Government Regulation of Occupational Safety: Underground Coal Mine Accidents 1973–75

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Abstract: The purpose of this paper is to determine the influence of federal mine safety inspections on underground coal mine accidents. An economic incentives model is developed to relate federal enforcement activities to accident rates. The determinants of accident rates are analyzed for 535 coal mines during the period 1973–75. Estimates based on these data when applied to the model indicate that increasing inspections by 25 per cent would have produced a 13 per cent decline in fatal accidents and an 18 per cent decline in disabling accidents. (*Am J Public Health* 1985; 75:497–501.)

Introduction

Since 1969, the federal government of the United States has initiated two major new regulatory programs designed to protect working people from the hazards of their occupations. The first of these, the Coal Mine Health and Safety Act (CMHSA), became law on December 30, 1969. A year later, the Occupational Safety and Health Act (OSH Act) of 1970 was enacted. Each led to the promulgation of a body of workplace health and safety standards. These standards have been enforced by federal inspectors who monitor workplaces for compliance with the standards. If violations are discovered, abatement is ordered and penalties may be imposed.

Underground bituminous coal mining has traditionally been one of the most hazardous industries. In the 20 years after 1950, more than one of every 400 underground miners was killed annually. This is about 30 times as high as the average fatality rate in manufacturing industries during this same period.

A number of investigators have attempted to measure the effectiveness of government regulation of coal mine safety, but published work in this field has been based on highly aggregated data and has not focused on the role of enforcement. Previous investigators have compared accident levels before and after the passage of the 1969 Act.[1–4] This approach effectively ignores the impact of differential enforcement. In addition, by comparing injury rates before and after 1970, these papers may capture not only the effect of legislation but of other historical changes affecting safety levels. A paper by Weeks and Fox[5] suggests that changes in fatality rates in 1979–82 were related to enforcement changes, but does not document the relationship between these changes and injury rates.

This study treats the level of safety regulation enforcement as a cause of compliance. Enforcement is measured by the frequency of inspection and the level of costs incurred when violations are cited. The operator (the coal mine employer) is hypothesized to balance the cost of compliance with safety regulations against the potential cost of being caught by government inspectors and the potential costs of accidents caused by noncompliance. The model used in this study has been described by economists during the last two decades although its application has usually been limited to the study of felonious criminal behavior.[6–8] Several authors have developed economic models of occupational safety and health, notably Oi and Viscusi.[9–11] Viscusi has also applied the economic incentives approach to evaluate OSH Act's impact on injury rates.[10]

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Background

Mine Characteristics Related to Safety

Geological Characteristics—The conditions under which coal is mined are variable, being largely determined by the characteristics of the coal seam. Coal is mined so that the height of the work area is approximately the same as that of the coal seam. Workers and machines maneuver more easily in the over six-foot high space created from thick seams than in the 30-inch high space common to thin seams. Because of this, one would expect more injuries in thin seams than in those with thick seams. Other geological conditions also influence the risk of injury. The strength of the geological formations above the coal seam affects the risk of injuries from falling rock. Also, the higher the methane content of coal, the more danger of an explosion.

Mining Technique—In the United States, most underground coal is removed by conventional mining or continuous mining techniques. The former method is older, slower, and less captial-intensive, and is also reputed to be more dangerous. In addition to these two techniques, about 2 per cent of the sample mines use the longwall technique, the most capital-intensive but also reputed to be the safest of the three techniques.

Mine Size—It is a common observation that, among larger underground mines, injury rates tend to decrease with mine size. This suggests that there are economies of scale in the provision of safety among these mines, and that lower injury rates are a result of these scale economies.

Unionization—Because coal mining is such a hazardous occupation, safety has traditionally been an important issue to miners and their union. Non-union miners, on the other hand, do not have the backing of a union to support their efforts to gain a safe workplace, nor do they have the protection of the safety provisions of a union contract and the help of safety experts that a union can provide.

The Captive Mine—A captive mine is directly or indirectly (through a subsidiary) owned by a firm that uses its output. Almost all captive output goes to the steel industry or public utilities. The owners depend on captive mines for a steady and predictable supply of coal. The fact that production at captive mines fluctuates less than production at other mines could lead to lower accident rates at the captives. Fluctuating production may influence safety in two ways.

