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Data Mining Mining Data: MSHA Enforcement Efforts, Underground Coal Mine Safety, and New Health Policy Implications

Thomas J. Kniesner and John D. Leeth

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Thomas J. Kniesner is the Krisher Professor of Economics and Senior Research Associate, Center for Policy Research at the Maxwell School of Citizenship and Public Affairs. John D. Leeth is Professor of Economics at Bentley College. The authors are grateful to the Mine Safety and Health Administration for providing the data necessary to complete this study. They are especially grateful to Fred Menke of MSHA for helping with their request for data and for answering their questions about MSHA procedures. Finally, the authors want to thank Dan Black, Gary Engelhardt, Bill Horrace, Jeff Kubik, Jeff Racine, John Moran, the members of Syracuse University's Economics Department Seminar and Syracuse University's Public Finance Breakfast, and the members of the Health and Safety Seminar of the McDonough School of Business at Georgetown University for their helpful comments. All communications can be sent to Thomas J. Kniesner; Center for Policy Research, 426 Eggers Hall; Syracuse University; Syracuse, NY 13244–1020 USA; (315) 443–4589; Fax: (315) 443–1081; TKniesne@Maxwell.Syr.Edu

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Executive Summary

Studies of industrial safety regulations, OSHA in particular, often find little effect on worker safety. Critics of the regulatory approach argue that safety standards have little to do with industrial injuries, and defenders of the regulatory approach cite infrequent inspections and low penalties for violating safety standards. We use recently assembled data from the Mine Safety and Health Administration (MSHA) concerning underground coal mine production, safety regulatory activities, and workplace injuries to shed new light on the regulatory approach to workplace safety. Because all underground coal mines are inspected at least once per quarter, MSHA regulations will not be ineffective because of infrequent inspections. We estimate over 200 different specifications of dynamic mine safety production functions, including ones using deliberately upward biased estimators, and cherry pick the most favorable mine safety effect estimates. Although most estimates are of insignificant MSHA effects, we select the single regression specification producing the most favorable MSHA impact from the agency viewpoint, which we then use in a policy evaluation. We address the question of whether it would be cost-effective to move some of MSHA's enforcement budget into alternative programs that could also improve the health of the typical miner. Even using cherry picked results most favorable to the agency, MSHA is not cost effective at its current levels. Even though MSHA is a small program when judged against others like OSHA and EPA, MSHA's targeted public health objective could be much better served (almost 700,000 life years gained on balance for typical miners) if a quarter of MSHA's enforcement budget were reallocated to other programs such as more heart disease screening or defibrillators at worksites.

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1. Introduction

There is much evidence that OSHA inspections have not been effective in reducing injuries (Kniesner and Leeth 1995, Chapters 1 and 2). One explanation is that there are too few OSHA safety inspections to make a difference to firms. OSHA inspections also might not matter much to worker safety because of low fines or irrelevant safety regulations. In contrast to the relatively infrequent OSHA inspections in construction or manufacturing, mines regulated by the Mine Safety and Health Administration (MSHA) are inspected quarterly. Also in contrast to OSHA inspections, mine safety inspectors can effect a work stoppage until a safety violation is corrected. We use recently assembled data on underground coal mine production, injuries, and safety inspection and other regulatory activity to examine econometrically the effectiveness of the regulatory approach to workplace safety where the law is potent and inspections frequent. We find that even if we cherry-pick results to maximize the estimated effectiveness of MSHA there is an excess of inspections in mining, which has a notable cost of foregone opportunities to improve the typical miner's health through other existing means.

By way of background, the Federal Coal Mine Health and Safety Act of 1969, as it is formally called, was the most comprehensive and stringent Federal legislation covering the mining industry. It included surface as well as underground coal mines, required two annual inspections of every surface coal mine and four at every underground coal mine, and greatly increased federal enforcement powers in coal mines. The Coal Act required monetary penalties for all violations and established criminal penalties for knowing and willful violations. The safety standards for all coal mines were strengthened and health standards adopted. The Coal Act included specific procedures for developing improved mandatory health and safety standards and established compensation for miners who were totally and permanently disabled by the by the progressive respiratory disease know as black lung. The annual enforcement budget of

MSHA is about 60 percent the size of OSHA's, $110 million. (For more details see http://www.msha.gov).

A focal point of our research is to estimate an econometrically sophisticated regression model of the connection between mine inspections and mine safety outcomes. We adopt the general dynamic panel model of Arellano and Bond (1991), which incorporates sluggish adjustment between desired safety outcomes along with endogeneity of both production and safety policy at the mine level. We purposely examine a large number (200+) of econometric specifications, including ones deliberately biased upwards, so as to find maximal MSHA effects.

The dynamic quarterly unbalanced panel model we estimate is in sharp contrast to the empirical specifications in the existing literature. Previous work examines aggregate trends in injuries without covariates directly related to MSHA activities and attributes success to MSHA if a downward trend in coal mine injuries continued or accelerated after MSHA (Lewis-Beck and Alford 1980, Weeks 1995) or infers a positive effect of MSHA on mine safety if injuries are lower in the post-MSHA period without any consideration of the pre-MSHA pattern of injuries (Neumann and Nelson 1982, Fuess and Loewenstein 1990).[1] Our research is distinctive not only because we allow for a general background trend in mine injuries but also because do not simply attribute unexplained changes in injuries to mine safety regulation as we have direct measures of safety regulation enforcement.

To summarize our results, we focus on estimates of the exogenous general deterrence effects of MSHA, which capture regulatory activities for the mine's enforcement district. In only 1/200 specifications are the estimated MSHA effects on injuries negative and large relative to their standard errors. Purposely ignoring the issue that statistical significance is suspect when the data have been mined ex ante (Lovell 1983), we then use the single set of parameter estimates most favorable to MSHA in a policy evaluation of the agency's current regulatory activities. Even if a modest amount of MSHA's relatively small enforcement budget, say 25 percent, were reallocated to other public health programs targeted to the demographic groups that are typically

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[1] For an examination of the effect of pre-MSHA state mining laws see Fishback (1992) and Boal (2003).

miners, there would be a substantial gain in health status of the target population (about 700,000 additional life years).

2. Estimates Needed to Calculate Cost-Effectiveness

We begin by describing the information needed to examine the cost-effectiveness of mine safety policy. We first answer the focal question of our research. What do we need to do econometrically with our newly constructed data set on underground coal mines to estimate the response parameters required for evaluating the workplace safety effects of MSHA?

2.1 Effectiveness

Effective safety inspections can reduce deaths and injuries simultaneously. If *totinj* is the total number of injuries (fatal and non-fatal) then the algebraic expression for the economic benefit (B) of reducing one workplace (mining) injury is the economic value of $d(totinj) = -1$, which is

$$B = \alpha_f VL + (1 - \alpha_f) VI \,. \qquad \textbf{(2.1)}$$

In (2.1) VL is the revealed value of life, VI is the revealed value of avoiding injury, and α_f and $(1 - \alpha_f)$ are the proportions of injuries involving fatal versus non-fatal injuries in coal mining. The value of injury reduction is a weighted combination of the values placed on avoiding fatal and non-fatal injuries.

2.2 Costs

Let *wonum* be the number of inspections per mine per quarter with at least one so-called withdrawal order (the mine must remove workers from the mine) because of a serious safety or health violation. Next, let *pennum* be the number of inspections per mine per quarter with at least one monetary fine for a serious safety or health violation. If MSHA inspections neither ignore dangerous conditions nor concoct ones that do not exist then the only way for MSHA to improve safety in underground coal mines is to increase the number of inspections. The additional inspections would then result in more withdrawal orders or more monetary penalties per mine.

If I is the number of inspections per mine then the maximum safety impact of additional inspections through additional withdrawal orders and monetary penalties is

$$d(totinj) = -\frac{\partial totinj}{\partial wonum}\frac{\partial wonum}{\partial I}dI - \frac{\partial totinj}{\partial pennum}\frac{\partial pennum}{\partial I}dI \ . \qquad \textbf{(2.2)}$$

In the case where the proportions of withdrawal order inspections and monetary penalty inspections are constants (b_j), $wonum = b_w I$ and $pennum = b_p I$. Substituting yields

$$d(totinj) = -b_w \frac{\partial totinj}{\partial wonum}dI - b_p \frac{\partial totinj}{\partial pennum}dI \ . \qquad \textbf{(2.3)}$$

Because diminishing returns to inspecting mines may hold in reality, (2.3) produces a lower bound to the number of inspections it would take to eliminate one injury, which in turn means that calculations based on (2.3) may overstate the cost-effectiveness of MSHA, giving the benefit of the doubt to the agency.

