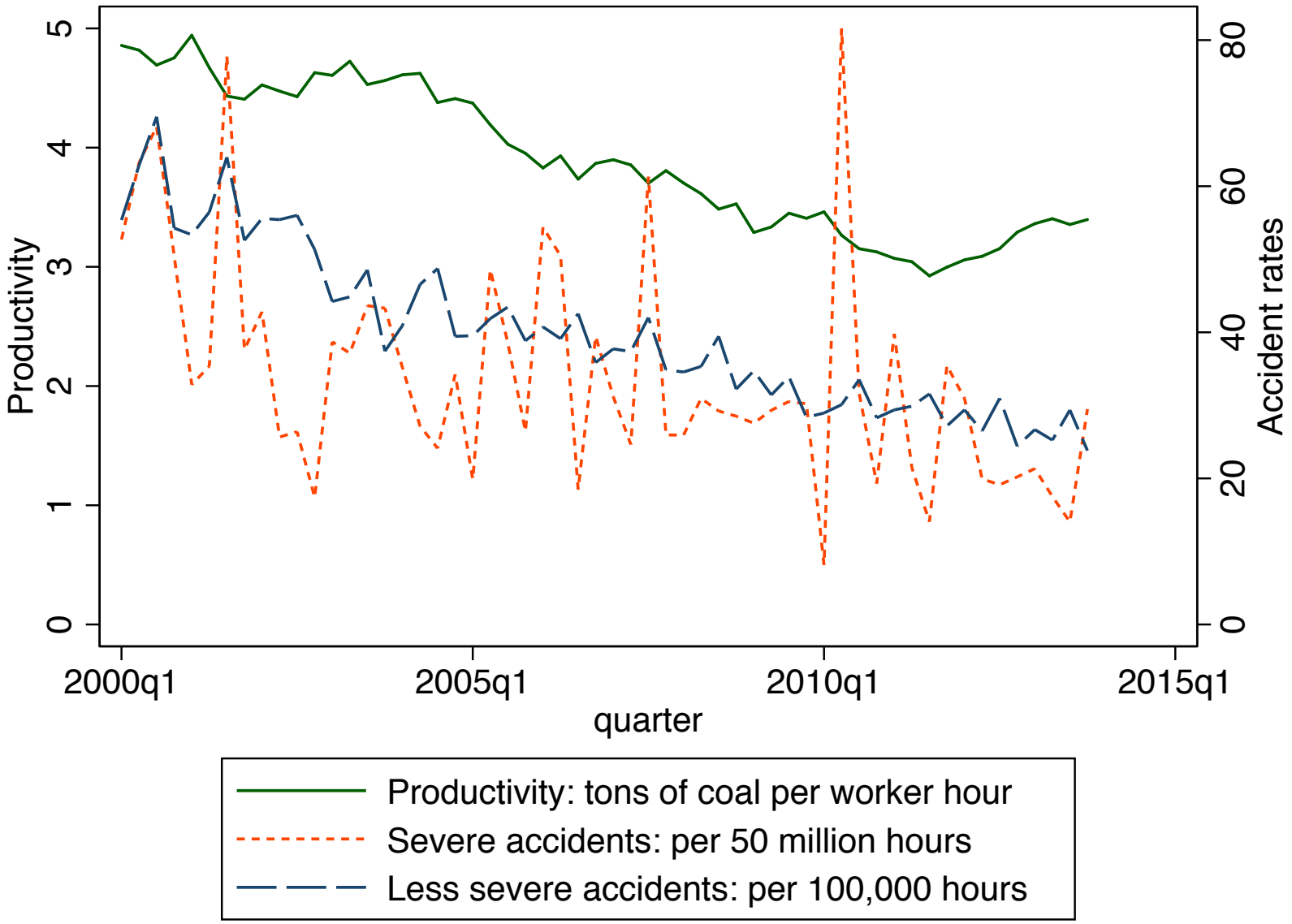
University of Arizona

August 7, 2017

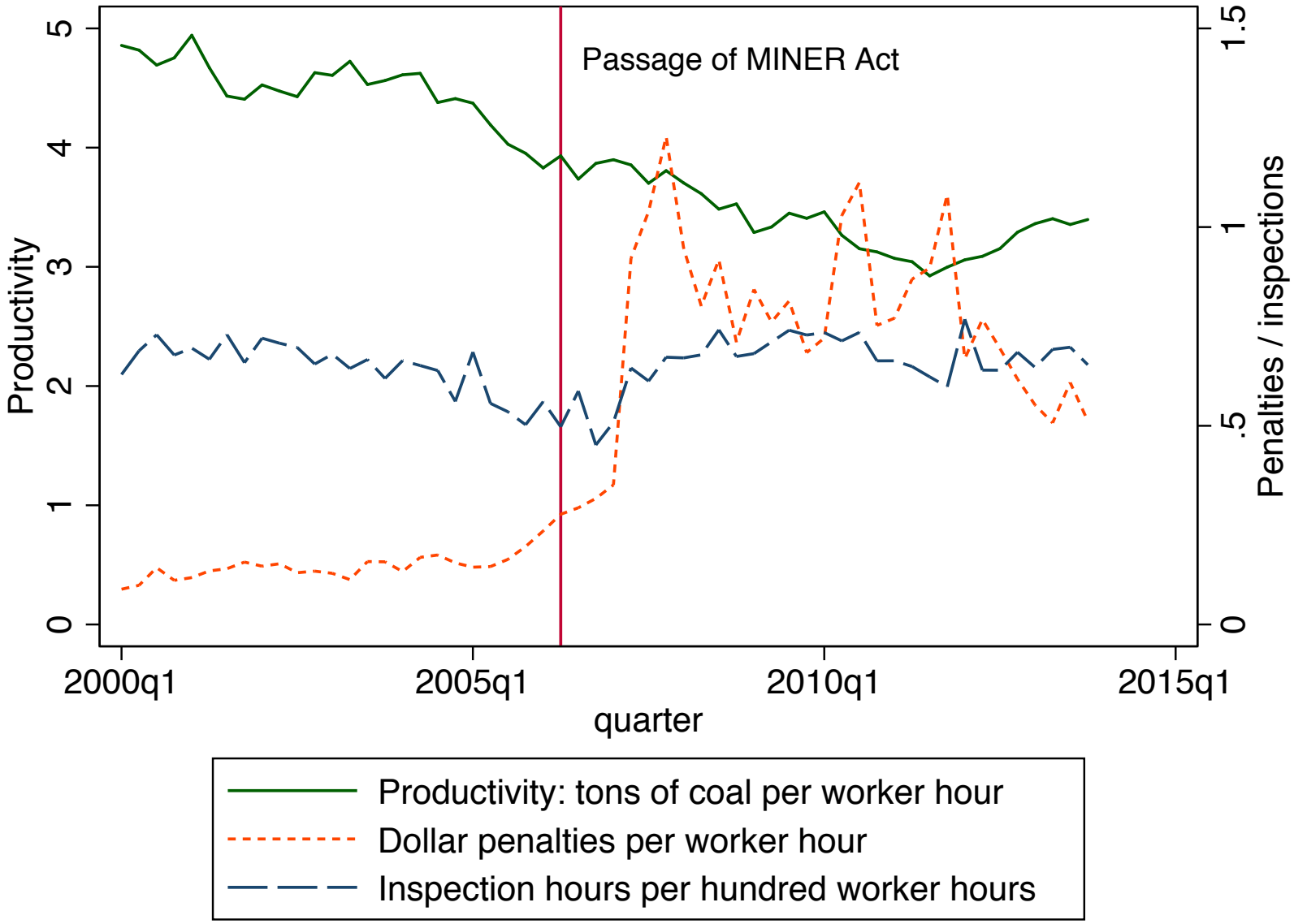
Introduction

- Over the past several decades, U.S. regulatory state overseeing worker safety has grown more complex
  - E.g., for coal mining, the Mine Safety and Health Administration (MSHA) and several related laws enacted
  - Creates complex structure which mines must follow
- Despite regulation, accidents still commonplace for underground coal mines
  - 295 fatalities between 2000 and 2014
- During this time period, coal mining productivity has declined
  - Regulations identified as a potential cause (Kuykendall and Qureshi, 2014)
- Productivity and safety both concerns for these mines
  - Underground coal mines produce both “coal” and “safety”
  - Regulatory state may impose tradeoffs between them

Productivity and safety at underground coal mines



Productivity and regulation at underground coal mines



Goals of paper

1. Does the regulatory state impose tradeoffs between productivity and safety?
   - What are the levels of the tradeoffs imposed by the regulatory state for underground coal mining?
2. How do events such as mine disasters affect these tradeoffs?
   - Provides insight into how regulatory state functions
3. To develop a new identification approach—of using shocks of accident costs—to understand tradeoffs imposed by regulation
   - Our identification approach may be applicable in other settings

Why should you care about our results?

- Wide-ranging policy debate in recent years about burden of the regulatory state
  - Greenstone et al. (2012): environmental regulations lower productivity 4.8 percent
  - Coffey et al. (2016): regulation lowers economic growth by 0.8 percentage points annually
  - Motivates recent EO by President Trump to limit regulations
- Does regulatory state impose safety levels that equalize marginal benefits with marginal costs of lost productivity?
- Underground coal mining is an important industry to consider
  - Sector employs over 45,000 workers in the U.S.
  - Safety is one of the most important regulatory goals here
- Study may also inform us about tradeoffs for other sectors
  - Many are at least as dangerous as underground coal mining
  - E.g., fishing, logging, and roofing

Worker safety rules likely to be weakened

The New York Times | https://nyti.ms/2mDf7QO

BUSINESS DAY

Worker Safety Rules Are Among Those Under Fire in Trump Era

By BARRY MEIER and DANIELLE IVORY MARCH 13, 2017

Even as the Labor Department awaits confirmation of a new secretary, officials say enforcement actions are moving forward against companies accused of violating workplace safety rules.