First, it may lead to high turnover which means that many workers will be relatively inexperienced at their current jobs. Since inexperience is a likely cause of high accident rates, commercial (non-captive) mines should have higher accident rates than captive mines. In addition, steady demand may allow the captive mine to invest in safety equipment, training, or safety practices that would be more costly and less effective for a mine whose production was less stable.

MSHA Enforcement

The Coal Mine Health and Safety Act of 1969 is part of the most intensive effort ever made to improve health and safety conditions in America's workplaces. Each underground coal mine is inspected at least four times a year for compliance with Mine Safety and Health Administration (MSHA) regulations. If the inspector finds a violation, the mine operator is told to abate it by a given date and is assessed a penalty. If the violation is not corrected by the abatement date, the inspector can issue a closure order, directing the removal of all production personnel from the affected area of the mine. A closure order may also be issued in cases of imminent danger to life or limb.

The magnitude of MSHA's enforcement program can best be appreciated by comparing it with the Occupational Safety and Health Administration (OSHA) program. MSHA and OSHA have roughly the same number of inspectors, but MSHA makes twice the number of inspections and cites about 30 per cent more violations than does OSHA. Since MSHA covers about 3,000 coal mines and OSHA covers about 3,000,000 workplaces, MSHA's inspections are three orders of magnitude more frequent.

Data

The research data were gathered largely from MSHA files for the years 1973–75. The sample of mines chosen consists of the 535 underground bituminous coal mines which produced at a rate of 100,000 tons of coal per year during at least one year of the 1973–75 period. The mines in this sample constitute approximately one-third of all underground mines, and produce about 90 per cent of all underground coal. Miners working at these mines incur 75 per cent of all underground fatalities and 84 per cent of all disabling injuries.

Where possible, data were collected on a quarterly basis; for most variables, there are a maximum of 12 quarterly observations per mine. In addition to data on production and employment, information was collected on a number of factors which may have a substantial impact on the underground coal mining production function. For each mine in this sample, there are data on:

- number of inspection days, penalties, and closure orders;
- mine size, as measured by the number of active mining sections;
- the mining technique used on each section;
- the seam height of the coal being mined;
- union status; and
- whether a mine is captive or sells its output primarily on the open market.

In this sample of mines, the average mine had five producing sections and employed 176 underground miners. Continuous mining was used in 64 per cent of the sections, while 35 per cent used the conventional method and only 1 per cent used longwall mining. The average seam height was slightly over five feet, with a range from only 27 inches to 20 feet. Unionized mines comprised 83 per cent of the sample, and 21 per cent were captive. These mines were inspected an average of 143.2 days a year. Annually, 106 violations were cited, with total annual penalties of just under $8,000 per mine. MSHA closed all or part of a mine an average of four times annually.

Table 1 displays changes in important variables during 1973–75. During this period of time, the fatal and disabling injury rates declined. The intensity of MSHA inspection (as measured by inspection days per producing section) stayed constant at about 30 days per section while variables measuring the cost of enforcement and the average number of closures increased substantially.

While the average penalty for violations was not large, the high frequency of inspection meant that a violation was likely to be cited shortly after it appeared. Thus, the benefit to the operator of violating MSHA regulations would be small because it would only accrue during the short time before it was cited and eliminated. Because of this, even penalties of less than $100 could have a substantial deterrent effect. The purpose of the statistical section of this paper is to determine whether this deterrent effect produced a significant reduction in injury rates in underground coal mining, examining the relationship between these variables at the individual mine level.

Determinants of Accident Rates

By increasing the cost of unsafe behavior, enforcement should lead to safer production methods and thereby to lower accident rates. Increased enforcement can be achieved either by an increase in the expected costs of penalties or the expected costs of closure orders.

The expected cost of penalties is the product of the probability of being cited and the expected penalty per citation. The measure of the probability of being cited used in this paper is the number of days each mine section is inspected, and the measure of the expected cost of penalties is the product of the number of days a section is inspected and the mine's average penalty per citation.