The most important aspect of our research will be the safety outcomes regressions that yield estimates of $(\partial totinj / \partial wonum)$ and $(\partial totinj / \partial pennum)$. Once we have regression estimates of the two partial derivatives we can set $d(totinj) = -1$ in (2.3) and solve for *dI* to determine the number of additional MSHA inspections needed to eliminate one workplace injury, which is

$$dI = \frac{1}{b_w\left(\frac{\partial totinj}{\partial wonum}\right) + b_p\left(\frac{\partial totinj}{\partial pennum}\right)} \ . \qquad \textbf{(2.4)}$$

To address the issue of cost effectiveness, we can compare the cost of the additional inspections computed at the average cost, ($AC \times dI$), to the benefits of the additional inspections evaluated in (2.1).

3. Conceptual Framework

It is helpful to place into an economic context of the firm the two partial derivatives in (2.4) that are the primary components of the cost of MSHA safety enforcement activities. The small-scale economic model of the firm we present clarifies how to estimate econometrically the effectiveness of MSHA in a way that improves on the existing empirical literature concerning the cost-effectiveness of the regulatory approach to enhancing mine safety.

Consider a mine in year *t* with an (endogenous) optimal stock of health and safety capital per mine, q_t. We denote the workplace injury rate by IR_t. Job risk outcomes are related to health and safety capital by the function $R(\bullet)$, which is the inverse of the production function for worker safety, $S(\bullet)$, such that

$$IR_t = R(q_t) = S^{-1}(q_t)\,. \qquad \textbf{(3.1)}$$

In the typical situation safety capital is productive and regulation not counterproductive to the workplace safety environment ($R' \le 0$ and $\partial q_t / \partial m_t \ge 0$, with m a vector of MSHA activities) so that $IR_t = R(q(m_t))$ and $\partial IR_t / \partial m_t \le 0$.[2]

In the econometric specification of the inverse safety production function that we estimate we acknowledge that the impact of MSHA enforcement involves multiple activities, each of which can have non-linear effects described by the reverse S-shape depicted in Figure 1. In particular, we will allow the starting level of MSHA enforcement to condition its marginal effectiveness, such that more enforcement may be ineffective when starting from either very low or very high initial levels. The shape in Figure 1 also implies that reducing MSHA somewhat from very high initial levels can be cost-effective.

Before we describe the econometric model and the resulting parameter estimates there are a few more conceptual details to flesh out in (3.1). First, safety capital wears out, as does all capital, so that $R(q_t) = R(\Delta q_t + (1-d)q_{t-1})$, where Δ indicates investment and d is the depreciation rate. It will also typically be the case that the function $R(\bullet)$ will be conditioned by the characteristics of workers and the technology contributing to injuries, such as worker safety training or scale of output (Viscusi 1992). Using Z_t to represent the other econometrically includable conditioning factors, the inverse safety production function is

$$IR_t = R(IR_{t-1}, m_{t-1} \mid Z_t)\,. \qquad \textbf{(3.2)}$$

The optimal amount of safety capital, q, at time t depends on its previous level and the firm’s desired investment in safety capital, both of which depend on previous injury levels and mine safety regulation enforcement, IR_{t-1} and m_{t-1}. It is convenient to

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[2] Although we prefer the safety production function characterization (Viscusi 1992) as a way of thinking about the regression specifications to follow, the model is econometrically indistinguishable from the behavioral regulation approach (Scholtz and Gray 1990) and the optimizing social regulator approach (Auld et al. 2001).

think of the previous injury rate, IR_{t-1}, as reflecting empirically the previous period's stock of safety and health capital, q_{t-1}. It will then be the case that $\partial IR_t / \partial m_{t-1} \leq 0$ if (after allowing for threshold effects depicted in Figure 1) MSHA has its intended effects on workplace activities. Because we do not have direct observations on investment in safety capital, Δq_t, the estimated effect of MSHA will reflect both the direct regulatory effect on safety plus any indirect effect through the agency's impact on health and safety investments not reflected in Z_t (Viscusi 1992).[3]

4. Econometric Background

The theoretical discussion of the last section emphasized the need for control covariates and dynamic adjustment to the ultimate equilibrium safety level, which leads naturally to the Arellano-Bond dynamic panel model that is summarized in general algebraic form as

$$y_{it} = \sum_{j=1}^{p} y_{it-j} a_j + x_{it} b_1 + w_{it} b_2 + u_i + e_{it} \qquad i = 1,\dots,N;\ t = 1,\dots,T_i, \qquad \textbf{(4.1)}$$

where a_j are p parameters to be estimated, x_{it} is a $1 \times k_1$ vector of strictly exogenous covariates, b_1 is a $1 \times k_1$ vector of parameters to be estimated, w_{it} is a $1 \times k_2$ vector of predetermined covariates, and b_2 is a $1 \times k_2$ vector of parameters to be estimated.[4] The u_i are random effects that are independent and identically distributed (*iid*) over mines with variance s_u^2, and the overall errors, e_{it}, are *iid* over the whole sample with variance s_e^2 and covariance $s_{ue} = 0$ for each mine over all time periods. When estimating the inverse safety production function of (3.2) with the Arellano-Bond estimator of (4.1) the dependent variable is a mine's total injuries; the predetermined variables include production levels and mine-specific MSHA enforcement activities, and exogenous

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[3] When estimating (3.2) we allow for distributed lags in IR and m and treat both as endogenous.

[4] A strictly exogenous variable, x_{it}, satisfies $E[x_{it}e_{is}] = 0$ for all t and s. A predetermined variable can have $E[w_{it}e_{is}] \neq 0$ for $s > t$ but $E[w_{it}e_{is}] = 0$ for all $s \leq t$. Put simply, if the error term at time t has some feedback on later realizations of w, then w is a predetermined variable. The idea is that unforecastable errors today might affect future changes in w.

variables include mine district MSHA enforcement activities plus mine district and time dummies.

The Arellano-Bond estimator proceeds by first differencing (4.1), which removes u_i and leaves the equation estimable by instrumental variables. Arellano and Bond derived a GMM estimator for a_j ($j \in \{1, \ldots, p\}$), b_1, and b_2 using as instruments the lagged levels of the dependent variable and predetermined variables and differences of the strictly exogenous variables.[5]

A practical problem with the Arellano-Bond estimator is that predetermined variables greatly increase the size of the instrument matrix. A very large instrument matrix makes GMM estimators perform poorly in small samples or makes the model inestimable.[6]

It also is important to note that there are two versions of the Arellano-Bond estimator, a one-step estimator and a two-step estimator, which adds additional complexity for the applied researcher. In the one-step estimator the Sargan test over-rejects the overidentifying restrictions when there is heteroskedasticity. However, the standard errors of the two-step estimator are biased downward in small samples. So, the researcher generally uses both the one-step and two-step Arellano-Bond estimators, but for different purposes. The two-step results are better for model specification testing of the over-identifying restrictions, and the one-step results are better for inferences on the regression coefficients. Finally, it is important to note that the dynamic model in (4.1) is not identified if the dependent variable is persistent (a pure random walk makes lagged

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[5] We estimate our dynamic panel regressions using XTABOND from STATA. The model rests on no second-order autocorrelation in the first-differenced errors; the XTABOND routine produces so-called robust (to heteroskedasticity) standard errors, incorporates the needed tests for autocorrelation as well as the Sargan test of the overidentifying restrictions. The Sargan test is poorly sized, however, and difficult to pass when the instrument set is relatively large as in our case (Hall and Horowitz 1996, Ziliak 1997); it is therefore not surprising that none of the regressions we discuss pass the Sargan test.