There is just one issue: The public isn't likely to know much about them.

In a sharp break with the past, the department has stopped publicizing fines against companies. As of Monday, seven weeks after the inauguration of President Trump, the department had yet to post a single news release about an enforcement fine.

West Virginia coal mine bill would curb safety regulations

By Kelly McCleary, CNN

Updated 2000 GMT (0400 HKT) March 15, 2017

Legislation would lower the number of times a mine inspector is required to examine facilities from four times a year to once.

Story highlights

West Virginia legislator wants to strip state investigators of their ability to conduct inspections

West Virginia led the nation in mining fatalities last year and has seen two deaths this year

(CNN) — A state senator in West Virginia wants to eliminate enforcement of state mining regulations, a move union officials say could set back miners' safety by decades.

Senate Bill 582 was introduced on Saturday by State Sen. Randy Smith. He proposes favoring federal standards over state standards on issues like mine ventilation, fire protection and accident investigations.

Idea of identification

- We use a novel identification strategy and detailed panel data
  - Panel data record location, coal production, hours worked, accidents, regulatory inspections, etc.
  - Still cannot credibly evaluate tradeoffs between safety and productivity with a regression of accidents on productivity
    - Both are choice variables of firms, resulting in endogeneity bias
    - I.e., firms with higher management quality may achieve fewer accidents and more productivity
    - Simple strategies, such as mine fixed effects, unlikely to work
- Our identification idea:
  - We use disasters (near a mine) and fatalities (at a mine) as quasi-random shifters
  - Idea: these events raise the cost of future accidents
  - Cause firms to make different choices
  - This allows us to understand tradeoffs faced by firms
- Formally, need:
  - Disasters and fatalities to raise cost of future accidents
  - Disaster/fatality is mean independent from unobservables

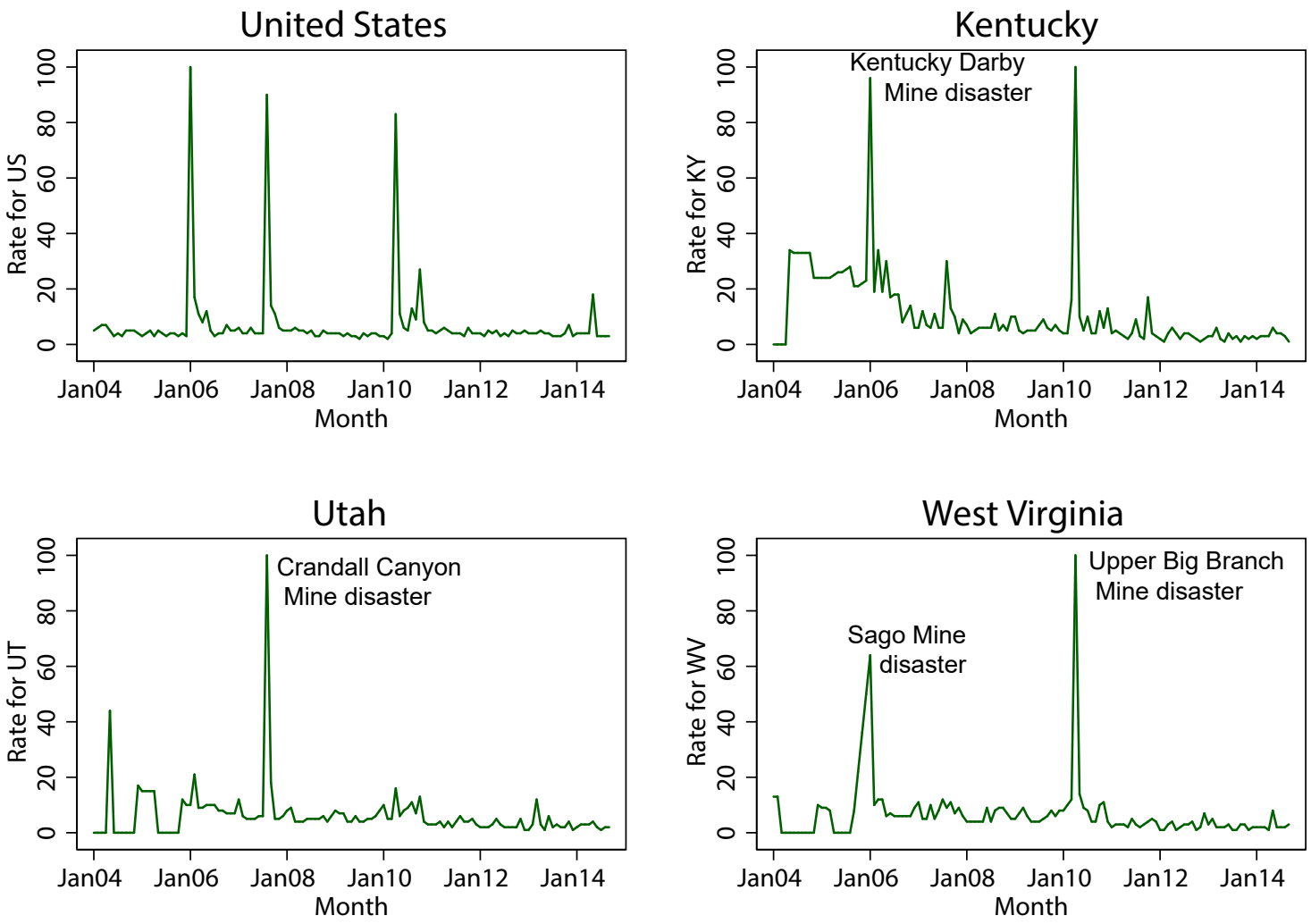
Are our identifying assumptions valid?

- Mines required to have systems in place to reduce severe risks
- No fatality would be allowed to occur if it could be foreseen by workers or management
  - Suggests validity of mean independence assumption
  - Perform falsification tests of *future* disaster/fatality
- There are a number of plausible mechanisms through which disasters or fatalities might increase costs of future accidents

1. They can lead to widespread public outrage
   - 2010 Big Branch Mine disaster led President Obama to declare, in a public eulogy, "owners responsible for conditions in the Upper Big Branch Mine should be held accountable"

     Massey Energy CEO Donald Blankenship indicted in 2014
   - Might raise implicit costs of future accidents near mine
   - Public attention following disaster concentrated near affected mine
2. They might change firm or worker perceptions regarding safety
3. They might increase government inspections

Google trends index for “mining accident” in U.S. and states with disasters



Relation to literature

Our paper builds primarily on two literatures:

- A literature has investigated link between productivity and safety
  - Sider (1983) examines underground coal mining—our model builds on his
  - Kniesner and Leeth (2004) examine whether MSHA enforcement reduces mine injuries, finding little effect
  - Boomhower (2014) finds that increased liability regulations lowered productivity and well blowouts for oil extraction
  - Hausman (2014) finds that electricity market restructuring allowed nuclear power plants to operate both more safely and efficiently
- Another literature considers impact of regulations on productivity
  - Studies noted above (Greenstone et al., Coffey et al.)
  - Gray (1987) finds safety regulations lowered productivity
  - Bridgman et al. (2006) finds productivity declines from regulation for sugar beet manufacturing

This paper:

- Adds a new source of identification
- Quantifies tradeoffs imposed by regulatory state

Remainder of talk

Study author on mine site visit

Historical fatalities in coal mining in U.S.

Regulation and disasters in coal mining

- Since 1900, over 100,000 workers killed in coal mines
  - Underground coal miners exposed to explosions, collapse, automotive accidents, etc.
- In response to dangers of coal mining, significant regulatory state enacted by U.S. government
  - Bureau of Mines, 1910
  - Federal Coal Mine Safety Act of 1952
  - Coal Mine Safety and Health Act "Coal Act" of 1969
  - Mine Safety Act of 1977
    - The 1969 and 1977 Acts created the Mine Safety and Health Administration, MSHA
  - MINER Act of 2006
- Many regulations in response to a disaster
  - Federal Coal Mine Safety Act followed 1951 Orient #1 explosion
  - Coal Act followed 1968 Consol #9 disaster, etc.
- We primarily consider underground coal mines
  - All disasters for underground coal mines
  - Present some evidence for surface coal mines also

Model

Simple neoclassical model of coal extraction with safety concerns:

- Mine chooses two labor inputs:
  - Production labor l_p and safety labor l_s
  - Leads to level of expected accidents and coal production
  - Mine faced with wage w, price of coal p, and accident cost c
- Production functions:
  - Expected mineral output: $f(l_p)$
  - Expected accident rate per production worker: A
  - $g(A)$ is per-worker safety input to achieve A, $l_s = s(A, l_p) = l_p g(A)$
    - $g(A)$ is monotonically decreasing
    - Homogeneity of degree one in accidents
- Expected profits for a mine are:

$$\pi(l_p, A|c) = pf(l_p) - cl_pA - w(l_p + l_pg(A))$$

- FOCs:

$$\frac{\partial \pi(l_p, A|c)}{\partial l_p} = pf'(l_p) - cA - w(1 + g(A))$$

$$\frac{\partial \pi(l_p, A|c)}{\partial A} = -cl_p - wl_pg'(A)$$

Implications of model

Proposition

Given regularity conditions on $f(\cdot)$ and $g(\cdot)$, the optimizing input choices $l_p^*(c)$ and $A^*(c)$ are decreasing in c.