When MSHA issues a closure order, there is no production and profits are lost. Thus the expected cost of closure orders is the product of the probability of a closure order and the profits lost when part of the mine is closed. We have no

TABLE 1—Mean Values for Selected Variables (sample of 535 mines)

Year	Disabling Injuries per 10^6 hours	Fatal Injuries per 10^6 hours	Annual Inspection Days Per Section	Annual Penalties	Annual Closures
1973	54.6	.560	31.7	$6860.	3.3
1974	39.5	.400	29.1	$7120.	4.0
1975	36.2	.406	33.1	$9700.	5.6
1973–75	43.0	.453	31.9	$7400.	4.3

measure of lost profits, but assume that this cost increases in proportion to the number of closure orders. Given this assumption, the expected cost of closures is proportional to the probability of being cited multiplied by the probability that a citation will be a closure. The measure used in this study is the number of days a section is inspected multiplied by the proportion of all citations at the mine that are closure orders.

The number of injuries at a mine in a given time period can be thought of as the outcome of an underlying Poisson process. Geological characteristics, mine technology, and safety inputs affected by MSHA enforcement are all determinants of the riskiness of the mine, i.e., the underlying probability distribution that an accident will occur in a given number of hours worked. This underlying probability distribution is assumed to be a Poisson process with parameter a. If n hours are worked in the mine, then its accident count will be Poisson with parameter a · n.

Two alternative specifications for the Poisson parameter, (A) and (B), were chosen:

A. $a = HRS \cdot (b_0 + b_1\overline{FINE} + b_2\overline{CLOSE} + b_3CONT + b_4LONG + b_5SECT + b_6THICK + b_7UNION + b_8CAPT)$

B. $\log(a) = \log(HRS) + (b_0 + b_1\overline{FINE} + b_2\overline{CLOSE} + b_3CONT + b_4LONG + b_5SECT + b_6THICK + b_7UNION + b_8CAPT)$

HRS: number of hours worked in underground mining in a calendar quarter
FINE: days of inspection per section multiplied by average penalty per cited violation, instrumental variables estimate*
CLOSE: days of inspection per section multiplied by the fraction of all citations that resulted in closures, instrumental variables estimate*
CONV: fraction of sections using conventional mining methods
CONT: fraction of sections using continuous mining methods
LONG: fraction of sections using longwall mining methods
SECT: number of producing sections in mine (size variable)
THICK: average seam thickness, in feet
UNION: union dummy = 1 if mine is unionized
CAPT: captive dummy = 1 if mine is captive

Since CONV + CONT + LONG = 1, CONV is dropped when (A) and (B) are estimated.

During background research for this paper, MSHA officials provided data to support the contention that almost all cited violations are abated rapidly. The average time between issuance of a notice and abatement of the underlying violation is less than seven days, and is shorter for orders.** On the basis of these observations, the effect of enforcement on accident rates is specified as contemporaneous.

On the other hand, MSHA inspection rates are designed to respond to *past* accident rates. For example, in 1973, MSHA initiated an Accident Prevention Program. This program, initially covered the 150 largest underground mines, was later expanded to the 200 largest. If, over the previous year, a mine's disabling injury frequency rate is greater than the national average, a mine inspector is stationed at that mine. The inspector stays at the mine until its disabling injury rate over the year prior to the current quarter drops below the national average. Thus inspection rates respond to past rather than current accident rates.

If inspections are determined on the basis of past accident rates, accidents have a lagged effect on inspections while inspections have a current effect on accident rates. This implies that equations (A) and (B) can be estimated without introducing simultaneous equations bias. While this appears to be a reasonable reflection of reality, it is possible that MSHA inspections respond rapidly to current injury rate changes. In this case, the coefficients of enforcement variables would be biased toward zero.

Results

The results, maximizing a Poisson likelihood function, are presented in Tables 2 and 3. (Standard errors are in parentheses.)

The two models produce similar results. Signs are the same in all but one case, and in this case (the coefficient of CLOSE in the linear fatal accident regression), the coefficient in neither specification is not significantly different from zero. For fatal accidents, both models had the same likelihood, but the exponential estimate of disabling accidents had a much higher likelihood. In discussing the results of this study, the exponential estimates will be used. Even though the estimated coefficients in the fatal accident regressions are generally not significant, the implied effects are discussed, since the coefficients represent the best available estimates of these effects.