[6] For illustration consider the case where the right-hand side of (4.1) contains exogenous variables, one lagged outcome, y_{t-1}, and no predetermined variables, so that in the estimated differenced form the regressors become Δx_t and Δy_{t-1}. At $t = 3$, y_1 is a valid instrument, at $t = 4$, y_1 and y_2 are valid instruments, which adds another column to the instrument matrix Z, and so on, which are in addition to the columns for each x. More generally, if p is the number of lagged y's in the model, i is the number of cross-section units, and T is the total number of time periods, then the number of columns in Z is $\sum_{i=p}^{T-2} i$. Predetermined variables are like lagged y's in terms of adding columns to the instrument matrix. In our estimation we work with 1–8 lags of y, 1–3 predetermined variables, 1–206 x's, with the maximum $T = 55$ and $i = 3450$, so that our models are often constrained by the maximum feasible width of Z in STATA.

levels of y weak instruments, and weak instruments lead to finite sample bias in panel instrumental variables models), so one should also test for a unit root in y_t before estimating (4.1) (Bond 2002).[7]

5. Data

To generate our data for estimation we merge five separate data sets provided by the Mine Safety and Health Administration covering inspections, violations, assessed penalties, injuries, and production and employment. The five data sets provide unique tracking numbers for each inspection, violation, and mine. Using the violations and inspections tracking numbers we link the information on assessed penalties and violations to information on inspections. We then combine enforcement information and quarterly data on production and employment based on mine identification numbers and beginning dates of the inspections. Likewise, we tie injury information to each mine and each quarter based on the date of injury and mine identification number.[8] The merged data set we use in estimation contains quarterly information on MSHA enforcement efforts and mining injuries, employment, and production during 1983–1997.

Although MSHA enforcement efforts may have an immediate effect on the frequency or severity of accidents, they are unlikely to change the immediate incidence of health-related problems such as hearing loss or black-lung disease. Mine-related diseases develop gradually so that it is unlikely we can adequately determine the effect of MSHA enforcement efforts on miner health using information spanning the 15 years available. Accordingly, we exclude from the original data set all inspections focusing on health (such as inspections of a mine's ventilation system or monitoring for dust, noise or silica). To narrow our focus further to inspections likely to improve miner safety directly we also exclude all MSHA actions not on mine property, activities related to education and training, investigations for discrimination, and audits of accident, injury, illness, and employment records. In every case where we exclude an inspection or MSHA activity we likewise exclude the resulting citations, orders, and penalties.

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[7] Simple and augmented Dickey-Fuller tests (Greene 2003, Chapter 20) reject the null hypothesis of a unit root in $totinj_t$, our focal dependent variable.

[8] Because MSHA does not list contractor production, employment, and injury data separately for each mine we exclude outside contractors from our research.

Figures 2–4 depict the history of mine safety, including the quarterly data in our estimation sample. What the annual data in Figure 2 show is that MSHA, as it post-dates the 1969 Coal Act, may have had its intended effect of improving safety, at least where fatal injuries are concerned. Figure 3 also reveals the possibility that non-fatal injuries too may be affected by MSHA, most recently since the mid-1980s. Finally, Figure 4, which plots the quarterly data in our estimation sample of 1983–1997, emphasizes the seasonality of injuries as well as supports the possibility that MSHA has been effective in reducing miner injuries since the middle 1980s.

Table 1 presents summary statistics on MSHA safety-related enforcement activities directed at coal mines operating during 1983–1997.[9] All monetary figures have been adjusted to reflect inflation to 2002. The first two panels provide information on individual citations and orders to withdraw miners from the worksite, the third panel reports MSHA penalties per inspection, and the last two panels provide total enforcement efforts per quarter.

Panels A and B of Table 1 reveal that most, but not all, MSHA penalties were imposed for serious violations of health and safety standards. About 60 percent of citations and 57 percent of withdrawal orders were issued for violations that MSHA inspectors viewed as significant and substantial, or likely to result in injury.

With an average of $184, initial fines on citations were fairly small. Fines on withdrawal orders were considerably larger, averaging $2,079, although only 60 percent of withdrawal orders imposed a separate monetary penalty.[10] MSHA adjusted initial penalties downward over time. Monetary penalties on withdrawal orders fell from their initial amounts an average of 39 percent and monetary penalties on citations fell from their initial amounts an average of about 14 percent.

The degree of operator negligence may at least partially explain the much larger average fine on withdrawal orders than on citations. Approximately 88 percent of the violations resulting in a withdrawal order were classified by MSHA inspectors as caused by a high degree of operator negligence or reckless disregard of mine safety, whereas

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[9] We define a mine as operating in a quarter if it employed at least one hour of labor.

[10] In many cases the monetary penalty for a violation resulting in a withdrawal order is added to a previous citation.

only about two percent of the violations resulting in the issuance of a citation were caused by a high degree of operator negligence or reckless disregard of miner safety.

Besides a monetary penalty, withdrawal orders also shut down production, which imposes a potentially large cost if operations are disrupted for an extended period. At least fifty percent of the withdrawal orders were terminated fairly quickly, in one day or less, but for a sizable number the days from issuance to termination extended for weeks and, in some cases, months and years. Because of the extremes the average number of days from issuance to termination is large, 32.2 days. Appendix A provides additional details of the distribution of lost days. As shown, 25 percent of all withdrawal orders from 1983 to 1997 extended for 6 days or more and 5 percent extended for 112 days or more. With such a potentially long shut down period, mines had strong incentives to avoid conditions likely to result in withdrawal orders. Additionally, the harsh penalties shown in Appendix A for failure to abate and imminent danger hazards likely motivated mines to rectify previously discovered problems and avoid conditions liable to result in death or severe injury. By way of contrast, the incentives to avoid citations resulting only in monetary penalties were quite small. From 1983 to 1997, 95 percent of all citations had initial fines less than $447 and 99 percent had initial fines less than $1,158. By law mines must continue to pay miners for the remainder of the shift during which a withdrawal order is issued and for up to 4 hours the next day if the withdrawal order is still in effect, meaning that the monetary losses from a withdrawal order almost always substantially exceed the losses from a simple citation resulting in a fine.

As can be seen in Panel C of Table 1, about 40 percent of MSHA safety inspections led to a monetary penalty, and about five percent of inspections resulted in a withdrawal order. About 31 percent of all inspections uncovered at least one serious violation of MSHA health and safety standards, and about five percent of inspections discovered at least one violation with a high degree of operator negligence. For inspections where a monetary penalty was imposed the initial fines for all citations and withdrawal orders issued during the inspection averaged $1,503. Over time, the monetary penalties fell by about 14 percent on average.

Panel D of Table 1 presents MSHA enforcement efforts per quarter. The average operating coal mine was inspected for safety-related problems 4–5 times per quarter but had slightly less than two inspections per quarter resulting in monetary penalties and 0.211 inspections per quarter resulting in withdrawal orders. Per inspection with fines, the average monetary penalty for all violations was $1,263. On average, MSHA reduced monetary penalties by about 16 percent from initial levels.

Finally, Panel E of Table 1 indicates quarterly enforcement efforts with all minor violations excluded, which are violations that MSHA inspectors believe are unlikely to result in injury. MSHA can improve miner safety to the extent that inspectors can identify serious violations of safety standards, violations likely to result in injury. MSHA discovered serious violations of safety standards in a large majority of mines each quarter. Slightly more than 71 percent of all mines received at least one monetary penalty for a serious violation of safety standards. Per quarter, the average operating coal mine had about 1.4 inspections resulting in monetary penalties for serious violations, 0.11 inspections resulting in withdrawal orders, and 0.18 inspections with one or more high degree of operator negligence violations. The average fine in a quarter for mines with serious violations that receive monetary penalties was $1,442. Over time monetary penalties fell on average by about 17 percent.

6. Econometric Results

We now describe the large number of specifications of a dynamic mine safety equation that we estimated. In contrast to Sala-I-Martin (1997) who examines several million regressions to find the true model of country growth, we search among a large number of regressions to find the single set of results the most favorable to MSHA. We then use our shamelessly data mined results in best-case calculations of the cost effectiveness of MSHA and it implications for improving the health and safety of the population typically working as miners.

