UNDERGROUND COAL MINING ACCIDENTS AND
GOVERNMENT ENFORCEMENT OF SAFETY REGULATIONS

by

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ABSTRACT

Enforcement of the Coal Mine Health and Safety Act of 1969 (CMHSA) has engendered a great deal of controversy in its seven year history. One of the critical elements of the debate over this legislation is whether enforcement of safety regulations by the Mining Enforcement and Safety Administration (MESA) has been effective in reducing work-related injuries. This dissertation attempts to determine the impact of MESA enforcement on fatal, disabling, and total accident rates in underground bituminous coal mining.

Chapter I examines the history of disabling and fatal injury rates in underground coal mining. The major causes of accidents are discussed. In addition, the CMHSA is described along with the strengths and weaknesses of its enforcement.

Chapter II presents a discussion of some important technological and institutional factors affecting accident rates in underground coal mines. These factors include geological conditions, mining technology, unionization, and vertical integration.

Chapter III reviews previous economic analysis of government regulation of occupational safety, and develops the model of government intervention. This model is based on the model of general deterrence developed by Becker and used widely in the area of the economics of crime and punishment.

In Chapter IV, we develop the specification used to estimate the effectiveness of MESA enforcement. A two-step system is hypothesized. First, the level of enforcement determines compliance with MESA regulations. Then, the rate of compliance determines accident rates.

Chapter V presents the results of this study and Chapter IV discusses them. The specification developed in Chapter IV is estimated using quarterly data from 1973 - 1975 on the 539 largest underground bituminous coal mines. A two stage least squares regression procedure is used, where inspection rates
and accident rates are treated as endogenous variables. The results confirm the hypothesis that inspections lead to a reduction in injuries. It is estimated that a fifty per cent increase in MESA inspection rates would lead to 11 fewer fatalities, 2400 fewer disabling injuries, and 3800 fewer non-disabling injuries per year among the mines in our sample. Or the other hand, no deterrent effect was found for penalties paid by mine operators for violations of safety regulations.

Other findings of the study are: (1) larger mines have, ceteris paribus, lower injury rates, (2) captive mines have lower injury rates, and (3) higher hourly production rates lead to higher injury rates. Two somewhat surprising results that indicate the need for future study are: (1) unionized mines seem to have higher non-fatal injury rates and (2) longwall mines have higher injury rates.

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FOR JUDY
INTRODUCTION
Introduction

Within the past six years, the Federal government has begun two major new regulatory programs designed to protect working people from the hazards of their occupations. The first of these, the Federal Coal Mine Health and Safety Act (CMHSA), became law on December 30, 1969. A year later, the Occupational Safety and Health Act of 1970 (OSHA) became law. Each act 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.

The enforcement of Federal occupational health and safety standards had engendered a great deal of lively, and often heated, debate. Some critics of enforcement claim that the regulations are counterproductive. They argue, in part:

1. Obeying many of the regulations does not create safer working conditions. It they are useful at all, it is only in a small number of cases. It is impossible to impose regulations about, say, guard rails, that will apply uniformly to all work situations.  

2. Even where regulations decrease workplace hazards, they do so at too high a cost. They
fuel inflation, cause extra unemployment, and hinder technological advance.²

3. The multitude of occupational health and safety regulations adds to the already excessive burden of government regulations on business. Small and medium sized firms especially find that there is too much to do in order to understand the regulations and comply with their demands.³

4. Many hazards are either momentary or are hidden from the inspector when he arrives. In these cases, it is difficult to discover the hazard and demand its correction.⁴

Other critics of Federal regulation of workplace hazards believe that industry compliance with Federal regulations would have a beneficial effect on the health and safety of workers, and that the price of compliance would not be too high. However, they believe that current enforcement practices are not effective in producing compliance. Some reasons offered in support of this position are:

1. Especially in the case of OSHA, inspections are too infrequent to induce employers to come into compliance before inspection. Even with post-inspection compliance, too few workplaces are inspected to have an
adequate impact.

2. When violations are found, penalties are very low or remain uncollected. This, again, makes pre-inspection compliance unlikely, especially when compliance costs are high.\(^5\)

3. When high penalties are assessed, such assessments often lead to protracted litigation, resulting in a reduction of the penalty and delay in correction of the violations.

4. Again in the case of OSHA, reinspections are too infrequent to assure the employers' compliance with the inspectors' demands.

On the other hand, the friends of occupational health and safety regulation believe that OSHA and CMHSA enforcement have had a substantial impact on injuries and disease. Supporters of the mining enforcement effort point to the dramatic decline in underground coal mining fatalities since 1969 as an indication of effectiveness. OSHA supporters can note specific instances of hazard abatement, although general industry injury statistics do not show any obvious trend.\(^6\)

Central to the debate over Federal regulation is whether a significant impact can be demonstrated for any aspect of Federal occupational health and safety regulation. If the behavioral impact of enforcement can be adequately quantified, some of the conflicting contentions about its effectiveness
can be tested.

In this study, we attempt to model and measure the impact of occupational safety enforcement in one industry, underground bituminous coal mining. This industry is chosen for several reasons. First, it has traditionally been one of the most hazardous. Second, data on injuries, production, employment, inspections, violations and fines are all available at the level of the individual mine. Finally, government inspections have been much more frequent in this industry than in those regulated by OSHA. This suggests that the effects of inspections are more likely to occur and, if they occur, more likely to be measurable.

A number of investigators have attempted to measure the effectiveness of government regulation of occupational hazards, but published work in this field has suffered from highly aggregated data and from inadequate methodology. (See Chapter II for a more detailed discussion of previous work). For example, previous investigators have compared accident levels before and after the passage of a new safety law. They have proceeded as if the existence of regulations, not their enforcement, has determined the behavior of regulated firms. In addition, they have failed to account for a number of factors in addition to regulation which may be responsible for changes in accident levels.