- In words: when cost of accidents goes up, mines choose fewer accidents and lower production labor input
- Implications:
  - Higher cost of accidents leads to more safety workers
  - Controlling for returns to scale, leads to lower productivity

Idea of estimation

- Productivity in our model is:

$$Y = \frac{f(l_p)}{l_p + s(A, l_p)}$$

- Main identifying assumption:
  - A disaster near a mine or a fatality at a mine raises c
- We estimate tradeoffs between productivity and safety along frontier:

$$\frac{\partial Y}{\partial A} = \frac{\frac{\partial Y}{\partial c}}{\frac{\partial A}{\partial c}}$$

- Importantly, we identify tradeoffs between productivity and safety knowing the presence, but not size, of cost shock

Estimation

- We perform regressions of form:

$$Y_{it} = \alpha_i + \gamma_t + \beta_1 \mathbb{1}\{d_{it+1}\} + \beta_2 \mathbb{1}\{d_{it}\} + \beta_3 \mathbb{1}\{d_{it-1}\} + \beta_4 X_{it} + \varepsilon_{it}$$

  - Unit of observation: mine/quarter
  - α_i: mine fixed effects; γ_t: quarterly dummies; X_{it}: other controls
  - d_{it}: disaster near mine or fatality at mine (which raises c)
  - Also have regressions with other dependent variables, e.g. A_{it}
- All regressions have *future* fatalities or disasters
  - Falsification test for hypothesis that disasters/fatalities raise c
  - Significance on these terms would allow us to reject model
  - Include *two* years (not shown in equation for brevity)
- Standard errors clustered at mine level
- Regressions weighted by mean workers at mine
- Main regressions presented graphically here, with tables in paper

Datasets

- Most of our data are from MSHA:
  - Employment/Production Data Set (Quarterly)
  - Accident Injuries Data Set
  - Inspections Data Set
  - Mines Data Set (for geographic locations)
  - We keep coal mines with $\geq$ 2,000 person/hours per quarter (4 full-time people)
  - Datasets are publicly available for download
  - Data period: 2000-14, but have 2 years of lags and leads in estimation
- Also have *American Community Survey* (ACS) data from IPUMS
  - Use occupation of “coal mining”
  - Examine number of “coal miners” and “managers” or “supervisors”
  - Data are from 2005-13
  - Only at state/year level

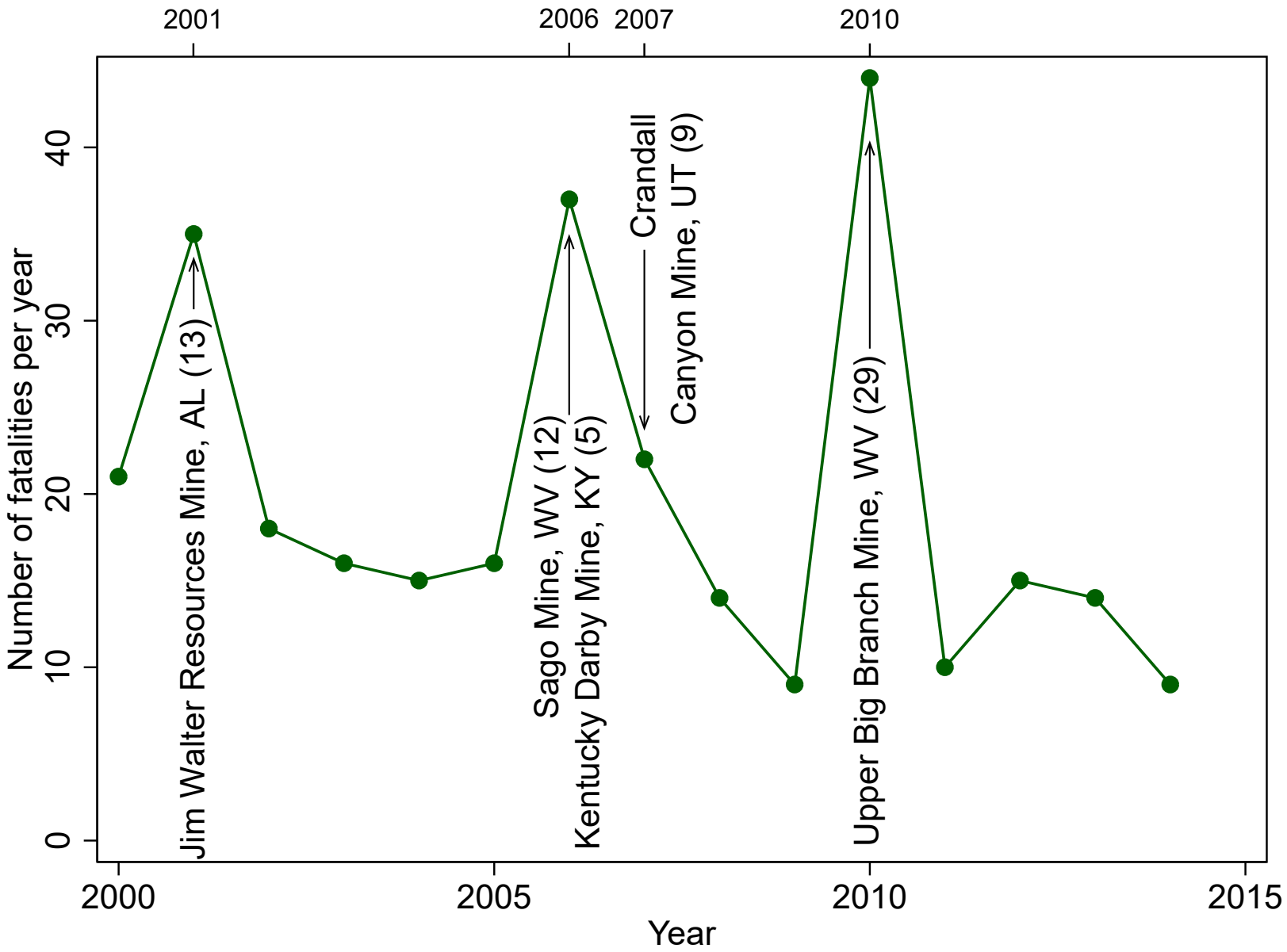
Summary statistics on accident occurrences in sample

Table: Underground coal mine accident occurrences in U.S.

Injury degree	Accident description	Severe injury	Number observed
Cases resulting in death	1	Yes	295
Cases with permanent total or partial disability	2	Yes	550
Cases with days away from work only	3	No	29,642
Cases with days away from work and restricted work	4	No	2,534
Cases with days of restricted work only	5	No	3,024
Cases without days away from work but with medical treatment	6	No	14,166

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

Fatalities and disasters in underground coal mines



Summary statistics at mine-quarter level

Table: Summary statistics at mine-quarter level

Variable	Mean	Std. dev.	Mean within-mine std. dev.	Min	Max
Coal production (thousands of tons)	174.2	360.4	69.2	0	3,091
Hours worked (thousands)	45.1	70.4	15.1	2	698
Employees	78.4	119.4	24.3	2	1,164
Productivity (tons per hour)	3.1	2.2	1.2	0	30
Less-severe accidents per million hours	45.0	81.0	56.9	0	3,077
Severe accidents per million hours	0.8	10.1	3.4	0	556
Fatalities per million hours	0.3	6.5	1.3	0	467
MSHA inspections	6.1	7.1	2.6	0	58
MSHA inspection hours	278.7	322.4	125.9	0	8,526
MSHA penalties (thousands of $)	22.3	70.0	32.9	0	1,982
MSHA violations	28.3	36.6	18.0	0	470

Note: summary statistics are for the estimation sample for underground mines for specifications that have disasters as the main regressor. Sample period is Q1:2000 through Q3:2012. N=24,035. See text for details of sample construction and variable definitions.