Our research also is similar to a meta-analysis on one data set because in the process of estimating a large number of econometric specifications we will as a by-product see if a pattern emerges with regards to the effectiveness of MSHA in influencing miner safety. The large number of regression specifications (200+) comes about because we consider various (1) safety measures (total injuries, injury rate, fatal injuries, non-fatal injuries, zero versus some injuries), (2) MSHA activities (specific abatement, general deterrence, both), (3) instrument sets (small, medium, large), (4) time frames (quarterly, annual), (5) distributed lag structures (1, 4, and 8 quarters), (6) output measures (production, labor hours), (7) degrees of non-linearity in MSHA effects (linearity, cubic, orthogonal polynomials), (8) time effects (yes, no), (9) location effects (yes, no), (10) non-exogeneity of MSHA's mine-specific abatement activities (yes, no), and (11) estimation techniques (GMM, OLS, Tobit, Heckit, count models). The conclusion emerging is that the results in the overwhelming number of cases are unfavorable to the safety enhancement objective of MSHA at current levels of regulation.

6.1 Key Regression Variables

Table 2 presents definitions of the regression variables. In using the Arellano-Bond dynamic panel model (4.1) on our quarterly mining data the focal dependent variable is $totinj_{it}$, which is the number of workers in quarter t at mine i that have a lost-workday injury, including death. Exogenous variables include quarterly time dummies and mine district location dummies, which are described in Appendix B. Always treated as predetermined is our primary measure of mining activity, the log of total employee hours worked, $lhour_{it}$.

We consider three specifications for MSHA activities: models with general (mine-district level) deterrence measures, models with specific (to the mine itself) deterrence measures, and models with both general and specific deterrence measures. Here the vector $m(\text{general})_{it} \equiv [lindamt_{it}, pennum_{it}, wonum_{it}]$, where *lindamt* is the log of the mine's enforcement district average monetary penalty per inspection with monetary penalty (calculated excluding mine i), *pennum* is the mine's enforcement district's inspections per mine with monetary penalty (excluding mine i), and *wonum* is the mine's enforcement district's inspections per mine with withdrawal order (excluding mine i). The vector $m(\text{specific})_{it} \equiv [posnum_{it}, sumwo_{it}]$, where *posnum* is the mine's number of inspections with monetary penalties, and *sumwo* is the mine's number of inspections with withdrawal orders.[11] So, when estimating the dynamic panel model of mine injuries (4.1) we examine specifications where m(general) is part of x and specifications where

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[11] All penalties (monetary and withdrawal orders) are for violations of standards deemed serious or substantial where the likelihood of an injury occurring is viewed to be likely, highly likely, or has already occurred.

m(specific) is part of w and include up to four lagged values of both y and m on the right-hand side for symmetry in dynamic adjustment in y to past shocks and policy changes.

To fix ideas, the prototypical model specification we estimate is

$$\Delta y_{it} = \sum_{j=1}^{4} \Delta y_{it-j} a_j + \sum_{j=0}^{4} \Delta x_{1it-j} b_{1j} + \sum_{j=0}^{4} \Delta w_{it-j} b_{2j} + x_{2it} g + \Delta e_{it}\,, \qquad \textbf{(6.1)}$$

where general deterrence is part of x_1, specific deterrence is part of w and time and location effects are conditioned out in x_2. Although one can consider the dynamic patterns in coal mine injuries here we are generally interested in equilibrium multiplier effects of MSHA, which are $(\frac{\sum_j b_{kj}}{1-\sum_j a_j})$, $k = 1, 2$.

6.2 Focal Regression

We could not produce a single regression using mine-specific abatement measures that had an estimated negative effect for MSHA, which we attribute to the inability of the instrumental variables approach to correct for the endogeneity of MSHA whereby additional injuries in a mine trigger additional inspections. Regressions with specific deterrence regressors that parallel our focal regression in terms of specification and instrument sets appear in Appendix C. For our subsequent cost-effectiveness calculations we selected the only regression from over 200 we estimated that simultaneously satisfied the following criteria: computational feasibility (maximum lag length for an instrument is 15 quarters), quarterly data; time and location dummies; four-quarter lags on the injury rate, production, and MSHA; at least one negatively signed MSHA coefficient that is 1.68 times its standard error; and the estimated equilibrium impact effect of MSHA is also negative ($\sum_j \hat{b}_j < 0$).[12]

The only (one-step Arellano and Bond) regression that satisfied the intersection of our model selection criteria just described produced the following result, where underline indicates that the coefficient was 1.68 times its (robust) standard error:

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[12] Remember that the 5 percent nominal significance level for a one-sided hypothesis test is only a heuristic because of the large amount of data mining behind the regression result. A useful approximate result described in Lovell (1983) for the connection between the true and claimed levels of significance is that a(claimed) = (k/c) × a(true), where a search has been conducted for the best k out of c candidate explanatory variables' coefficients.

$$
\begin{aligned}
Dtotinj_t = {} & \underline{0.39}Dtotinj_{t\text{-}1} + \underline{0.15}Dtotinj_{t\text{-}2} + \underline{0.06}Dtotinj_{t\text{-}3} + \underline{0.04}Dtotinj_{t\text{-}4} \\
& + \underline{1.10}Dlhour_t - 0.07Dlhour_{t\text{-}1} - \underline{0.06}Dlhour_{t\text{-}2} - \underline{0.04}Dlhour_{t\text{-}3} - 0.06Dlhour_{t\text{-}4} \\
& - 0.01Dlindam_t - 0.02\Delta lindam_{t\text{-}1} - 0.01\Delta lindam_{t\text{-}2} + 0.03Dlindam_{t\text{-}3} + 0.02Dlindam_{t\text{-}4} \\
& - 0.04Dpenum_t - 0.04\Delta penum_{t\text{-}1} - 0.12\Delta penum_{t\text{-}2} + 0.04Dpenum_{t\text{-}3} + 0.06Dpenum_{t\text{-}4} \\
& - 0.08Dwonum_t - \underline{0.73}\Delta wonum_{t\text{-}1} + 0.07\Delta wonum_{t\text{-}2} + 0.29Dwonum_{t\text{-}3} - 0.45Dwonum_{t\text{-}4} \\
& + g_1 \text{ time dummies} + g_2 \text{ location dummies.} \qquad \textbf{(6.2)}
\end{aligned}
$$

$h_{lindam} = 0.015$, $h_{penum} = -0.25$, $h_{wonum} = -0.16$

P(No 1st order serial correlation) = 0.00, P(No 2nd order serial correlation) = 0.11

Our focal regression (6.2) yields an equilibrium impact multiplier for *lindam* that is small, positive and statistically insignificant (which we will subsequently ignore in our policy simulations), an equilibrium impact multiplier for *penum* that is –0.31, which implies an elasticity at the means of – 0.25, and an equilibrium impact multiplier for *wonum* that is −2.53, which implies an elasticity at the means of – 0.16.[13] Interestingly, both of the estimated MSHA effects in (6.2) are close to the results in Scholtz and Gray (1990) for the general deterrence effects of OSHA.

7. MSHA Cost-Effectiveness Calculations

Before considering the economic and policy implications of our results we note that some might view omitting possible health improvements from MSHA inspection activities as a gap in our research. In 1970, the year after passage of the Coal Mine Act, the number of death listings with any mention of coal workers' pneumoconiosis (black lung disease) was 2,189; by 1996 the number of death listings had dropped 35 percent to 1,417 (U.S. Department of Health and Human Services 1991, 1999). The incidence of coal workers' pneumoconiosis fell even more dramatically than the number of death

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[13] To try to enlarge the estimated effect of MSHA we have also estimated the statistically most biased dynamic panel regression models, which are OLS, IV fixed effects and IV first-differences (Blundell, Bond, and Windmeijer 2000; Bond 2002). In the IV fixed effects results no general deterrence coefficient was at least 1.68 times its standard error, and the results from IV first differences did not satisfy the basic stability condition that $\sum_j a_j < 1$. OLS results yield no coefficient for either *lindam* or *penum* that is both negative and at least 1.68 times its standard error and $\hat{h}_{wonur} = -0.19$. Finally, the estimated effects of MSHA are positive when we smooth our quarterly data by annualizing it.

listings. During the first round of the NIOSH Coal Workers' X-Ray Surveillance Program (1970–1973), 11 percent of miners had some form of coal workers' pneumoconiosis. During the sixth round of surveillance (1992–1996), 2.8 percent of miners had some form of coal workers' pneumoconiosis, which is about a 75 percent drop from the initial level (U.S. Department of Health and Human Services 1999). Although MSHA may have been a factor in improving miner health, other factors may also have contributed, such as improvements in technology, union efforts, greater worker awareness, and even reductions in smoking incidence.