On the other hand, this study treats the level of en-
enforcement of the regulations as the most important cause of compliance. Enforcement is measured by the frequency of inspection and the level of penalties for violations.

Consider the analogy of highway speed limits. Without any enforcement, the impact of speed limits depends only on people's belief that it is important to obey traffic regulations. If there were a substantial number of police who issued warnings (tickets with little or no fine), fewer drivers would speed. The more patrol cars and the higher the fine for speeding, the fewer people would drive above the speed limit.

The relationship between enforcement and compliance is the first part of the model of behavior used in this study. The operator (as the coal mine employer is called) balances the cost of compliance with CMHSA regulations against the potential costs of being caught by the Mining Enforcement and Safety Administration (MESA) and the potential costs of accidents caused by non-compliance. The operator will be in compliance with all regulations for which the cost of compliance is less than the expected value of the potential MESA assessments and accident costs. MESA can influence compliance, therefore, by policies that affect the likelihood that infractions will be detected or by policies affecting the size of assessments (fines) levied on violators.

The object of this study is not simply to discover how
effectively MESA enforcement brings operators into compliance, but also to determine how MESA enforcement affects injury rates. The goal of MESA is, after all, not to bring mine operators into compliance with its regulations, but to decrease morbidity and mortality among coal miners. MESA's ability to do this depends on the effectiveness of its regulations in reducing mining accidents and injuries as well as its ability to enforce its regulations. In order to represent MESA's effectiveness in reducing accidents, the behavioral model contains a relationship between operators' compliance with MESA regulations and the incidence of work-related injuries. Without a negative relationship between compliance and injuries, MESA enforcement policies cannot reduce occupational injuries.

This study focuses on accidents and injuries. In so doing, we have neglected the impact of MESA enforcement on occupational disease. This paper does not focus on disease since there is a long delay between changing dust conditions and changes in the incidence of coal workers' pneumoniosis. This delay makes it impossible at this time to empirically evaluate the effect of MESA enforcement on disease.

The technique used to study enforcement used in this study is not innovative. It has been used by economists during the last decade, although its application has usually been limited to the study of felonious criminal behavior. In this literature, potential muggers, burglars, and murders
are treated as if they were "economic men," balancing the expected gain from their crimes against the likelihood of being caught and the expected penalty if caught. This approach has its limits, but most of the criticism directed against this model of individual behavior seem less relevant to its application to business organization which are, after all, economic in nature. The model of economic man seems well-suited to white-collar crimes.

Although enforcement is an important aspect of government safety activities, the focus of this study limits our ability to draw conclusions about the effectiveness of the overall Federal effort in coal mine safety. Other Federal activities would undoubtedly have significant impact even if enforcement produced few results. For example, some compliance with MESA regulations is induced simply by their existence. Even when a law is not enforced, the regulatees' sense of morality may lead them to obey it. In addition to its enforcement activities, MESA has developed and supported education and training for mine supervisors and workers. During 1973, total attendance at coal mine health and safety courses was 278,274.\(^8\) The Technical Support division provides engineering consulting services to the coal industry on health and safety problems.\(^9\) Finally, between $25 million and $30 million a year is spent to support research and development in coal mine health and safety.\(^10\)

From this perspective, the limitations of this study be-
come apparent. The study proposes to describe the likely
effects of in safety enforcement on accident rates. While
such information is crucial in evaluating the effectiveness
of the resources devoted to mine safety inspections, it can-
not evaluate the overall impact on implementation of the Coal

On the other hand, this study is a first step in the
evaluation of enforcement. Using the results of the study,
we can judge whether we believe that through the inspection
and citation process, MESA has been effective in reducing
injury levels in underground coal mining. From this point,
others may wish to pursue the question of whether MESA
inspections lead to an efficient and equitable outcome, or
whether more or less government resources should be devoted
to this activity. This more ambitious goal involves balancing
the cost of the resources used in the process of inspection
and abatement of hazards against the gains in health and
longevity which are produced. It also means evaluating the
effectiveness of other methods, such as training, research,
and worker's compensation, in reaching the same objectives.

This study will contain six chapters. Chapter I will
take a historical look at the incidence of disabling and fatal
injuries in coal mining, will discuss the types of hazards
faced by coal miners, and will discuss the enforcement of
the Coal Mine Health and Safety Act of 1969. Chapter II will
present a discussion of some important technological and institutional factors affecting accident rates in underground coal mines. Chapter III will review the pertinent literature of the effectiveness of government regulation of occupational safety and on the economics of law enforcement and will present a model of government intervention in occupational safety. Chapter IV will develop a statistical specification to which available data can be applied, and will discuss a number of potential econometric problems. Chapter V presents the results of this study. Finally, Chapter VI briefly reviews the study and discusses its results.
CHAPTER I

OCCUPATIONAL SAFETY IN
UNDERGROUND BITUMINOUS COAL MINING
The Dangers of Underground Coal Mining

Mining coal is a very hazardous profession. Geological conditions, technology, the nature of the mined material, and production pressures, have combined to face the coal miner with three times the risk of injury and twenty times the risk of fatal injury as the average industrial worker. In this chapter, I would like to summarize the statistics about accidents in underground coal mines, and to discuss the Mining Enforcement and Safety Administration, which currently is attempting to reduce the number of injuries suffered by our nation's coal miners.¹

The simplest way to understand the problem of injuries in underground coal mining is to compare its rate with those of other industries. Table 1 makes such a comparison. In the column titled "Injury Frequency Rate," we see the number of injuries per million hours worked. Only those injuries serious enough to result in over a full day's lost work are counted in this index. The severity rate is essentially the number of days of work lost as a result of injury per million hours worked. The "Severity Rate" column therefore measures how serious the accidents were as well as how often they occurred.