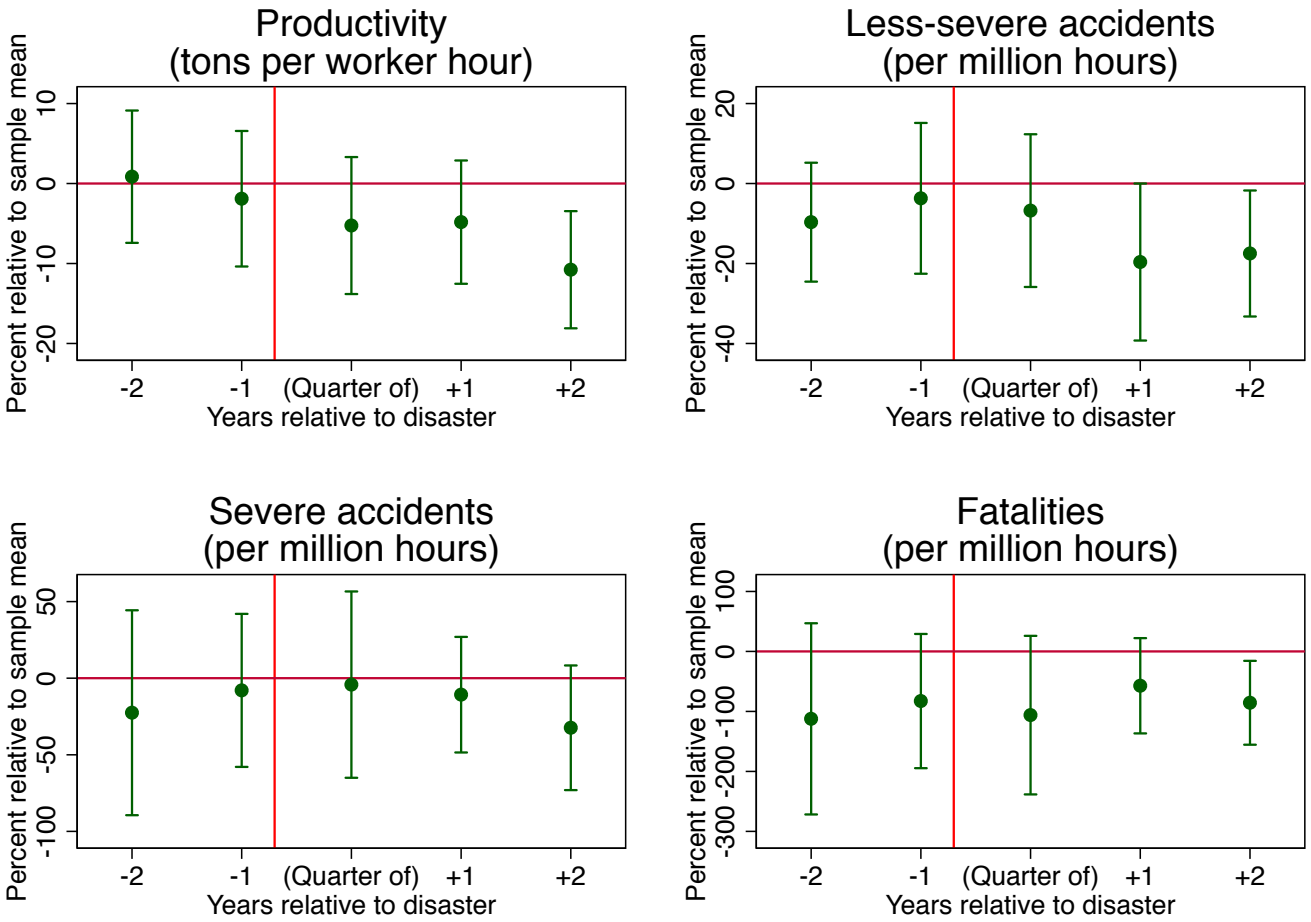
ACS data summary statistics

Table: ACS state-year level data summary statistics

Variable	Obs.	Mean	Std. dev.	Min	Max
Number of workers (thousands)	219	4.1	6.0	0.0	29.3
Number of miners (thousands)	219	1.0	1.5	0.0	7.7
Number of managers (thousands)	219	0.6	0.8	0.0	3.9
Number of other workers (thousands)	219	2.6	3.8	0.0	19.2
Mean income of workers (thousands of $)	219	61.0	24.4	11.1	253.8
Mean income of miners (thousands of $)	171	53.2	19.0	0.8	165.5
Mean income of managers (thousands of $)	179	87.7	39.2	0.0	301.0
Mean income of other workers (thousands of $)	215	56.7	21.1	12.3	176.9

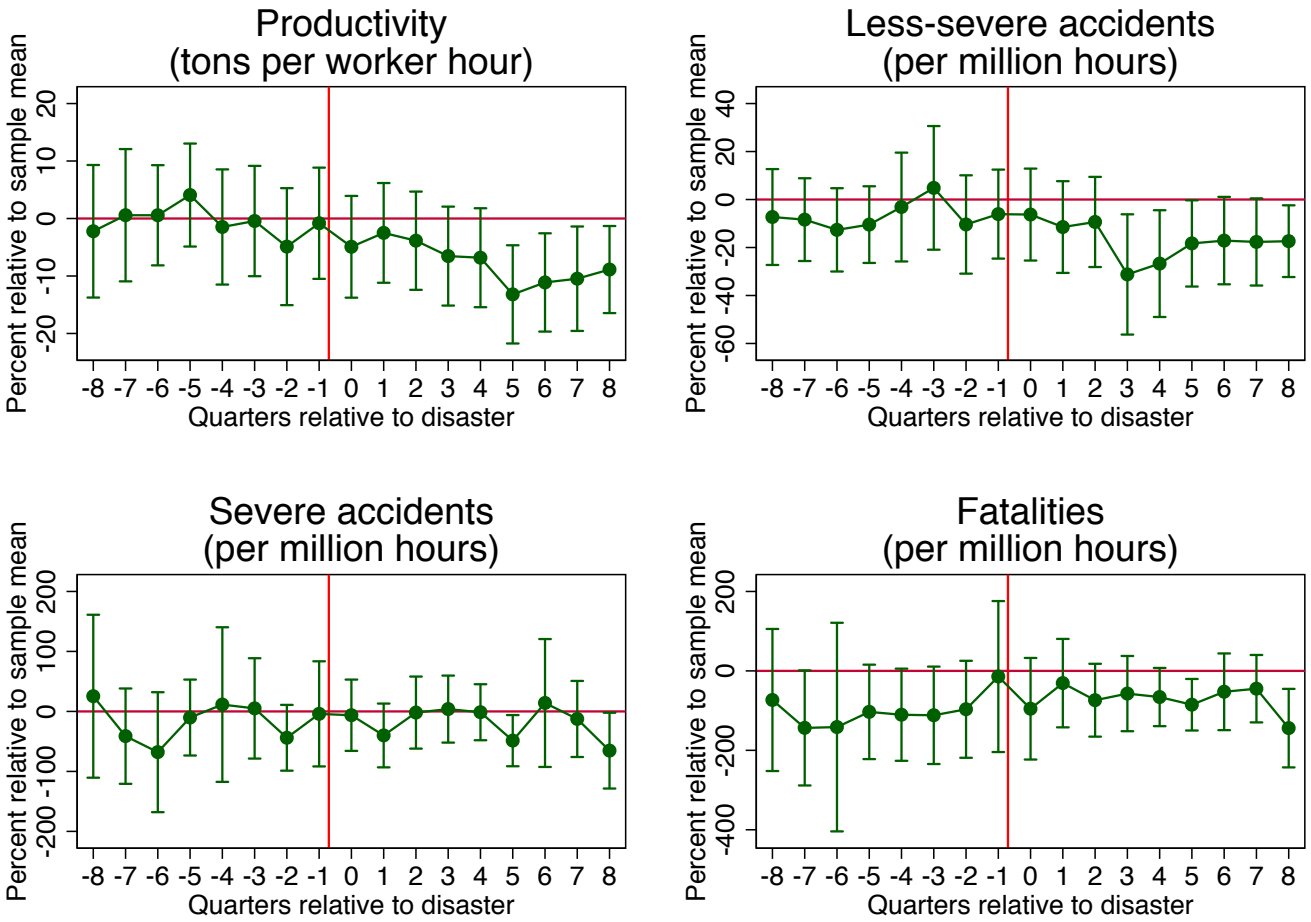
Note: summary statistics are for the ACS data and extend from 2005 through 2013.