Attempting to disentangle all the potential influences on miner health would be difficult econometrically, to say the least. Even more problematic would be trying to relate health improvements to specific inspections given the long lag-time between worker exposure and any signs of worker ill health. Our research, therefore, focuses on the impact of MSHA general and safety-related inspections on miner safety. We exclude from our empirical work enforcement activities not on mine property, including computer generated dust sampling, education and training activities, and inspections geared specifically toward health issues. Because general and safety-related inspections uncover few health-related problems, changes in the number of the inspections we examine should have little impact on miner health.[14]

7.1 Baseline Values

We now turn our attention to the arithmetic details of safety inspections' costs and benefits. Viscusi (1993) and Viscusi and Aldy (2002) argue that the range of reasonable value-of-life estimates is from $3 million to $7 million and that the value of a lost workday injury is about $50,000 ($1990). The highest reported implicit value of injury in Viscusi (1993) is Biddle and Zarkin's (1988) estimate based on willingness to accept, $131,495. We base our calculations of the costs and effectiveness of MSHA on the estimates of the economic losses from fatal and non-fatal injuries just mentioned.

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[14] In our estimation sample we have data on 499,940 serious violations of MSHA standards (violations believed to result in injury). Of the almost half million violations in our data 94 percent were discovered during either general or safety related inspections and six percent were found during other MSHA enforcement activities. In the inspections in our estimation sample, over 99 percent of the citations were for safety violations.

7.2 Benefits

During 1983–1997 there were 428 fatalities and 91,773 nonfatal lost workday injuries in our estimation sample. The proportion of fatal injuries in all injuries was 0.0046, and the corresponding proportion of nonfatal lost workday injuries in all injuries was 0.9954. The value of reducing one injury established earlier in (2.1) is

$$B = 0.0046VL + 0.9954VI\ , \qquad \textbf{(7.1)}$$

where *VL* is the value of a life saved, and *VI* is the value of an injury prevented.

Using the highest value of life and value of injury figures mentioned above so as to make the gains from MSHA as large as possible, the benefit of reducing an injury in underground coal mines (converted to \$2002) is

$$B = 0.0046 \times 9{,}447{,}000 + 0.9954 \times 176{,}800 = \$219{,}443\,. \qquad \textbf{(7.2)}$$

7.3 Costs

In Section 6 we located the one of approximately 200 regressions with the largest significant estimated effects of *wonum* and *pennum*. Based on our cherry picked regression the largest possible injury reducing effect of inspections leading to a withdrawal order or a monetary penalty is then

$$d(totinj) = -2.53\frac{\partial wonum}{\partial I}dI - 0.306\frac{\partial pennum}{\partial I}dI\,.^{15} \qquad \textbf{(7.3)}$$

Here,

$$wonum = \frac{I \times \dfrac{wo}{I}}{M} \text{ and} \qquad \textbf{(7.4)}$$

$$pennum = \frac{I \times \dfrac{pen}{I}}{M}\,. \qquad \textbf{(7.5)}$$

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[15] Attempts to find subtle threshold effects of the type depicted in Figure 1 were mostly unsuccessful so our calculations use a constant value for the impact of MSHA. The cubic in MSHA that will capture the non-linearity of threshold effects also produces collinearity among m, m^2, and m^3 that necessitates the use of orthogonal polynomials regression. In the orthogonal polynomials regressions paralleling (6.1) the only polynomials with a coefficient whose value exceeded 1.0 were for $\Delta wonum_{t-3}$ and $\Delta wonum_{t-4}$, and in both cases the coefficients (of $\Delta wonum^2(t-3)$ and $\Delta wonum(t-4)$) were negative, which is contrary to the possible ineffectiveness of MSHA at relatively high or low levels of enforcement depicted in Figure 1. On the other hand we also estimated simple dynamic censored (ZINB, Tobit, and Heckit) regression models that take explicit account of the fact that about 50 percent of the observations on the dependent variable are zero. The results show that MSHA has no effect at the extensive margin and all of its effect is at the intensive

From 1983 to 1997 for the mines in our estimation sample there were 6,249 inspections with at least one withdrawal order for a serious violation, 79,888 inspections with a monetary penalty for at least one serious violation, and 252,411 inspections. The fraction of withdrawal order inspections in all inspections was 0.0248, and the fraction of monetary penalty inspections in all inspections was 0.3165. In the last quarter of 1997 the number of mines that had been operating for at least 5 quarters (the minimum necessary to be in the estimation sample) was 572.

Substituting the inspection and mines' operating numbers into equations (7.4) and (7.5) and then substituting the derivatives of equations (7.4) and (7.5) with respect to I into (7.3) yields

$$d(totinj) = -2.55\frac{0.0248}{572}dI - 0.306\frac{0.3165}{572}dI = -0.00011dI - 0.00017dI\ . \quad \textbf{(7.6)}$$

Setting $d(totinj) = -1$ and solving for dI, we determine the number of additional inspections MSHA would need to eliminate one workplace injury. Using the upper bound regression results from Section 6 produces a lower bound for dI = 3,584.

We have MSHA supplied information on inspector time for 99 percent of the 252,411 inspections of the underground coal mines in our estimation sample. Time is broken down into four categories: travel, report writing, surface inspections, and mechanized mining unit inspections. For the total sample the average and median total inspection times were 29.8 hours and 8 hours. Excluding the longest 1 percent of inspections by total time, the average and median inspection lengths were 24.7 hours and 8 hours.

According to the *Position Classification Standard for Mine Safety and Health, GS-1822*, a starting underground coal mine inspector would have a government service classification of 9. In 2001, GS-9, step 1 received an hourly wage of $15.93 (http://www.opm.gov/oca/01tables/gshrly/html/01gshr.htm).

Ignoring overhead costs and using the median inspection length, the minimum cost of the 3,584 additional inspections needed to reduce total coal mine injuries by one would then be (in $2002) equal to $3{,}584 \times 8 \times \$16.17 = \$463{,}966$.

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margin, which is imply that at low levels of injury MSHA is ineffective at reducing injuries (to zero). For econometric background on sophisticated censored dynamic panel models see Hu (2002).

7.4 Cost/Benefit

What then is the cost-benefit ratio when we ignore the fact that we cherry-picked regression results to get the most favorable impact of MSHA and in turn use the least possible cost of an inspection? The estimated cost of eliminating an injury is $463,966 and the benefit from eliminating an injury is $219,443. The implied cost/benefit ratio for the most favorable case we can construct for MSHA is about 2.1 > 1. At current levels safety inspections are not cost-beneficial.

7.5 Cost of Reducing One Fatality

We might also address the cost-effectiveness issue somewhat differently and focus on either reducing fatalities in isolation or on reducing non-fatal injuries in isolation. Because 0.46 percent of all injuries are fatalities, to eliminate a fatality one would require reducing total injuries by 1/0.0046 = 217. Because few injuries in mining are fatal, equation (6.6) indicates that the number of additional inspections required to eliminate one miner death would then be 779,155. Evaluated at the median time per inspection the cost of eliminating one fatality would be 779,156 × 8 × $16.18 = $100,865,530.

As a reference point for comparison and evaluation we can consider that regulatory allocations involve an opportunity cost as they impose real financial costs on consumers and taxpayers because the money spent on regulatory costs would otherwise be spent on other bundles of consumer commodities. Based on such risk-risk tradeoff considerations, economists have estimated that when government agencies propose risk reducing regulations that impose a cost per life saved at levels of about $69 million or more ($2002), then on balance the regulation is harming individual health (Viscusi 1994, 1998). So, it is important to recognize that the MSHA cost of saving a life is about 1.5 times the cutoff point for an acceptable life-saving regulation from broad social perspective that a policy analyst should use.

To put the amount of additional inspections needed to reduce fatalities by one into perspective (again ignoring the general lack of statistical significance of MSHA safety inspections), in 1997 the total coal enforcement budget for MSHA was $107 million (Budget of the United States Government, Fiscal Year 1999). In 1997 there were 72,390 inspections of coal mines.[16] The total cost per inspection in 1997 was therefore \$1,478, which includes more than just labor cost of the inspector. In \$2002, the cost of eliminating one fatality would then be 779,156 × \$1,501 $\cong$ \$1.17 billion, which is over 10 times the annual enforcement budget. Put differently, the increase in inspections needed to eliminate one miner death is more than 10 times the total number of inspections now conducted by MSHA.