We can see that, in 1970, underground coal mining had a much higher injury rate than other major industries, and that injuries in that industry tended to be more serious.
Compare, for example, the underground coal mining statistics with those of lumber and wood products and of contract construction. The latter two are industries chosen by the Occupational Safety and Health Administration for special attention because of their high injury rates. Underground coal mining is significantly more hazardous than both.

The fatality rate in underground coal mining is even more startling than the disabling injury rates. In each of the 20 years after 1950, more than one out of every 400 underground workers was killed in an accident. This is about thirty times as high as the average fatality rate in all manufacturing industries during this same period.

Underground coal mining, while inherently quite dangerous, is not necessarily as dangerous as its history would indicate. Safer coal mines are clearly possible. There is some evidence for this in Table 2, which presents a time series of fatal and disabling injuries. Fatal injury rates fluctuated in a narrow range in the period 1965 - 1970. But, beginning one year after the passage of the Coal Mine Health and Safety Act, the fatal injury rate dropped significantly, and has remained at about one half its previous rate. Similarly, the non-fatal disabling injury rate fell in 1974 and remained low in 1975. We cannot determine from Table 2 whether the decrease in injury rates is caused by enforcement of the CMHSA, but some improvement in the safety of America's coal mines
seems to have occurred.

Comparing coal mine injury rates in major industrialized countries also indicates that American coal mining is more hazardous than coal mining in Europe. Table 3 displays fatal injury rates in coal mining, as compiled by the International Labor Organization. These published rates show that other countries have traditionally had significantly lower fatal accident rates than has the United States. The recent low rates in the United States had already been achieved by the Western European coal mining countries in the 1950's.2

The Nature of Underground Hazards

Coal mining often occurs thousands of feet underground. The coal must be mechanically torn from the earth, weakening the geological structure and releasing explosive gas and dust. There are several widespread causes of injury and death in this industry. The relative importance of these risks engendered by this process is related to the specific geological formation in question and to the technology employed to remove the coal.

This section summarizes the major causes of injuries in underground coal mining. Table 4 displays the relative importance of various hazards in fatal and non-fatal injuries. It can be seen from Table 4 that the most important causes of fatal and non-fatal accidents overlap but are not identical.

Falls of roof and face have caused more fatalities than
any other coal mining hazard. As the coal is removed from the seam, an "empty space" is left behind - a space which must withstand the pressure of up to several thousand feet of the earth's surface that lie above it. Without proper support, the roof and face (the "wall" from which the coal is mined) are likely to collapse, burying any miner unfortunate enough to be close to them. In earlier times, the roof was supported by timbers, placed between the floor and the roof and braced. The use of timbers presents some problems. The placing of these timbers is a slow process. In addition, the timbers may interfere with the mobility of the heavy machinery now used, and may be accidentally dislodged. Currently, roof bolting is a more common form of support. The roof bolt is used to bind together the strata of rock which make up the roof, in order to strengthen them sufficiently to withstand the pressure of the earth above them.

Haulage accidents are the second most common cause of death in underground coal mining. After it is mined, the coal must be brought to the surface. This can be done by locomotives, conveyors, or shuttle cars. During the coal hauling, workers can be run over, thrown against the roof or ribs, squeezed between cars, or electrocuted. Especially in mines with "low coal" - where the coal seam can be 30 inches or less from floor to roof - the men and machines have little ability to get out of each other's way. In general, mines
are dark, cramped, honeycombed with passages and replete with blind spots in a way that makes moving machinery a constant hazard.

The third major cause of deaths is gas and dust explosion. Explosions are also the primary cause of accidents in which five or more miners are killed. Without proper control techniques, extremely hazardous concentrations of methane gas or coal dust can build up in the mine. Methane gas is trapped in the coal seam, and is released by the breaking up of the seam into chunks small enough to be transported to the surface. At the same time, coal dust is generated. This dust is suspended in the air and settles on the roof, ribs, and floor. A spark caused by a machine's hitting a rock or an improper electrical connection can set off an explosion that travels with tremendous speed through the mine. Miners may be killed by the explosion or by the released gases.

Methane gas must be diluted to prevent a large enough buildup to threaten an explosion. In any mining situation a significant amount of air must be circulated through the mine by the use of multiple air intakes and multiple ventilation fans at the surface. In order to dilute the methane the flow of this air must be strong at the working face where the gas is liberated. The higher the rate of liberation of the gas, the more ventilation is required. High rates of liberation can be caused either by a high concentration of methane
in the coal seam or by rapid mining of the coal.

The second cause of explosions, excessive coal dust, cannot be controlled by general ventilation. Control of coal dust involves preventing explosive concentrations from becoming suspended in the air. One method of doing this is wetting the coal dust, at the point of its creation (the working face) so that it falls to the floor, rather than becoming suspended in the air. Another method of controlling the explosive hazard is to mix the coal dust with large amounts of rock dust which is incombustible. This will prevent combustion from travelling from one suspended coal dust particle to another. The latter method, while reducing the explosion hazard, may not reduce the health hazard of suspended coal dust. In this way, it may not always be an acceptable procedure.

As with methane gas, more coal dust is created when the coal is being cut more rapidly. The speed of production at the coal face and the concentration of coal dust in the mine are often directly related.

Much underground machinery is run on electricity. Most notably, trolleys are run with a bare wire to supply their power. As mechanization has increased, the uses of electricity have also increased, with concomitant increased risks. The two main risks from this source are as a source of ignition for a fire or explosion and as a cause of electric shock.
Electricity is often a hazard that works in conjunction with other hazards to produce an injury. For example, a machine may wander off course, causing a miner to fall into an unguarded trolley wire and be electrocuted.

Another possible source of ignition of dust or methane is explosives, which are used to break the coal away from the seam in conventional mining. Use of less dangerous "permissible" explosives and better control of dust and gas, as well as a shift to continuous methods of mining (which do not use explosives) all may make this hazard less of a threat to life.