Effects of a disaster in state on productivity and safety



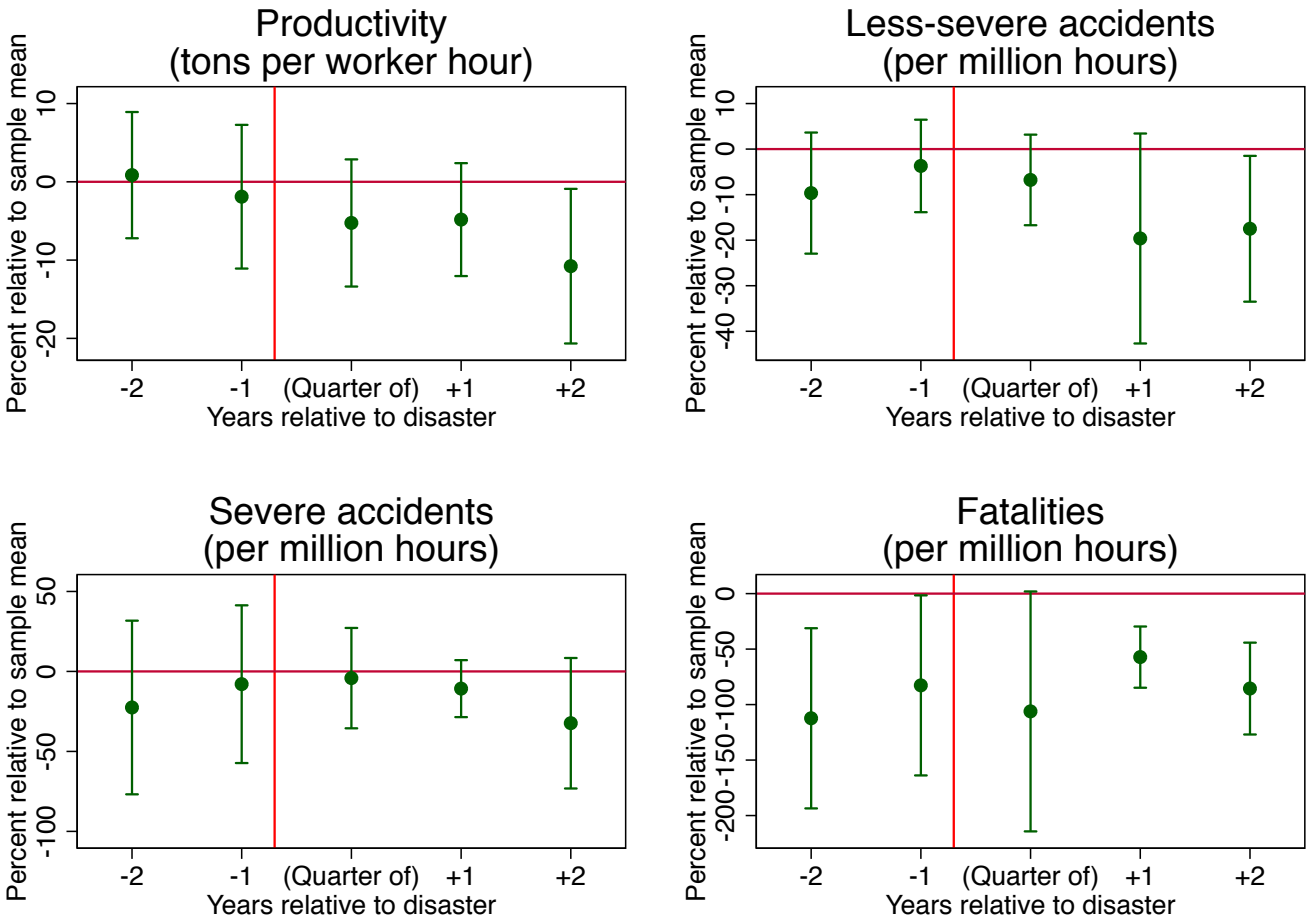
Note: each box reports selected regressors from one regression and each dot is a regression coefficient expressed as a percent of the sample mean of the regressor. Dependent variables are indicated in the titles. Each regression includes the following additional regressors: mine fixed effects, quarter fixed effects, state fixed effects interacted with hours worked, and state fixed effects interacted with number of employees, and is weighted by the mean number of workers at the mine. The vertical lines show 95% confidence intervals, based on standard errors clustered at the mine level.

Effects with quarterly (not annual) dummies



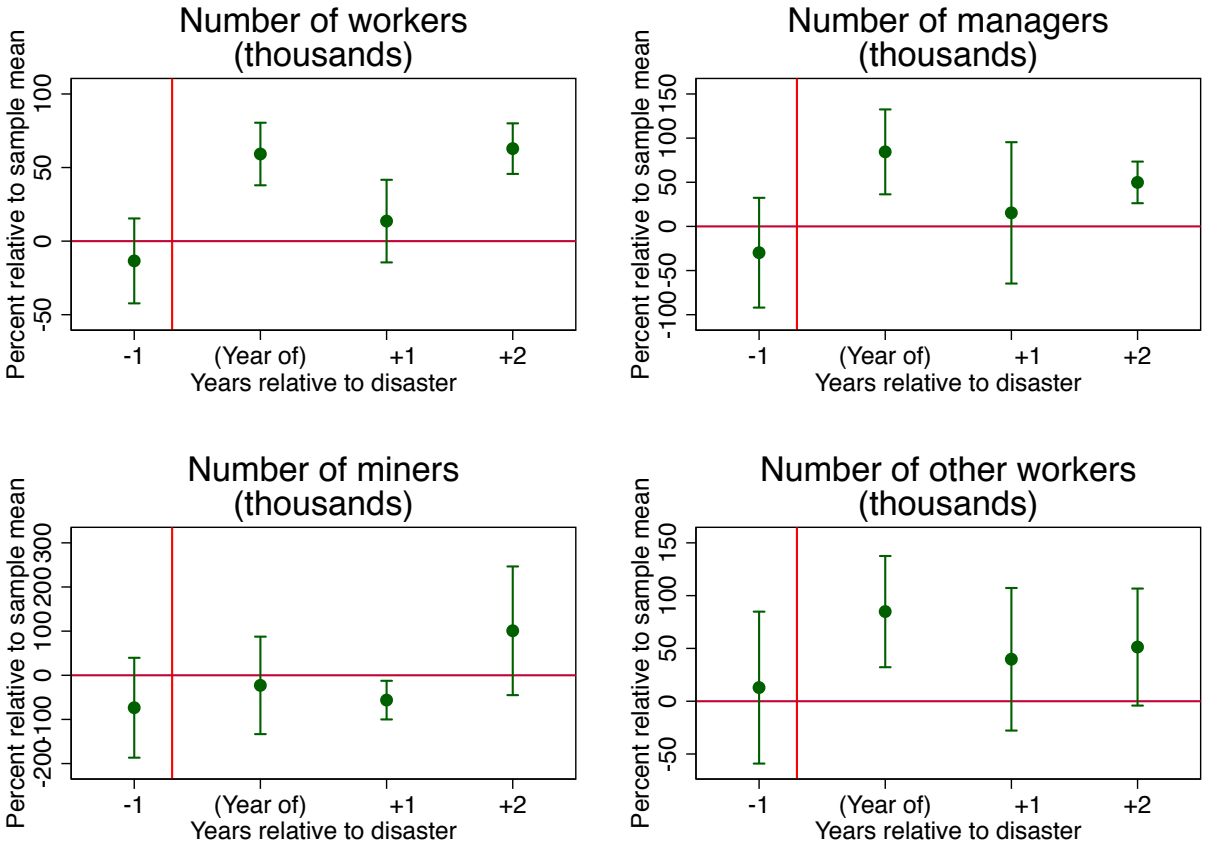
Note: each box reports selected regressors from one regression and each dot is a regression coefficient expressed as a percent of the sample mean of the regressor. Dependent variables are indicated in the titles. Each regression includes the following additional regressors: mine fixed effects, quarter fixed effects, state fixed effects interacted with hours worked, and state fixed effects interacted with number of employees, and is weighted by the mean number of workers at the mine. The vertical lines show 95% confidence intervals, based on standard errors clustered at the mine level.

Effects with cluster at state (not mine) level



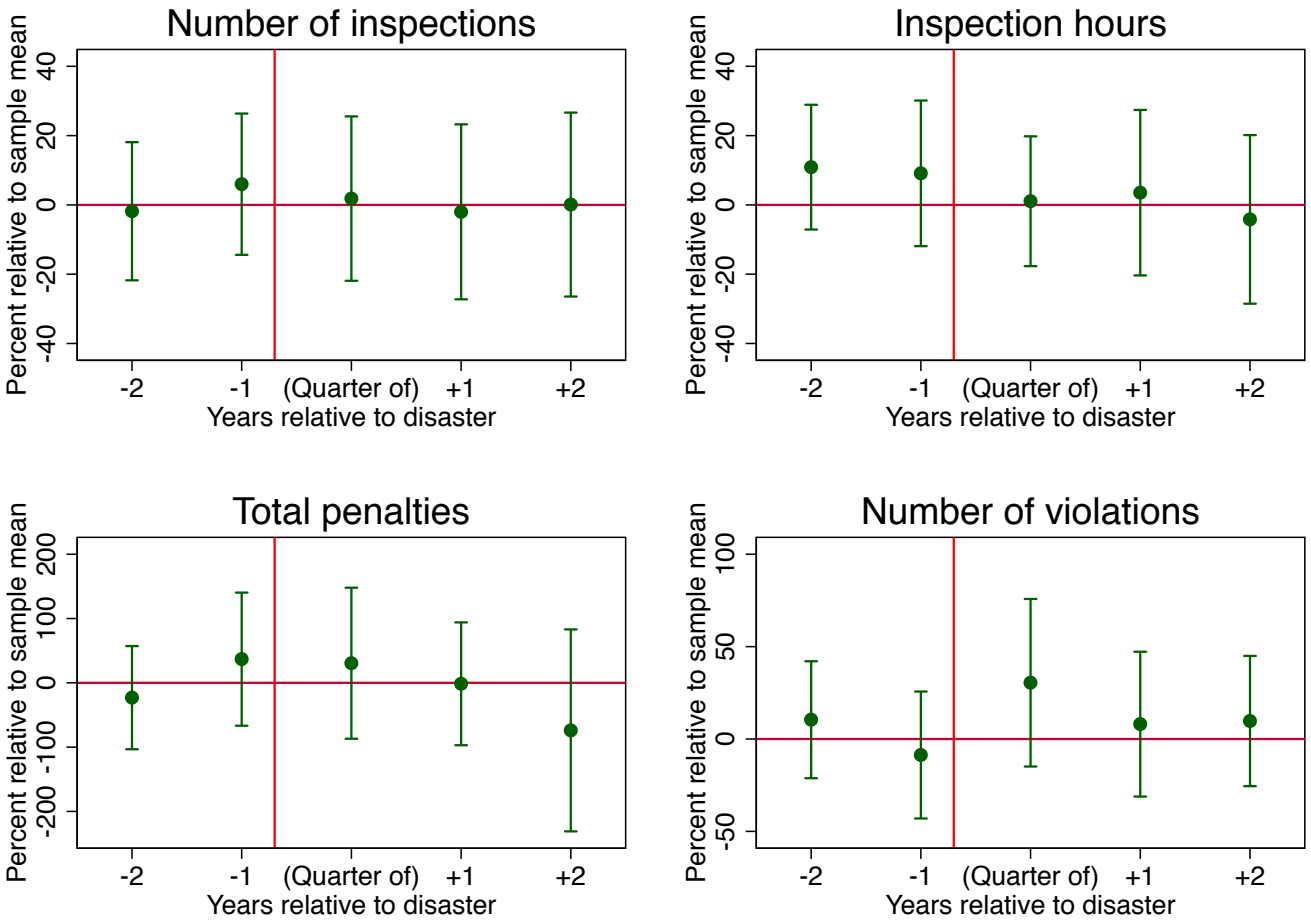
Note: each box reports selected regressors from one regression and each dot is a regression coefficient expressed as a percent of the sample mean of the regressor. Dependent variables are indicated in the titles. Each regression includes the following additional regressors: mine fixed effects, quarter fixed effects, state fixed effects interacted with hours worked, and state fixed effects interacted with number of employees, and is weighted by the mean number of workers at the mine. The vertical lines show 95% confidence intervals, based on standard errors clustered at the mine level.