7.6 Cost of Reducing One Injury

To eliminate one non-fatal injury would require an additional 3,601 inspections using equation (7.6). The lower bound estimate of eliminating a non-fatal injury using the median inspection time and the average cost per inspection is then 3,601 × 8 × \$16.18 = \$466,167, which is over 2.6 times the estimated benefit of an injury foregone.

8. Discussion: Policy Implications for Miners' Health

It has frequently been suggested that regulatory programs be subjected to continued OMB review for cost and effectiveness (Kniesner and Viscusi 2003 and references therein). We close with an example of how a cost-effectiveness review could be applied to MSHA because it may help to frame the policy implications of our empirical results. It will make things more transparent, too, to recast our estimated MSHA effects in terms of life years gained, on balance, if some of the MSHA enforcement budget were reallocated to a few identifiable programs likely to affect the health of miners.

8.1 Cost Per Life Year Saved by MSHA

As we have noted, the proportion of fatal injuries to all injuries is 0.0046, and the proportion of nonfatal lost workday injuries to all injuries is 0.9954. Totinj combines both fatal and nonfatal lost workday injuries. The number of lost life years saved from reducing one injury is then

$$B = 0.0046 \times (\text{lost years due to death}) + 0.9954 \times (\text{lost years due to nonfatal injury}) .$$

The average age of miners killed on the job in the estimation sample is 37.9. Based on life expectancy tables posted at the National Center for Health Statistics the

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[16] MSHA supplies inspection data for underground, surface, and mills – including mandatory inspections

remaining life expectancy of a 38 year old is 40.7 years. Using a 5 percent real interest rate (as applied in Tengs et al. 1995) the discounted number of life years saved from avoiding one mining death is then 17.3.

The average days lost from work due to a nonfatal injury in the estimation sample is 39.17. We calculate average days lost replacing reported days lost with statutory days lost for all permanent total or permanent partial disabilities with reported days lost of zero. On average, a miner loses 0.107 of a work year from a nonfatal injury. Substituting 17.3 for lost years due to death and 0.107 for lost years due to nonfatal injury into the equation above, the number of life years saved for every miner injury avoided is 0.186.

From previous calculations, the minimum cost of avoiding one injury using government inspectors' salary rates expressed in $2002 is $463,996. Combining results, the least cost per life year saved estimate in $2002 is $463,996 ÷ 0.186 = $2,494,602.[17]

8.2 Improving Health for the Target Population

Our estimates imply that using the most optimistic estimated effects from Section 7, it costs about $2,500,000 per life year gained via MSHA enforcement activities. The appropriate public policy issue, then, is whether there are cheaper ways to improve the health of the population overall or of miners in particular.

A rich source of information for our ultimate policy evaluation exercise is again Tengs et al. (1995), who calculate government cost per life year gained for 500 health enhancing interventions. If one takes a transcendental view that a life year is a life year no matter whose it is, then there are many programs Tengs et al. discover that have a per life year cost of nearly $0.[18] Suppose in addition to budget neutrality we add the second consideration that any movement of resources out of MSHA's safety enforcement budget be put into programs likely to affect persons with the demographic characteristics of the

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and investigations, enforcement activities not on mine property, and education and training evaluations.

[17] Tengs et al. (1995) only consider reducing mortality risks. Based on our calculations the marginal cost of reducing one fatality is at least $375,471,940 in 2002 dollars. Dividing by 17.3 (the number of discounted life years), the cost per life year saved by reducing only mortality risk is then about $21,703,580.

[18] A short list includes installing car windshields with adhesive bonding instead of rubber gaskets, laws requiring smoke detectors in homes, mandatory motorcycle helmet laws, banning residential growth in tsunami-prone areas, banning sale of three-wheel ATVs, rubella vaccinations for children age two, and smoking cessation advice for pregnant women who smoke. For the interested reader we note that the most expensive programs per life year gained ($2002) include sickle cell screening for non-black low risk newborns ($42 billion) and applying chloroform limits on private wells to emissions at the 48 worst case pulp mills ($123 billion).

typical miner. What net gain in health, as measured by life years, could be obtained by moving 25 percent of MSHA's enforcement budget (having one fewer inspection per mine per year) into alternative programs that could benefit the population of miners? The results are surprising despite the relative small budgetary level of MSHA.

MSHA is small relative to other well-known regulatory agencies. In recent years the overall budget of OSHA has been 1.7 times the budget of MSHA, and the annual budget of the EPA has been 24.6 times the budget of MSHA. Let us just consider now the annual enforcement budget of MSHA, which is about $110 million. One-fourth of the MSHA enforcement budget is $27.5 million. At a cost of $2,500,000 per life year, a 25 percent reduction in MSHA inspections would reduce life years by about 11, which is less than one statistical miner's life. Using the list in Tengs et al. (1995), programs that could affect the health of persons who might be in the population of miners would include more heart disease screening or more on-site defibrillators, as suggested recently by OMB, which would each produce a life year at a cost of $40. So, moving $27.5 million from the MSHA enforcement budget into more heart disease screening or defibrillators would gain on balance 687,489 = (687,500 – 11) life years for the affected population, which is equivalent to about 16,800 statistical miners' lives.

The point of the exercise is to demonstrate that even a program as small as MSHA can have relatively large opportunity costs. We have shown that a modest amount of reallocation of program expenditures can make a substantial improvement in the public health of the target population. Although there are specific mandates via OSHA and MSHA addressing workplace health and safety, funding levels for OSHA and MSHA and their target activities are legislative decisions. As policy analysts, we argue for cost-effective government policy in the area of promoting health and longevity. Our estimates demonstrate the sizeable potential gain in miners' health from budgetary reallocation to other existing programs. We believe our estimates clearly imply a need for government to take a more transcendental view by considering public health more generally and consider more comprehensively the options available to improve the health of the working population.

Appendix A. Withdrawal Orders: Days from Issuance to Termination, 1983-1997

Violation	Section of Act	Mean	Standard Deviation	Percentiles 25th	50th	75th	95th	Max	Number[1]
All		32.2	167.2	0	1	6	112	4,656	36,704
Failure to abate	104B	59.4	221.5	0	3	25	282	4,633	8,651
Unwarrantable failure to comply	104D1	22.9	121.8	0	1	5	52	3,431	8,186
Subsequent similar	104D2	15.3	125.8	0	0	2	26	1,777	13,781
Imminent danger	107A	43.9	202.6	0	1	8	178	4,656	6,086

Source: Authors' calculations.

[1] Withdrawal orders lacking termination dates are excluded from the calculations.

Appendix B: Enforcement Districts

The enforcement of MSHA standards is divided between the Coal Mine Safety and Health and Metal and Nonmetal Mine Safety and Health groups. In turn the groups are broken down into enforcement districts (11 in coal and 6 metal and nonmetal) and field offices (65 in coal and 50 metal and nonmetal). The 11 coal mining enforcement districts are:

District 1	Anthracite coal mining regions in Pennsylvania
District 2	Bituminous coal mining regions in Pennsylvania
District 3	Maryland, Ohio, and Northern West Virginia
District 4	Southern West Virginia
District 5	Virginia
District 6	Eastern Kentucky
District 7	Central Kentucky, North Carolina, South Carolina, and Tennessee
District 8	Illinois, Indiana, Iowa, Michigan, Minnesota, Northern Missouri, and Wisconsin
District 9	All states west of the Mississippi River, except Minnesota, Iowa, and Northern Missouri
District 10	Western Kentucky
District 11	Alabama, Georgia, Florida, Mississippi, Puerto Rico, and Virgin Islands

Besides conducting inspections, the regional offices also review mine plans for safety concerns. The mine operator devises appropriate engineering plans and then the engineering specialists at MSHA review and approve the proposed plans. Once approved, the mine operator must follow the plans. Specific areas include control of mine roof and ventilation system.

District managers are responsible for supervising inspectors in their districts. MSHA has acknowledged that there is inconsistency in how inspectors interpret standards. To help remedy the problem, it has established a District Managers Council (DMC) which meets quarterly to discuss and try to correct enforcement inconsistencies.