The above causes account for almost all fatal injuries. In addition, they are causes of many, but not most, of the non-fatal accidents in underground coal mining. Injuries while handling materials (especially props, ties, and timbers) are the major cause of non-fatal injuries. Machinery accidents are also very common. The most common of these are injuries from the roof bolter, with continuous-miner injuries occurring one-third as often.

The Coal Mine Health and Safety Act of 1969

"Dead Miners have always been the most Powerful Influence in Securing Passage of Mining Legislation."

Russell Sage Foundation Study on Coal Mine Fatalities, 1942.6

The passage of the 1969 Coal Mine Health and Safety Act was effectively secured during the week of November 20, 1968.
On that date, the Consolidation Coal Company mine near Farmington, West Virginia had an explosion that killed 78 miners. The public reaction to that incident was strong enough to lead the passage of a mine health and safety bill that had languished in congress during the previous year.

The 1969 Act was not the first attempt by the Federal government to improve coal mine safety. When the Bureau of Mines was created in 1910, one of its responsibilities was to investigate mine safety. Unfortunately, it was given no inspection powers. In fact, the Bureau of Mines was specifically denied the right to conduct inspections. Public Law 49, passed in 1946, was the first statute to give the Bureau the right to make inspections. However, the effectiveness of safety inspections under this act was severely limited by the fact that there were no provisions for mandatory safety standards, and the inspectors had no authority to impose legal sanctions on those who operated dangerous mines.

During 1946 and 1947, when many coal mines were operated by the Federal government, an agreement was reached between the Department of the Interior and the United Mine Worker's Union to establish a Federal Mine Safety Code. While the code was operative during the period of government control, it became no more than a guide afterward. There was no legal authority to enforce the code.

The first law to provide for mandatory safety standards
in coal mining was Public Law 552, passed in 1952. The 1952 Act provided for mine safety inspections at least once a year and gave Bureau inspectors the power to issue orders to close a mine considered too dangerous to work in. Even though it was a significant improvement over its predecessors, the 1952 Act had two important weaknesses. First, its provisions only extended to underground mines employing more than 15 people. Second, it was designed only to prevent major disasters, leaving to the state mine safety departments the responsibility to control other, less severe hazards. This emphasis is mirrored in the fact that the only statutory penalty available to enforcers of the Mine Safety Code was the power to close down an excessively hazardous mine.

The provisions of the 1952 Act remained unchanged until 1966, when the Act was broadened to include smaller underground mines. The 1966 amendments also attempted to shift somewhat the focus of Federal safety activities from the prevention of disasters to mine safety in general. However, until 1969, surface mines were not covered; health hazards were not covered; and enforcement and inspection activities were limited.

In summary, early regulation of coal mine safety was limited in scope and did not have an enforcement program with adequate statutory authority and inspection resources.

The 1969 Act went well beyond all its predecessors. It is part of the most intensive effort ever made to improve
health and safety conditions in our nation's workplaces. Under the Act, the Department of the Interior promulgates health and safety regulations for all coal mines. These regulations are currently enforced by the Mining Enforcement and Safety Administration (MESA). Each underground coal mine is inspected at least four times a year for compliance with MESA regulations. If the inspector finds a violation, a "notice of violation" (usually called "notice") or a "closure order" (usually called "order") is issued. A notice will specify the nature of the violation and an abatement date. If an inspection is made after the abatement date and the violation is not corrected, and if no extension of the abatement date has been agreed to, an order is issued. The order calls for the removal of all production personnel from an area or mine. An order may also be issued in cases of imminent danger to life or limb.

A copy of each notice or order is sent to an assessments office, where a MESA assessor determines a penalty appropriate to the violation, the mine's history of violations and the mine's size.

There is a great deal of informal bargaining that follows the issuance of notices and orders, as well as a significant amount of legal contest. The operator can contest either the citation or the associated penalty through an administrative law review procedure within the Department of the Interior.
Its decisions are appealable to the District Court of the United States.

Implementation of the 1969 Act

Enforcement of the 1969 Act's provisions has been intensive. MESA has more than one inspector for every three mines, and inspects mines an average of fifteen to twenty times a year. The magnitude of MESA's enforcement program can perhaps best be appreciated by comparing it with OSHA's. MESA and OSHA have roughly the same number of inspectors, but MESA makes twice the number of inspections and cites about thirty per cent more violations than does OSHA. Since MESA covers about 5,000 mines and OSHA covers about 5,000,000 workplaces, MESA's inspections are three orders of magnitude more frequent.

MESA is required by law to inspect each underground mine at least four times a year. The law also requires one inspection every five days for those mines which liberate excessive quantities of methane (which MESA defines as one million cubic feet per day), which have had any gas ignition or explosion within five years that resulted in death or serious injury, or which have "other especially hazardous conditions."

In addition, MESA has established other policy rules for extra inspection of certain mines. If there was a fatality within the past year, or there are any especially difficult
to control natural conditions, like bad roof conditions, MESA inspectors will come to the mine at least once every 10 days, for a so-called "ten-day spot" inspection. Some especially hazardous mines receive even more intensive inspection, in the "daily spot" program.

In July 1973, the Accident Prevention Program was instituted. This program is aimed at the largest underground mines. It was at first restricted to mines with 200 or more underground workers. Later, it was expanded to include all mines with over 150 underground workers. Among mines in this group, all those with injury frequency rates above the average are inspected daily. Such inspections continue until the mine's injury rate falls to lower than average.