Effects of a disaster on the number of coal mining workers in state, by category



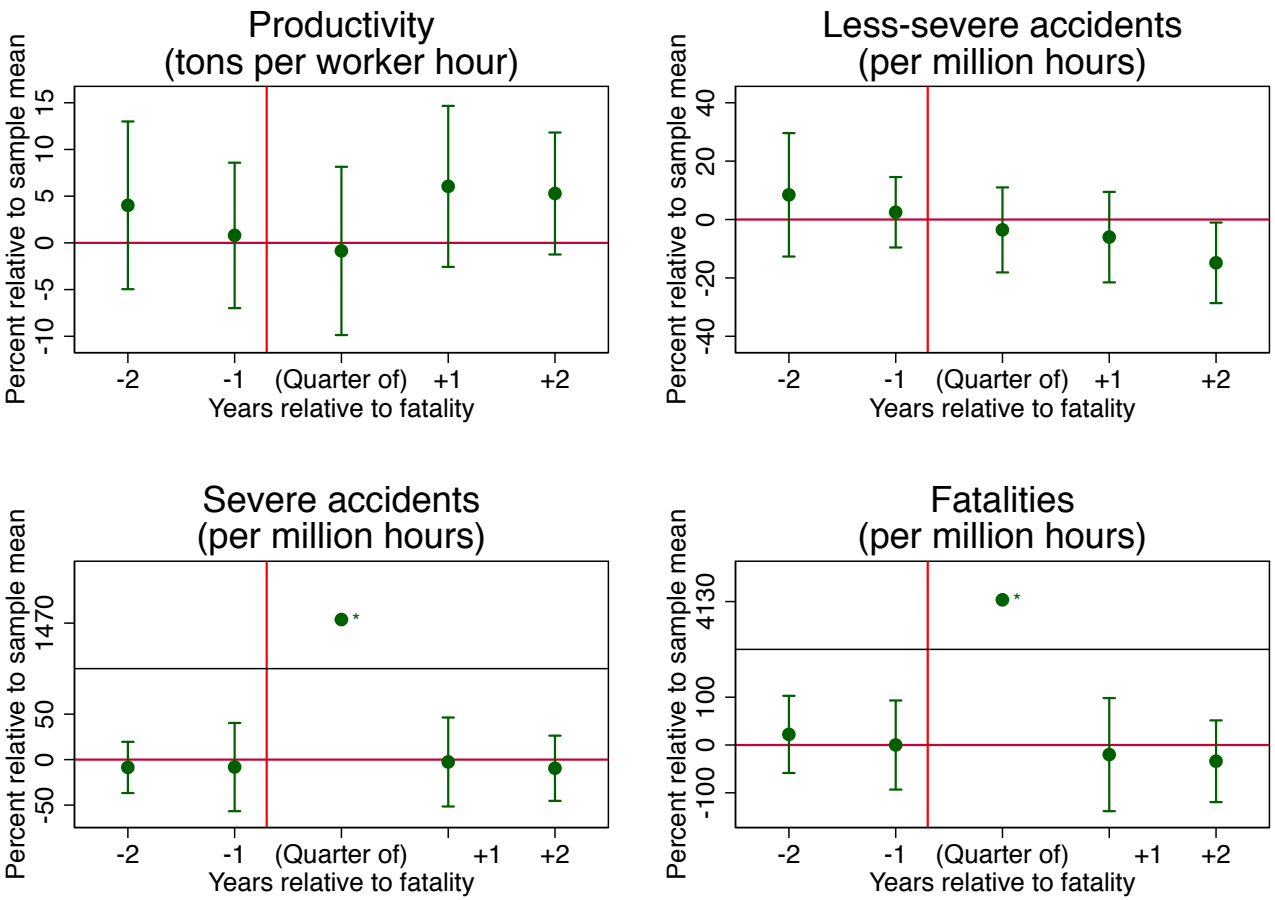
Note: regressions use state-year level ACS data. Each box reports selected regressors from one regression and each dot is a regression coefficient expressed as a percent of the sample mean of the regressor. Dependent variables are indicated in the title. Each regression includes the following additional regressors: state fixed effects, year fixed effects, and logged state GDP per capita, and is weighted by the mean number of workers in the state. Standard errors are clustered at the state level. The vertical lines show 95% confidence intervals, based on standard errors clustered at the mine level.

Effects of a disaster in state on MSHA activity



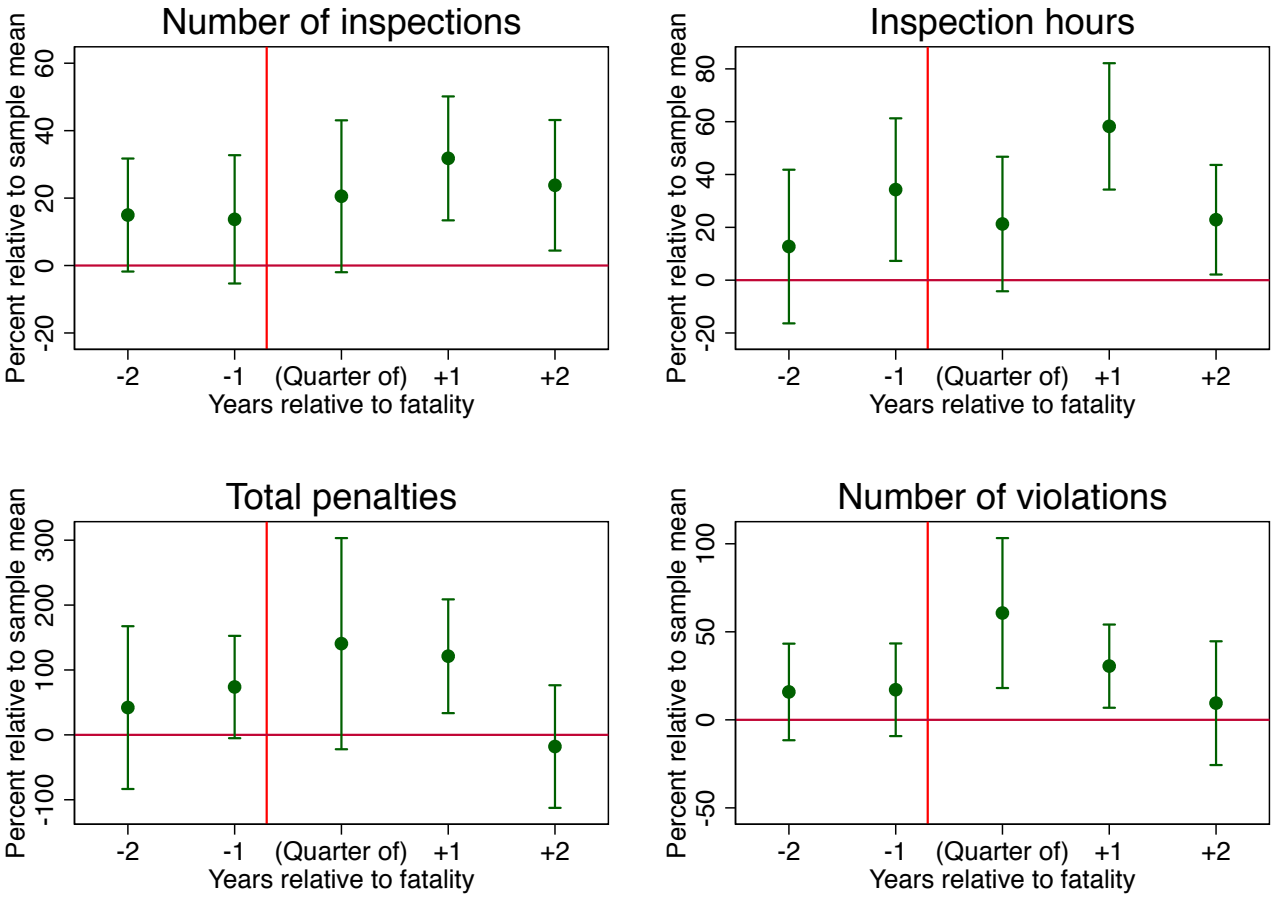
Note: each box reports selected regressors from one regression and each dot is a regression coefficient expressed as a percent of the sample mean of the regressor. Dependent variables are indicated in the titles. Each regression includes the following additional regressors: mine fixed effects, quarter fixed effects, state fixed effects interacted with hours worked, and state fixed effects interacted with number of employees, and is weighted by the mean number of workers at the mine. The vertical lines show 95% confidence intervals, based on standard errors clustered at the mine level.