The Office of Assessments determines the size of monetary penalties. The criteria for penalties include the size of the business, the seriousness of the violation, and the degree of the mine operator's negligence. When a major accident is reported, the district manager dispatches MSHA personnel to the site. The mine operator has control and responsibility for rescue efforts but must seek approval from MSHA for actions taken.

In a report by the Office of the Inspector General on metal/nonmetal mining enforcement and compliance assistance activities it was recommended that MSHA should improve guidance to district offices regarding program implementation and operation to enhance consistency in program performance and management. The report also found disparities in the inspector resources available per mine on a district basis. Factors that should be considered in allocating inspector resources include mine size, geographic clustering, and travel time. The report also discovered that the mix of activities between enforcement and compliance assistance fluctuated among the districts and within a district from year to year. There was no consensus among district managers about the relative effectiveness of enforcement activities and compliance-oriented activities. All of the district managers believed both types of activities had merit but the difficulty was allocating time between activities. (Mine Safety and Health Administration 2001.)

Appendix C: General Deterrence Regressions*

$$
\begin{aligned}
Dtotinj_t = {} & \underline{0.32}Dtotinj_{t-1} + \underline{0.12}Dtotinj_{t-2} + 0.02Dtotinj_{t-3} - 0.01Dtotinj_{t-4} \\
& + \underline{0.56}Dlhour_t - 0.23Dlhour_{t-1} - 0.04Dlhour_{t-2} - 0.02Dlhour_{t-3} - 0.01Dlhour_{t-4} \\
& + \underline{0.26}Dposnm_t - \underline{0.13}\Delta posnm_{t-1} - \underline{0.08}\Delta posnm_{t-2} - 0.04Dposnm_{t-3} - 0.04Dposnm_{t-4} \\
& - 0.25Dsumwo_t + 0.08\Delta sumwo_{t-1} - 0.02\Delta sumwo_{t-2} - 0.05Dsumwo_{t-3} - 0.09Dsumwo_{t-4} \\
& + g_1 \text{ time dummies} + g_2 \text{ location dummies.} \qquad \textbf{(C.1)}
\end{aligned}
$$

$h_{posnum} = -0.043$, $h_{sumwo} = -0.041$

P(no 1st order serial correlation) = 0.00, P(no 2nd order serial correlation) = 0.17

$$
\begin{aligned}
Dtotinj_t = {} & \underline{0.32}Dtotinj_{t-1} + \underline{0.12}Dtotinj_{t-2} + 0.02Dtotinj_{t-3} - 0.01Dtotinj_{t-4} \\
& + \underline{0.52}Dlhour_t - 0.22Dlhour_{t-1} - 0.04Dlhour_{t-2} - 0.03Dlhour_{t-3} - 0.01Dlhour_{t-4} \\
& + \underline{0.29}Dposnm_t - \underline{0.13}\Delta posnm_{t-1} - \underline{0.07}\Delta posnm_{t-2} - 0.03Dposnm_{t-3} - 0.03Dposnm_{t-4} \\
& - 0.26Dsumwo_t + 0.12\Delta sumwo_{t-1} + 0.01\Delta sumwo_{t-2} - 0.02Dsumwo_{t-3} - 0.07Dsumwo_{t-4} \\
& - 0.03Dlindam_t - 0.03\Delta lindam_{t-1} - 0.03\Delta lindam_{t-2} + 0.03Dlindam_{t-3} - 0.0004Dlindm_{t-4} \\
& - 0.16Dpenum_t - 0.11\Delta penum_{t-1} - 0.14\Delta penum_{t-2} - 0.0003Dpenum_{t-3} - 0.10Dpenum_{t-4} \\
& - 0.02Dwonum_t - 0.68\Delta wonum_{t-1} + 0.09\Delta wonum_{t-2} + 0.27Dwonum_{t-3} - 0.52Dwonum_{t-4} \\
& + g_1 \text{ time dummies} + g_2 \text{ location dummies.} \qquad \textbf{(C.2)}
\end{aligned}
$$

$h_{posnum} = 0.048$, $h_{sumwo} = -0.027$, $h_{lindam} = -0.058$, $h_{penum} = -0.76$, $h_{wonum} = -0.10$.

P(no 1st order serial correlation) = 0.00, P(no 2nd order serial correlation) = 0.17

*underline indicates that the coefficient was 1.68 times its (robust) standard error

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Table 1. MSHA Enforcement Activities, All Active Underground Coal Mines, 1983-1997

	Mean/ Percent	Median	Standard Deviation	Minimum	Maximum
A. Citations (Observations = 971,117)					
Initial fine ($2002)	$184	$115	$526	$18	$66,043
Reduction of fine from initial level	13.7%	0%	35.0%	–3493%	100%
Serious violation	60.4%				
High degree of operator negligence	2.4%[1]				
B. Withdrawal Orders (Observations = 37,205)					
Initial fine ($2002)[2]	$2,079	$1,214	$4,132	$26	$68,822
Reduction of fine from initial level[2]	39.0%	0%	46.4%	–665%	100%
Serious violation	56.9%				
High degree of operator negligence[3]	88.4%[3]				
Days from issuance to termination[4]	32.2	1	167.2	0	4,656
C. Safety-Related Inspections (Observations = 371,684)					
Monetary penalty imposed	40.2%				
Total initial fine ($2002) for all violations found[5]	$1,503	$320	$6,911	$26	$713,260
Reduction of fine from initial level[5]	13.9%	0%	34.9%	–2400%	100%
Withdrawal order issued	4.6%				
Serious violation discovered[6]	30.6%				
High degree of operator negligence violation discovered	4.9%				
Withdrawal order issued for a serious violation	2.4%				
D. Safety Enforcement Activities per Mine per Quarter (Observations = 80,592)					
Number of inspections	4.612	3	4.999	0	78
Number of inspections with a monetary penalty	1.855	1	2.132	0	30
Average initial fine per inspection with fine ($2002)[7]	$1,263	$431	$4,409	$26	$373,494
Reduction of fine from initial level[7]	16.2%	0	35.4%	–1250%	100%
Number of inspections with a withdrawal order	0.211	0	0.581	0	16
Number of inspections with a serious violation	1.410	1	1.821	0	25
Number of inspections with a high degree of operator negligence violation	0.227	0	0.594	0	14

E. Safety Enforcement Activities Per Mine per Quarter, Excluding Nonserious Violations (Observations = 80,592)

Number of inspections with a monetary penalty	1.409	1	1.820	0	25
Number of inspections with a withdrawal order	0.108	0	0.429	0	11
Average initial fine per inspection with fine ($2002)[8]	$1,442	$515	$4,664	$26	$378,847
Reduction of fine from initial level[8]	17.2%	0%	36.0%	–806%	100%
Number of inspections with a high degree of operator negligence violation	0.184	0	0.534	0	13

Source: Authors’ calculations.

[1] Excludes the 13,545 citations failing to report the degree of operator negligence.
[2] Statistics are calculated for the 22,000 withdrawal orders with an attached monetary penalty.
[3] Excludes the 14,083 withdrawal orders failing to report the degree of operator negligence.
[4] Excludes the 501 withdrawal orders lacking termination dates.
[5] Statistics are calculated for the 149,519 inspections imposing a monetary penalty.
[6] Monetary penalties were assessed on all inspections discovering a serious violation.
[7] We calculate the average by first totaling all monetary penalties for a given inspection. Then for each mine in each quarter, we average the penalty per inspection across all inspections with penalties. Statistics are generated for the 67,594 nonzero observations.
[8] Averages are determined as described above excluding all nonserious violations. Statistics are generated for the 57,517 nonzero observations.