In the period 1972-74, the average inspection resulted in only one notice's being issued.\textsuperscript{10} In spite of this fact, the large number of inspections per mine meant that approximately 21 notices and one order per year were issued to the average mine. The average assessed penalty per mine was almost $3500 per year. These averages, do not capture the impact of the Act on larger mines since they include both small and large mines. The 200 largest underground mines account for more than 60 per cent of the employment and production in underground coal mining, and over 50 per cent of the injuries.\textsuperscript{11} These larger mines are inspected more often and have more violations and penalties than the over 2000 smaller mines.
For example, we can look at the record of mines owned by the Eastern Associated Coal Company almost all of whose mines are large. Between January 1971 and December 1973, the average annual number of notices for all coal mines was 19 and the average annual assessed penalties were $2800.\textsuperscript{12} However, the average mine owned by Eastern Associated Coal had 94 notices per year, and its mean annual assessment was $19,500.\textsuperscript{13} Eastern Associated Coal was assessed over $400,000 per year in MESA penalties.*

**Problems in MESA Enforcement**

In spite of its intensive effort at inspecting underground coal mines, MESA has not been immune from criticism. Questions about its efficacy have surfaced most recently as a result of the March 9, 1976 explosion at the Scotia Coal Company mine at Oven Fork, Kentucky. Fifteen miners were killed as a result of this blast, and eleven more were killed in a blast which occurred during early stages of an investigation of the March 9 disaster.

An article by Tom Bethell\textsuperscript{14} in the United Mine Workers Journal, points to some of the weaknesses of MESA enforcement.

\* Even though this paper focuses on MESA's inspection activities, it would be misleading not to mention the fact that the Department of the Interior has, in the past six years, greatly expanded its safety research and technical assistance functions. Especially in the area of roof control, a major effort in research, assistance, and education of workers and foremen has been undertaken. This effort is clearly aimed at helping motivated operators and workers to minimize the threat of coal mining's primary cause of on-the-job fatalities.
at the Oven Fork mine. The major problem leading to the disaster was the fact that Scotia liberated 500,000 cubic feet of methane gas per day, and that not enough air was brought into the mine to sufficiently dilute that gas to below explosive concentrations.

"Miners who have worked at Scotia are practically unanimous about four things. First that there was never enough air. Second, that company officials always knew when federal inspectors were coming. Third, that air regulators were adjusted to provide sufficient ventilation on whichever sections the inspectors visited (leaving other sections with less air than normal). Fourth, that when the inspectors were gone, it was right back to business as usual."15

Bethell makes the argument that mine operators can hide many of their worst safety practices from the MESA inspectors. The inspector must first report to the office and then take a long journey in the man-trip to where the coal is being mined. In mines with more than one working section, it may take a long time to get from one working section to the others. With telephone communications between various parts of the mine, it is not difficult to see how preparations could be made for the inspector's arrival.

For those unsafe conditions which are found by the inspector, the assessed penalty would, in theory, be a deterrent to future violations. From January 1970 to the date of the explosion, MESA inspectors had written up 855 violations at Scotia. Of these, 650 had been settled. These violations had been originally assessed at $204,489. They were settled
for $78,877.\textsuperscript{16} Bethell argues that the original penalties were not very great, but the reduced amounts for which they were settled were not sufficient incentive for safer mining, since the capital cost of additional air intake shafts and fans would be $750,000.

The compromise of original assessments is not unique to Scotia. Looking back at the example of Eastern Associated Coal Company (see page 33), we see a similar ratio of assessments to payments. Although $1,231,397 in penalties was assessed against Eastern between January 1, 1971 and November 30, 1973, only $236,459 had been collected as of November 30, 1973. The other $994,938 remained outstanding.\textsuperscript{17} Nor is Eastern an exception. In the years 1971-74, MESA assessed a total of $48,014,380 in penalties. During the same period $8,885,862 was collected.\textsuperscript{18} This low collection rate does not represent the outcome of management effort and legal expenses on the part of the coal operators. Rather, it is the result of lax collection procedures and a past willingness by MESA to settle for low collection rates rather than to pressure the mine operators.

The problem is clear. In the United States, underground coal mining has been an unusually hazardous occupation throughout its history. The Mining Enforcement and Safety Administration was created to reduce injuries in that occupation. One of the major tools for that effort is the inspection of
mines and the assessment of penalties of violations of the act. The question we will address is whether that effort has produced the intended results.
TABLE 1

INJURY RATES BY SELECTED INDUSTRY GROUPS IN 1970

<table>
<thead>
<tr>
<th>Industry</th>
<th>Frequency Rate</th>
<th>Severity Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Manufacturing</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transportation equipment</td>
<td>7.9</td>
<td>488</td>
</tr>
<tr>
<td>Electrical equipment</td>
<td>8.1</td>
<td>333</td>
</tr>
<tr>
<td>Chemical and Allied Products</td>
<td>8.5</td>
<td>562</td>
</tr>
<tr>
<td>Textile Mill Products</td>
<td>10.4</td>
<td>579</td>
</tr>
<tr>
<td>Petroleum and coal products</td>
<td>11.3</td>
<td>1116</td>
</tr>
<tr>
<td>Tobacco manufacturers</td>
<td>11.9</td>
<td>332</td>
</tr>
<tr>
<td>Paper and Allied Products</td>
<td>13.9</td>
<td>937</td>
</tr>
<tr>
<td>Machinery except electrical</td>
<td>14.0</td>
<td>583</td>
</tr>
<tr>
<td>Leather</td>
<td>15.2</td>
<td>534</td>
</tr>
<tr>
<td>Rubber and plastics</td>
<td>18.6</td>
<td>795</td>
</tr>
<tr>
<td>Fabricated Metals Industries</td>
<td>22.4</td>
<td>1003</td>
</tr>
<tr>
<td>Food and Kindred Products</td>
<td>28.8</td>
<td>1156</td>
</tr>
<tr>
<td>Lumber and Wood Products</td>
<td>34.1</td>
<td>2891</td>
</tr>
<tr>
<td>Primary Metals Industries</td>
<td>16.9</td>
<td>1128</td>
</tr>
<tr>
<td><strong>Non Manufacturing</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Communication</td>
<td>2.5</td>
<td>235</td>
</tr>
<tr>
<td>Personal Services</td>
<td>7.3</td>
<td>276</td>
</tr>
<tr>
<td>Wholesale Retail Trade</td>
<td>11.3</td>
<td>452</td>
</tr>
<tr>
<td>Contract Construction</td>
<td>28.0</td>
<td>2100</td>
</tr>
<tr>
<td><strong>Mining</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stone quarrying and milling</td>
<td>13.3</td>
<td>2123</td>
</tr>
<tr>
<td>Metal Mining and milling</td>
<td>23.7</td>
<td>3238</td>
</tr>
<tr>
<td>Non Metal Mining and milling</td>
<td>24.1</td>
<td>2624</td>
</tr>
<tr>
<td>Coal mining and preparation</td>
<td>41.6</td>
<td>7792</td>
</tr>
<tr>
<td>Underground Coal Mining</td>
<td>53.8</td>
<td>10121</td>
</tr>
</tbody>
</table>