Effects of a mine fatality on productivity and safety



Note: each box reports selected regressors from one regression and each dot is a regression coefficient expressed as a percent of the sample mean of the regressor. Dependent variables are indicated in the titles. Coefficients with an asterisk ($\star$) are significant at the 1% level. Each regression includes the following additional regressors: mine fixed effects, quarter fixed effects, state fixed effects interacted with hours worked, and state fixed effects interacted with number of employees, and is weighted by the mean number of workers at the mine. The vertical lines show 95% confidence intervals, based on standard errors clustered at the mine level.

Effects of a mine fatality on MSHA activity



Note: each box reports selected regressors from one regression and each dot is a regression coefficient expressed as a percent of the sample mean of the regressor. Dependent variables are indicated in the titles. Each regression includes the following additional regressors: mine fixed effects, quarter fixed effects, state fixed effects interacted with hours worked, and state fixed effects interacted with number of employees, and is weighted by the mean number of workers at the mine. The vertical lines show 95% confidence intervals, based on standard errors clustered at the mine level.

Robustness of results to alternative specifications

1. Effect of disaster within 200KM on productivity and safety:
   - Results consistent with base results based on state

   Results
2. Effect of disaster within 200KM with distance interactions:
   - Disasters have more local impact on less-severe accidents than on productivity or fatalities

   Results
3. Long-run impact of a disaster in state:
   - Second-year results consistent with base specification
   - Weak results that productivity drops in long-run

   Results
4. Effect of a disaster in state on mine workers' income in state (ACS data):
   - Not much impact on wages

   Results
5. Fatalities at surface coal mines on MSHA inspections:
   - Similar to underground coal mine inspection results
   - Results for productivity and accidents on fatalities is weaker
   - No surface coal mine disasters to consider

   Results

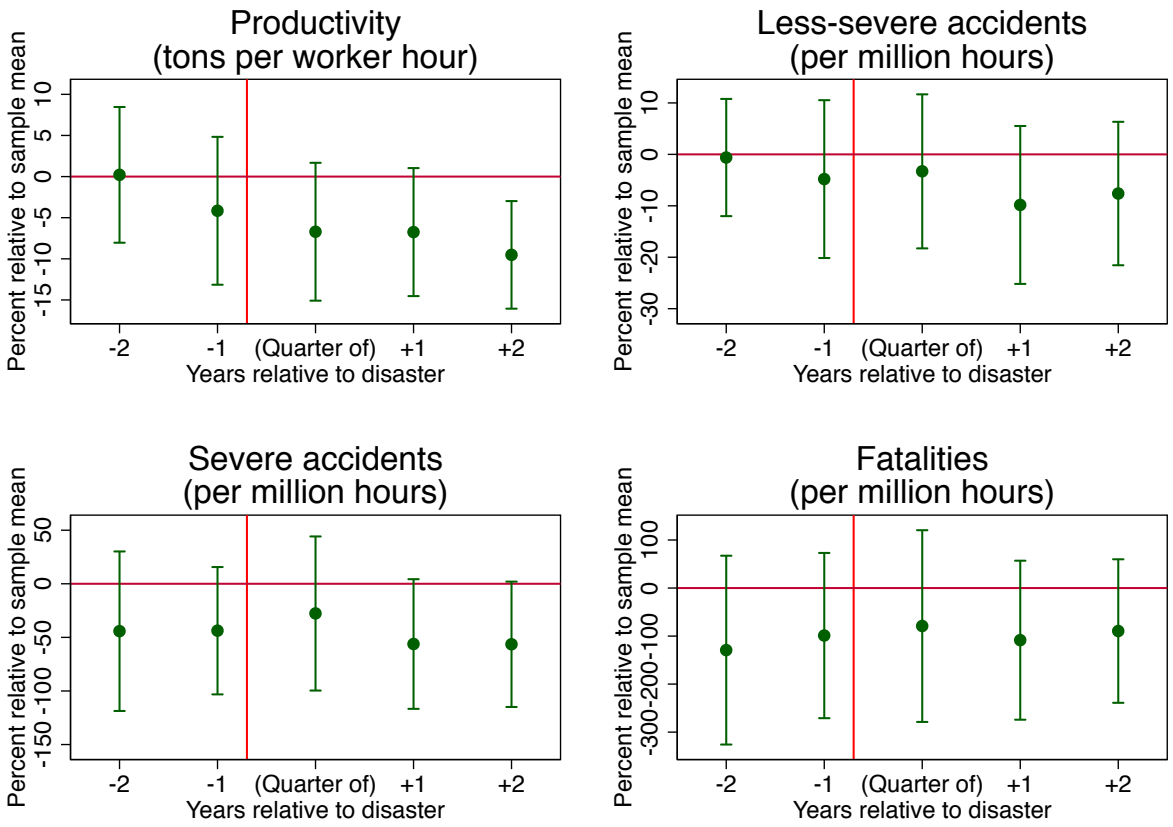
Dollar magnitudes of impact following disaster in state

- Reductions in fatalities:
  - Use central "Value of statistical life" estimate of $6.5 million
  - Reductions in fatalities in second year after nearby disaster equivalent to $1.63 per hour
  - Negative-but-insignificant pre-trends suggest this is overstated
- Reductions in less-severe accidents:
  - National Safety Council estimates $30,000 costs
  - Reduction in second year after disaster of $0.24 per hour
- Productivity drop:
  - Disaster leads to 0.33 (11%) lower coal production per hour
  - If firms could hire workers at a total cost of $40 / hour, they would need 11.9% more workers, adding $4.76 per hour worked
  - With production drop, at $50/ton coal price, this costs $16.5 / hour
- Much higher costs than benefits following disaster:
  - **Conservatively, costs are 2.67 times monetized safety gains**
  - Number of factors suggest this ratio may be larger:
    - Long-run productivity declines following disaster
    - Negative (though not significant) pre-trend on fatalities
    - Possibility of lower production

Conclusions

- Underground coal mining remains a dangerous sector where regulatory state may make mines tradeoff production and safety
  - Mine regulation in this sector is substantial
- Mine disasters nearby lead to large decreases in both accidents and productivity
  - Falsification tests using pre-trends adds credibility to results
- Smaller effects after mine fatality
- Regulatory state appears to be imposing a substantial productivity burden
  - Costs are 2.67 or more times greater than benefits following a disaster using published VSL numbers
- Our approach to understanding benefits and costs of regulation may be applicable to other sectors

Disasters on productivity and safety within 200KM



Note: each box reports selected regressors from one regression and each dot is a regression coefficient expressed as a percent of the sample mean of the regressor. Dependent variables are indicated in the titles. Each regression includes the following additional regressors: mine fixed effects, quarter fixed effects, state fixed effects interacted with hours worked, and state fixed effects interacted with number of employees, and is weighted by the mean number of workers at the mine. The vertical lines show 95% confidence intervals, based on standard errors clustered at the mine level.