Table 3 supports the hypothesis that MSHA enforcement leads to fewer accidents. Using the estimated coefficients of equation (B), the impact of increasing MSHA inspections by 25 per cent was projected, producing declines in the fatal accident rate of 13 per cent, and in the disabling

TABLE 2—Linear Estimates of Injury Rates (per 10^6 hours) (Asymptotic standard errors in parentheses) n = 5776

Dependent Variable	Fatal Injuries	Disabling Injuries
Constant	0.79*	82.4*
	(.17)	(.82)
Average Penalty (thousands of $) × Inspection Days	−0.29*	−36.3*
	(.17)	(.78)
Per Cent Orders × Inspection Days	−0.27	−29.0*
	(.29)	(1.27)
Mining Technique		
Continuous	−0.18	−6.7*
	(.09)	(.47)
Longwall	0.82	151.*
	(.52)	(2.25)
Number of Sections	−0.01	−1.5*
	(.008)	(.04)
Seam Thickness (feet)	0.053*	0.09
	(.02)	(.09)
Union Dummy	−0.16	8.0*
	(.13)	(.67)
Captive Dummy	−0.14*	−18.0*
	(.06)	(.28)

*Significant at $p < .05$

*See Appendix for further explanation.

**Personal communication: John Greenhalgh, Chief, Division of Program Evaluation, MSHA.

TABLE 3—Exponential Estimates of Injury Rates (per 10^6 hours) (Asymptotic standard errors in parentheses) n = 5776

Dependent Variable	Fatal Injuries	Disabling Injuries
Constant	−0.40	5.07*
	(.33)	(.02)
Average Penalty (thousands of $) × Inspection Days	−0.87*	−1.48*
	(.44)	(.02)
Per Cent Orders × Inspection Days	0.67	−1.21*
	(.95)	(.05)
Mining Technique		
Continuous	−0.12	−0.02*
	(.18)	(.01)
Longwall	1.08	2.87*
	(.78)	(.04)
Number of Sections	−0.03	−0.073*
	(.02)	(.001)
Seam Thickness (feet)	0.076*	0.024*
	(.033)	(.002)
Union Dummy	−0.15	0.44*
	(.25)	(.01)
Captive Dummy	−0.42*	−0.62*
	(.17)	(.01)

*Significant at $p < .05$

accident rate of 18 per cent. Table 4 summarizes this study's estimates of the impact of MSHA on accidents by applying the results of the regression analysis to accident rates in the 535 coal mines in the sample. The estimated specification cannot differentiate between the effects of increasing inspection rates and those of increasing the costs of violations. The same result would be projected from a 25 per cent increase in penalties and in the probability of closure orders.

Some prior hypotheses are supported by the regression results, while others are not supported:

- Injury rates decrease as mine size increases. All other things equal, expected accident rates in mines with ten producing sections can be compared with those in mines with only five sections. On the average, the larger mines will have .01 fewer fatalities per million hours worked and three fewer disabling accidents per million hours worked.
- Mines with thicker seams were predicted to be safer than similar mines with thinner seams. However, seam height has a small positive association to fatal accident rates. An increase of 50 per cent of average seam height would mean an increase in fatal accident rates of 4 per cent, but almost no change in disabling accident rates.
- Unionized mines do not appear to be safer than others. While unionized mines appear to have fewer fatal accidents, the excess disabling accident rate at unionized mines is large. A possible explanation rests on the fact that non-fatal accidents tend to be under-reported.[12] If the United Mine Workers of America (UMWA) monitors accident reporting for completeness, unionized mines will report a higher percentage of accidents. Even when they have a higher accident rate, non-union mines may have fewer *reported* non-fatal accidents.
- Captive mines are safer than others, as indicated by lower accident rates. Captive mines of similar size and other relevant conditions appear to have an average of 28 per cent fewer fatalities and 53 per cent fewer disabling accidents per million hours worked than do commercial mines.
- Continuous mining is safer than conventional mining. There are consistently large differences estimated in the accident rates of continuous and conventional coal mining, for both classes of accidents.
- Longwall mining does not appear to be safer than continuous or conventional mining. For both types of accidents, longwall mining had much higher accident rates than the other two methods. This finding is contrary to the popular belief that the longwall method is the safest. It may reflect the fact that the longwall method is relatively new to US mining, and that our lack of experience leads to more accidents even if the method is inherently safer. Furthermore, only 2 per cent of the sample mines used the longwall technique.