### TABLE 2

<table>
<thead>
<tr>
<th>YEAR</th>
<th>NUMBER OF INJURIES</th>
<th>RATE PER 10^6 HOURS OF WORK</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FATAL</td>
<td>NON-FATAL DISABLING</td>
<td>TOTAL</td>
</tr>
<tr>
<td>1965</td>
<td>251</td>
<td>10,071</td>
<td>10,322</td>
</tr>
<tr>
<td>1966</td>
<td>227</td>
<td>9,619</td>
<td>9,846</td>
</tr>
<tr>
<td>1967</td>
<td>213</td>
<td>9,506</td>
<td>9,719</td>
</tr>
<tr>
<td>1968</td>
<td>307</td>
<td>9,137</td>
<td>9,444</td>
</tr>
<tr>
<td>1969</td>
<td>190</td>
<td>9,425</td>
<td>9,615</td>
</tr>
<tr>
<td>1970</td>
<td>255</td>
<td>11,049</td>
<td>11,304</td>
</tr>
<tr>
<td>1971</td>
<td>176</td>
<td>10,930</td>
<td>11,106</td>
</tr>
<tr>
<td>1972</td>
<td>156</td>
<td>12,450</td>
<td>12,606</td>
</tr>
<tr>
<td>1973</td>
<td>132</td>
<td>11,607</td>
<td>11,739</td>
</tr>
<tr>
<td>1974</td>
<td>132</td>
<td>8,481</td>
<td>8,613</td>
</tr>
<tr>
<td>1975</td>
<td>154</td>
<td>11,001</td>
<td>11,155</td>
</tr>
</tbody>
</table>

Sources:  


# TABLE 3

COAL MINING FATALITIES  
(underground only)  
EUROPEAN ECONOMIC COMMUNITY VS. UNITED STATES  
PER MILLION MAN HOURS  
1958-1972

<table>
<thead>
<tr>
<th></th>
<th>West Germany</th>
<th>Belgium</th>
<th>France</th>
<th>Italy</th>
<th>Netherlands</th>
<th>Community</th>
<th>U.S.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1972</td>
<td>.46</td>
<td>.53</td>
<td>.21</td>
<td>2.20</td>
<td>.26</td>
<td>.40</td>
<td>.60</td>
</tr>
<tr>
<td>1967</td>
<td>.54</td>
<td>.53</td>
<td>.33</td>
<td>1.59</td>
<td>.17</td>
<td>.46</td>
<td>1.05</td>
</tr>
<tr>
<td>1963</td>
<td>.66</td>
<td>.64</td>
<td>.33</td>
<td>.37</td>
<td>.19</td>
<td>.55</td>
<td>1.28</td>
</tr>
<tr>
<td>1958</td>
<td>.67</td>
<td>.42</td>
<td>.59</td>
<td>.83</td>
<td>.35</td>
<td>.61</td>
<td>1.26</td>
</tr>
</tbody>
</table>

**Sources:**  

MESA, see Table 2.

TABLE 4

Percentage Distribution of Injuries, by Principal Cause

Bituminous Coal Mines, 1970

<table>
<thead>
<tr>
<th>Principal cause of injury</th>
<th>Percent Fatal</th>
<th>Percent Non-fatal, Disabling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Falls of roof, face, or rib</td>
<td>40.4</td>
<td>19.4</td>
</tr>
<tr>
<td>Haulage</td>
<td>18.2</td>
<td>19.1</td>
</tr>
<tr>
<td>Gas or Dust Explosions</td>
<td>20.2</td>
<td>0.1</td>
</tr>
<tr>
<td>Machinery</td>
<td>12.8</td>
<td>16.9</td>
</tr>
<tr>
<td>Electricity</td>
<td>5.4</td>
<td>3.2</td>
</tr>
<tr>
<td>Handling Materials</td>
<td>1.0</td>
<td>24.2</td>
</tr>
<tr>
<td>Explosives</td>
<td>1.0</td>
<td>0.8</td>
</tr>
<tr>
<td>Falls of persons</td>
<td>0.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Handtools</td>
<td>0.0</td>
<td>4.7</td>
</tr>
<tr>
<td>All others</td>
<td>0.0</td>
<td>6.5</td>
</tr>
</tbody>
</table>

CHAPTER II

TECHNOLOGICAL AND INSTITUTIONAL FACTORS
IN COAL MINE SAFETY
Technological and Institutional Factors in Coal Mine Safety

The level of safety varies greatly among underground coal mines. Because each coal mine faces a unique set of technological and institutional constraints, the economic model which has just been presented can only account for a part of this variation. These technological and institutional constraints may affect either the trade-off between production and accidents, or the mine operator's behavioral response to economic pressures. In the following section, several of the most important of these factors will be discussed.

Geological Conditions

"In varying degrees, depending upon materials used and technique to be followed, a factory manager can create the working environment. There are certainly limitations to his creative freedom, but compared to the restrictions which nature imposes upon an underground coal mine operator the range of personal selection appears very wide. The mine operator must begin with the specifications which geologic factors provide."  