Table 2. Variable Definitions and Summary Statistics

Variable	Mean	Median	Standard Deviation	Minimum	Maximum	Description
Dependent Variable						
Injuries (*totinj)*	1.884	0	4.124	0	97	Number of lost-workday injuries including fatalities
General Deterrence						
Average fine ($2002)	$1,706	$1,378	$1,261	$82	$24,707	Enforcement district average monetary penalty per inspection with monetary penalty
Log average fine (*lindamt*)	7.222	7.229	0.675	4.411	10.115	Natural logarithm of average fine
District inspections with fines (*pennum*)	1.536	1.313	0.789	0	6.833	Enforcement district inspections with monetary penalties per mine
District inspections with withdrawal orders (*wonum)*	0.122	0.076	0.149	0	2.357	Enforcement district inspections with withdrawal orders per mine
Specific abatement						
Inspections with fines (*posnum)*	1.633	1	2.076	0	25	Number of inspections with monetary penalties
Inspections with withdrawal orders (*sumwo)*	0.128	0	0.473	0	11	Number of inspections with withdrawal orders
Mine Size						
Hours	36,927	12,965	61,514	1	875,668	Total employee hours worked
Log hours (*lhour)*	9.474	9.470	1.585	0	13.683	Natural logarithm of hours
Sample Size = 48,932						

Source: Authors' calculations

Figure 1
Threshold Effects in MSHA

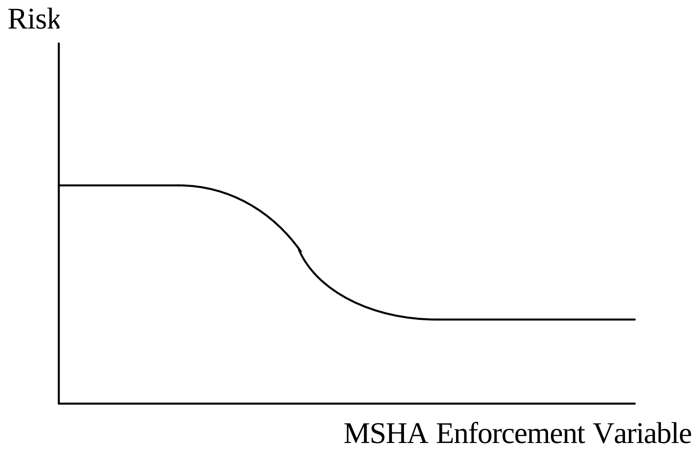

Figure 2
Annual Fatalities Per Million Employee Hours
Underground Bituminous Coal Mines, 1931–1997

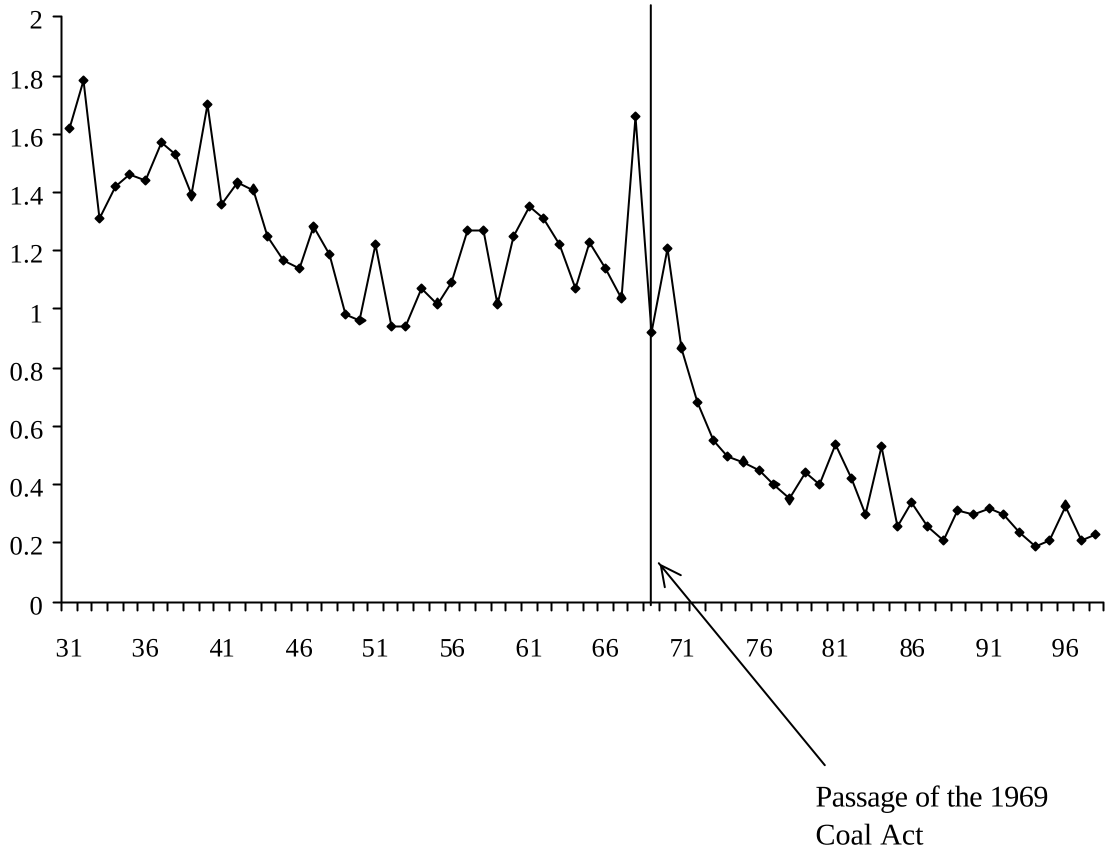

Figure 3
Annual Nonfatal Disabling Injuries Per Million Employee Hours
Underground Bituminous Coal Mines, 1931–1997

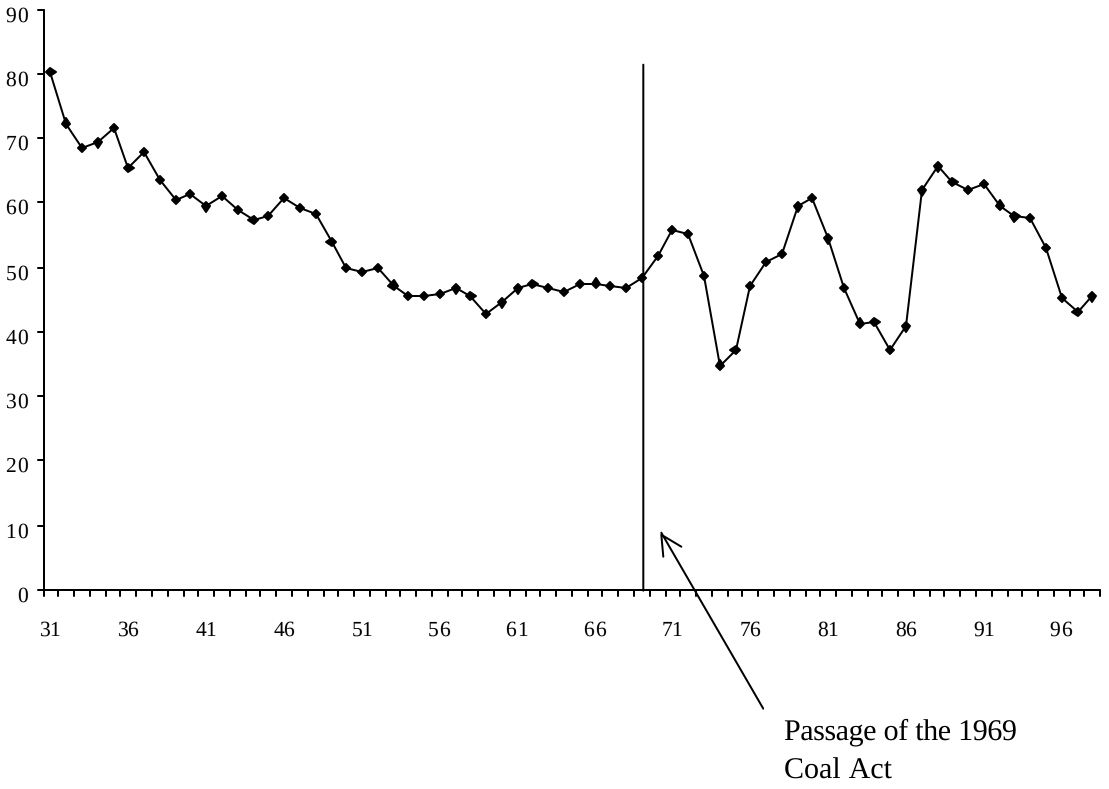

Figure 4
Quarterly Injuries Per Million Employee Hours in Estimation Sample
Underground Bituminous Coal Mines, 1983:1–1997:4