TABLE 4—Estimated Average Annual Changes in Injuries Caused by Increasing MSHA Inspections by 25 Per Cent

	Per Cent Change In Injury Rate*	Average Change In Annual Injuries*
Fatal Injuries	20 to 7	13 to 3
Disabling Injuries	15 to 20	860 to 1300

*The first number in each column is computed from the linear estimate while the second is computed from the exponential estimate. The change in annual injuries is computed assuming a 2.5 per cent decline in labor productivity when inspections increase by 25 per cent.

Discussion

The estimates generally confirm the hypothesis that MSHA enforcement has reduced accidents in underground bituminous coal mining. These results only partially confirm those reported by Neumann and Nelson.[4] Using aggregate data for the years 1950 to 1976, they estimate the effects of the 1969 Act by using a dummy variable for the years after 1970. They estimate that fatal injury rates per ton of output fell in the period after the CMHSA became effective, but that disabling injury rates per ton rose. The Neumann and Nelson results may have been influenced by more complete reporting of disabling injuries following the passage of the 1969 Act, a possibility that they offer, but suggest is unlikely. Alternatively, their dummy variable approach may capture historical changes other than the effect of the 1969 Act, while the current study captures only the impact of enforcement differentials among mines and over time. If non-regulatory changes, such as the decline in labor relations and the 1973 increase in the demand for coal, differentially affected fatal and non-fatal injury rates, the inconsistent results of the two studies could be explained.

If the enforcement of safety regulations led to no decline in labor productivity, the estimated consequences of increasing inspection rates by 25 per cent would be, annually, 5 to 14 fewer deaths and 1,000 to 1,400 fewer disabling injuries at these mines. The assumption of no impact on productivity is unrealistic. Neumann and Nelson estimate that one-third of the productivity decline in the early 1970s was caused by the CMHSA. There was a 31 per cent decline in output per day worked between 1970 and 1975, one-third of which (10 per cent) may be attributable to the Act. The impact of a 25 per cent increase in inspections can be recalculated assuming that work-hours and therefore exposure would have been 2.5 per cent higher. In this case, there would have been three to 13 fewer fatalities and 860 to 1,300 fewer disabling injuries. If these results could be applied to all underground mines (and they may not be applicable), a 25 per cent inspection rate would lead annually to four to 17 fewer deaths and 1,000 to 1,500 fewer disabling injuries. It should be stressed that statistical problems caused by simultaneity or by omitted variables would lead to an underestimate of MSHA's impact by this study. Thus, the results are conservative estimates of regulatory effectiveness.

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APPENDIX

Statistical Issue—Unobserved, Unchanging Differences among Mines

Past investment history, management's interest in safety, or unchanging unmeasured geological conditions may lead to the level of accidents being higher in certain mines than would be predicted by the model presented above. Such unobserved variables would bias the coefficients of equations (A) and (B). MSHA inspectors are likely to have more information on hazardousness than is available in this study, and to inspect more frequently at more hazardous workplaces. Unobserved variables positively associated with hazardousness are thus also likely to be positively associated with inspection rates. If this is the case, the coefficient of INSP and CLOSE in the incorrectly specified equation will be greater than the true coefficient. An upward bias in b_1 and b_2 in (A) and (B) would strengthen confidence in any negative estimates of these two coefficients—that is, estimates indicating that MSHA enforcement reduced injury rates.

We have attempted to eliminate the bias by using instrumental variables estimates of FINE and CLOSE that are not highly correlated with unobserved variables affecting inspection rates. In the case of FINE, we estimate the following regression:

$$\text{FINE} = c_0 + c_1\text{CONT} + c_2\text{LONG} + c_3\text{SECT} + c_4\text{UNION} + c_5\text{YR} + c_6\text{DIST} + n$$

where,

YR = a net of dummies representing the year of the observation
DIST = a net of dummies representing the district of the mine observed

The instrumental variables in the above equation were chosen because *a priori,* they were believed to be correlated with FINE and CLOSE and have little correlation with omitted variables affecting inspection rates. The variable YR is used because MSHA's total allocation of resources to inspections has changed from year to year, and it is expected that these changes would be reflected in the number of days that individual mines were inspected. In addition, as reflected in Table 1, MSHA policy changes led to increases in penalties and orders during 1973–75, an impact which YR is meant to capture. DIST reflects differences in enforcement resources and thereby inspection rates among MSHA districts.