Each coal operation is mined from a seam or seams with unique qualities. The range of natural conditions found in coal mines is very wide. Coal seams may be thick or narrow; they may be flat or sloped. The operation may encounter significant quantities of water. The strata surrounding the seam may be strong or weak. There may be little or much methane gas in the seam. All of these factors will affect both the speed of the mining process and the safety of the miners. We describe three of these factors below:
1. Seam thickness. The thickness of the coal seam is perhaps the most important geological factor in both productivity and safety. Commonly, the mining machine will make a cut 18 feet deep and 18 feet wide, so that one machine cycle should, ceteris paribus, remove an amount of coal proportional to seam height. Other factors tend to increase this first-approximation advantage of high seams. Coal is mined so that the height of the "room" is approximately the same as that of the coal seam. This means that men and machines maneuver more easily in the over six-foot high rooms created from thick seams. Because of this, productivity is further enhanced, and safety is more easily achieved in high coal. This reasoning is supported in Table 1, which contains data on productivity and accident rates in 1970. The highest productivity occurs in mines with seams that are over six feet thick. Moreover, accident rates are lowest in this same group of mines,

2. The nature and strength of the roof over the coal seam. A weak roof is more difficult to support or to bolt so that work under it can proceed safely.

3. Gassiness of the seam. Methane gas is trapped in coal seams, and released when the coal is mined. A gassy mine may release millions of cubic feet of methane in one day. High concentrations of methane in the air increase the likelihood of explosion. Extra precautions must be taken by
the operator of a gas mine who wishes to keep concentrations of methane at a safe level.  

Of the geological factors mentioned, the only one for which data are available is seam thickness. Any of the others may have some effect on safety or production, but cannot at this time be used in statistical estimation.

**Underground Mining Technology**

A map of a large underground mine displays an enormous honeycomb of passages over an area that may cover ten square miles or more. (See Figure 1). The mining process creates these passages called "rooms" and the columns of coal between them called "pillars." This most common technique of underground mine development is called the "room and pillar method."

To see how the room and pillar method operates, we can look at Figure 2. The upper part of that figure is the area of the working face, where the coal is extracted. The coal at the end of each of the rooms (A - E) must be removed from the seam and transported to the surface. After that, cuts will be made perpendicular to the rooms created, leaving a block of coal surrounded by four passages. Then, the process will begin again. This will continue as long as the seam remains workable.

In the United States, the two major methods of removing coal from the coal seam are conventional mining and continuous mining. Both methods are used in the room and pillar system.
The first of these is the older method and, in our sample, is used only about one third as often as continuous mining. In conventional mining, the coal is broken from the face by the use of explosive charges. The coal is first cut, to provide room for its expansion and to define the edge of the material that is dislodged by the explosion. Next, holes are drilled to accommodate explosive charges. Then, the charges are placed and exploded. Finally, the coal is loaded, usually by mechanical loaders.

In continuous mining, a single machine breaks the coal from the seam and loads it. The continuous miner, as this machine is called, mechanically rips the coal from the seam. The most common type has a rotating drum with sharp bits. The bits dig into the coal when the drum is placed against the face. The coal falls to the floor, where it is picked up by loading arms.

A third method, the longwall method, is by far the most popular mining technique in Europe, but has only recently been introduced in the United States. In our sample of the 550 largest underground coal mines in the United States, only two per cent of the mines used this technique. The longwall mining machine is a single-operation machine, like the continuous miner. However, unlike the continuous miner, the longwall machine moves beside a long block of coal, ripping the coal off as it advances. The roof above the miner is
held up by hydraulic jacks. After an area is passed, the roof is allowed to cave in behind the machine. In contrast to the room and pillar method, a network of rooms and pillars does not remain after the coal is mined using the longwall method.

The three methods of mining differ in capital costs, labor productivity, and safety problems. Conventional mining has the lowest capital intensity and the lowest labor productivity. Longwall mining is the most capital-intensive and has the highest output per man-hour. Continuous mining falls between the two other methods.

The unique safety problems of conventional mining are caused by the fact that the coal is removed from the seam by explosives, rather than by mechanical breaking. Explosives increase the danger of an explosion accident. The suddenness of the explosion also leaves the mine operator with limited means of controlling the coal dust hazard. Rock dusting is essentially the only method that can be used as a control measure. Continuous and longwall mining may use water infusion (force water into the coal seam) or spraying in addition to rock dusting.

Both conventional and continuous mining have more difficult roof control problems than those of longwall mining. There are two reasons for this. First, the room and pillar method leaves behind only columns of coal to support the roof. Since
the roof behind the longwall miner is allowed to collapse, there is more support for the overlying strata. The geological stress is not transferred to the surrounding area, so there is less stress placed on the area still to be mined. Second, the roof support method in longwall mining (hydraulic jacks) is an integral part of the mining machine. As such, its use is less subject to human error and/or production pressure with resultant inadequate roof control. Roof bolting is a bottleneck in many conventional and continuous mining operations, and, thus, especially likely to receive insufficient attention when more production is needed.

In general, the differences between the three methods of underground coal mining are significant. For the purposes of specifying a model based on the tradeoff between production and safety, it is necessary to consider each method separately, since there is evidence that each method defines a different segment of the relationship between safety inputs, production inputs, output of coal, and injury rates.

The United Mine Workers of America (UMWA)

Because coal mining is such a hazardous occupation, safety has traditionally been an important issue among both miners and their union. However, the unorganized miner does not have the backing of a strong union to support his efforts to gain a safe workplace; nor does he have the protection of the UMWA contract and safety programs. Individual miners or groups of
miners can rely only on their own limited resources to enable them to convince their employer to improve safety conditions.