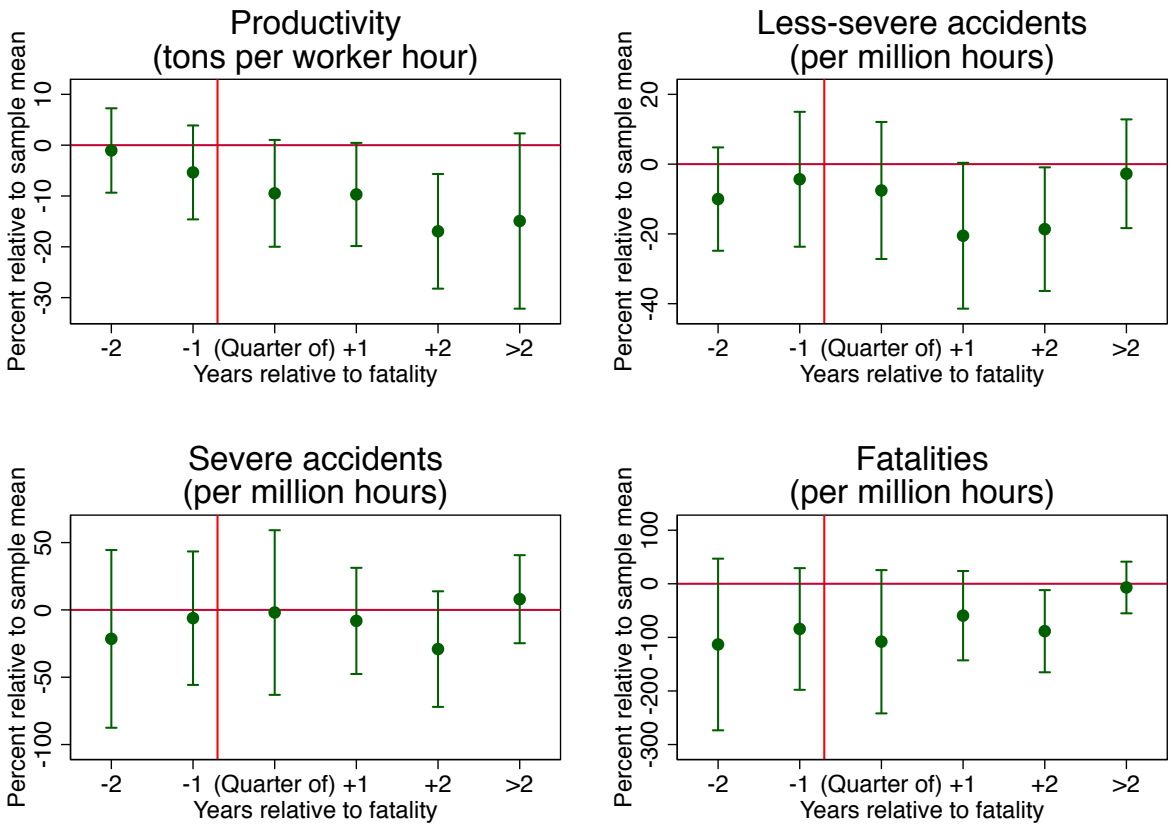
Back

Disasters within 200KM with interactions

	Productivity (tons per worker hour)	Less-severe accidents per million hours	Severe accidents per million hours	Fatalities per millions hours
	(Pre-trend coefficients in regression but omitted from table)			
Quarter of disaster				
Base	−0.24	−3.06	0.08	−0.35
	(0.17)	(5.66)	(0.41)	(0.35)
Base × distance (100KM)	0.04	0.46	−0.25	0.10
	(0.13)	(3.46)	(0.32)	(0.22)
First year after				
Base	−0.11	−9.74*	−0.32	−0.37
	(0.15)	(5.18)	(0.26)	(0.24)
Base × distance (100KM)	−0.09	4.23*	−0.11	0.04
	(0.11)	(2.54)	(0.11)	(0.05)
Second year after				
Base	−0.32**	−8.82**	−0.48*	−0.37*
	(0.14)	(3.97)	(0.27)	(0.21)
Base × distance (100KM)	0.03	4.23	0.03	0.09
	(0.10)	(2.57)	(0.14)	(0.07)
R^2 within	0.22	0.05	0.01	0.01
N	24,035	24,035	24,035	24,035

Back

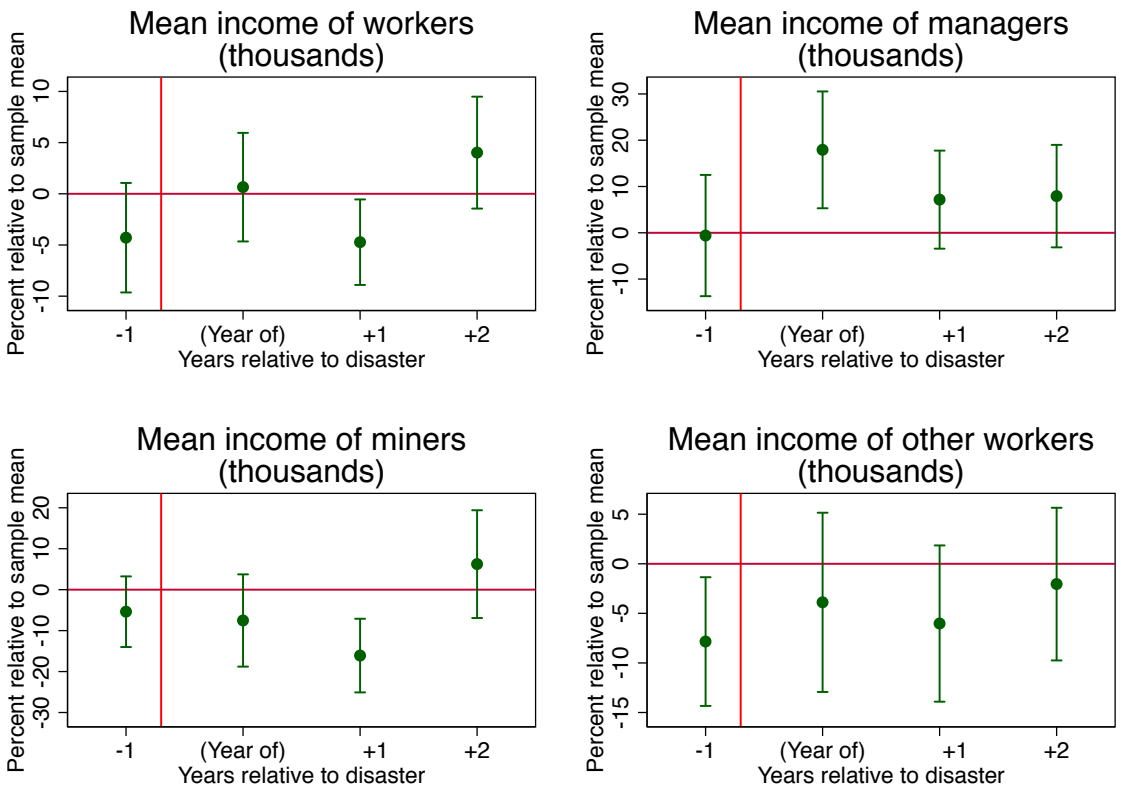
Disasters in state with long-run effects



Note: each box reports selected regressors from one regression and each dot is a regression coefficient expressed as a percent of the sample mean of the regressor. Dependent variables are indicated in the titles. Each regression includes the following additional regressors: mine fixed effects, quarter fixed effects, state fixed effects interacted with hours worked, and state fixed effects interacted with number of employees, and is weighted by the mean number of workers at the mine. The vertical lines show 95% confidence intervals, based on standard errors clustered at the mine level.

Back

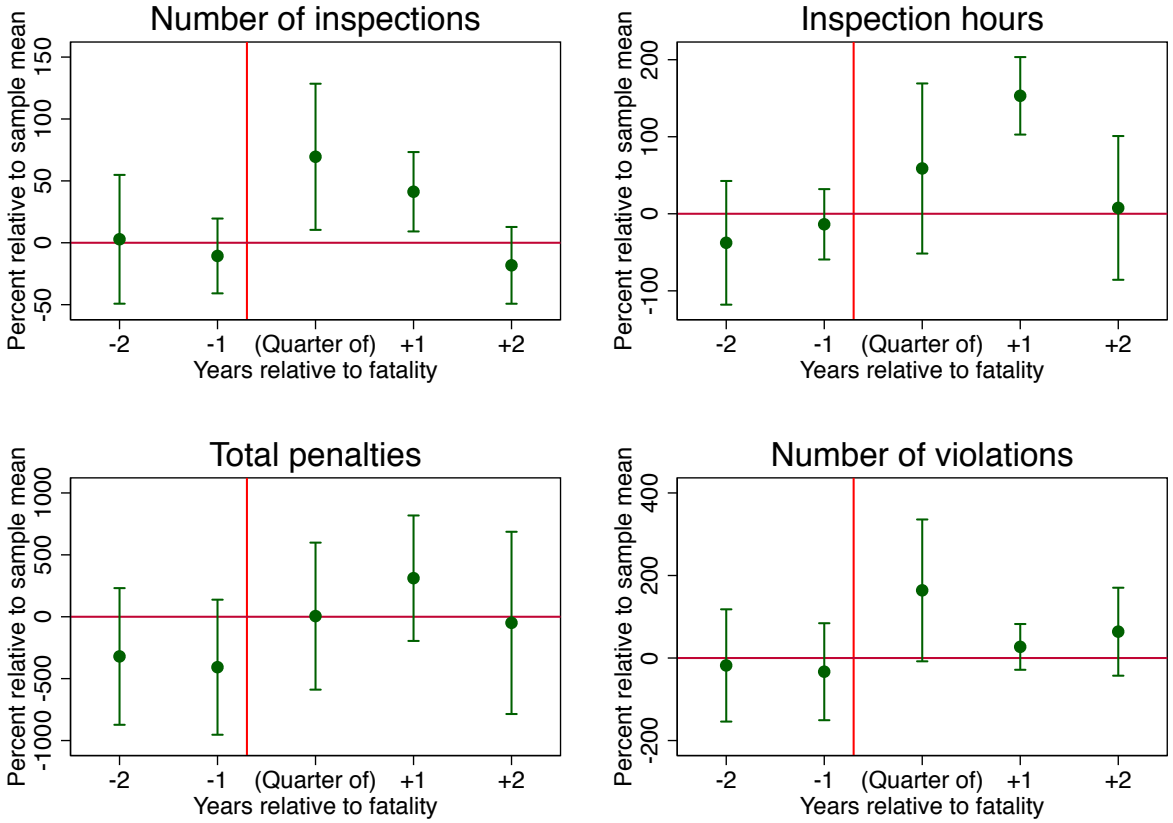
Effects of a disaster on the mean income of employed coal mining workers in state, by category



Note: regressions use state-year level ACS data. Each box reports selected regressors from one regression and each dot is a regression coefficient expressed as a percent of the sample mean of the regressor. Dependent variables are indicated in the title. Each regression includes the following additional regressors: state fixed effects, year fixed effects, and logged state GDP per capita, and is weighted by the mean number of workers in the state. Standard errors are clustered at the state level. The vertical lines show 95% confidence intervals, based on standard errors clustered at the mine level.

Back

Results for surface mine fatalities



Note: each box reports selected regressors from one regression and each dot is a regression coefficient expressed as a percent of the sample mean of the regressor. Dependent variables are indicated in the titles. Each regression includes the following additional regressors: mine fixed effects, quarter fixed effects, state fixed effects interacted with hours worked, and state fixed effects interacted with number of employees, and is weighted by the mean number of workers at the mine. The vertical lines show 95% confidence intervals, based on standard errors clustered at the mine level.

Back