Under the UMWA contract, local unions have safety committees. These committees can inspect any part of the mine and make recommendations for safety improvements. If a section of the mine has a hazard which the committee believes is an imminent danger to life or limb, it may demand that all workers be withdrawn from that section until the condition has been abated.\(^5\)

In addition to the safety committee, the union miner has rights not accorded the non-union miner. Of course, the union miner may grieve about unsafe conditions. He is aided in this by the inclusion of twelve explicit agreements on special safety problem areas in his contract.\(^6\) The contract also has minimum manning requirements for continuous miners and roof bolters - increasing the ability of operators of those machines to perform their work safely.\(^7\) In addition, since the 1974 agreement was reached, each miner has had the right to refuse to perform a job that he believes is an imminent danger.\(^8\) The refusal may take place before any grievance is settled, and without the intervention of the safety committee.

In support of the local union safety effort, the national union has its own safety program.\(^9\) As part of this program, the UMWA has helped develop a training course which is given to all safety committeemen. It also has a staff of about
36 safety officials, who travel to the mines in order to assist the safety committees. The UMWA safety inspectors give advice on both technical matters and on strategy. They also perform independent safety inspections on a routine basis, or when a fatal accident has occurred. These safety officials have been given a special training program lasting approximately two weeks.

Finally, the union has taken an active role in overseeing the enforcement of the Coal Mine Health and Safety Act at union mines. It has done this through supplying local safety committees with a manual on the enforcement of the law, and through monitoring MESA's enforcement of the law.

Because of the active role of the UMWA in safety matters, we expect that unionized mines would be safer than non-union mines, and would comply more fully with the provisions of the CMHSA. These hypotheses will be included below in the fully specified model.

The Captive Mine

A significant portion of the coal produced in the United States is not produced to be sold on the market. In 1974, about 15 percent of all bituminous and lignite coal was produced by captive mines. A captive mine is directly or indirectly (through a subsidiary) owned by a firm which consumes its output. About 60 percent of all captive output goes to the steel industry, while another 35 percent is used by public utilities. Table 1,
taken from the 1975 Keystone Coal Industry Manual, lists the companies and tonnages involved in captive production.

It has often been asserted that captive mines are safer than other coal mines.\textsuperscript{11} Although aggregate statistics seem to support this assertion, its validity has not been tested within the framework of a multivariate model of mining accidents. Christenson\textsuperscript{12} has noted that captive mines\textsuperscript{*} tend to work the thickest coal seams and to be much larger than other mines. (Table 2) This observation raises the possibility that their low accident rates are related to geological factors, or to scale factors. Thus, their better safety records may be caused by factors other than the fact that they are owned by the industry that uses their product.

On the other hand, captive mines may have attributes other than geology and scale that contribute to their better safety records. Continuity of production is generally conceded to be the most important function of captive mines. Steel and electric companies often depend on the captive for a steady supply of coal.\textsuperscript{13} If the parent company has temporarily increased needs for coal, it can go to the open market. The fact that production at captive mines fluctuates less than production

\textsuperscript{*}Christenson's "integrated" classification is similar to captive classification. His integrated group is slightly larger than the captive group, including the entire tonnage of companies that sell only part of their output on the open market.
at other mines may lead to fewer accidents at the captives.

There are two reasons for this. First, fluctuating production rates mean high turnover. High turnover means that currently employed workers may be forced to change tasks within the mine more often. As employment contracts, long-term employees must take over some of the jobs vacated by terminated employees. As employment expands, a movement by long-term employees back to their old jobs may take place. In addition, more employees are likely to be newly hired when employment is rising. Commercial mines, therefore, are likely to have more movement from task to task within the mine. They are also more likely to have more employees with little underground experience.

Both job and task inexperience may be causes of excess accident rates. Studies by Smith\textsuperscript{14} and by Rosen\textsuperscript{15} have tested models in which accident rates are related to changes in employment. In both cases, increases in employment were accompanied by increases in accident rates. A recent study of fatalities in underground coal mining by Theodore Barry and Associates\textsuperscript{16} directly examined the relationship between years of experience and accident rates. In this study, workers with less mining experience tended to have somewhat higher fatality rates than other miners. In addition, the relationship between task experience and fatalities in the Barry study were striking. Although the study suffers from lack of an appropriate measure
of the task experience of the population at risk, any reasonable assumption about the distribution of this variable implies that workers with little task experience have very high fatality rates.

A second reason for lower accident rates in captive mines is that a steady demand for coal may allow the captive mine to invest in safety equipment, training, or practices that would be more costly and less effective for a mine whose production was less stable. For example, a captive mine might be willing to invest in safety training for its employees, knowing that the probability of their being terminated is low. A commercial mine, with higher turnover, might be less willing to do this. (See, e.g., Piore (1973).)
TABLE 1

Injury rates and productivity in underground bituminous coal mines, by seam thickness, 1970.

<table>
<thead>
<tr>
<th>Thickness of vein, inches</th>
<th>Injuries per $10^6$ man-hours</th>
<th>Production, tons per man-hour</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatal</td>
<td>Non-fatal</td>
</tr>
<tr>
<td>Less than 25</td>
<td>----</td>
<td>83.81</td>
</tr>
<tr>
<td>25 to 36</td>
<td>4.62</td>
<td>65.72</td>
</tr>
<tr>
<td>37 to 48</td>
<td>1.14</td>
<td>64.19</td>
</tr>
<tr>
<td>49 to 60</td>
<td>1.20</td>
<td>59.09</td>
</tr>
<tr>
<td>61 to 72</td>
<td>0.36</td>
<td>50.65</td>
</tr>
<tr>
<td>73 to 84</td>
<td>0.64</td>
<td>26.52</td>
</tr>
<tr>
<td>85 to 96</td>
<td>0.74</td>
<td>38.74</td>
</tr>
<tr>
<td>97 to 108</td>
<td>0.66</td>
<td>44.99</td>
</tr>
<tr>
<td>109 and more</td>
<td>2.14</td>
<td>48.40</td>
</tr>
</tbody>
</table>

Table 2
CAPTIVE COAL PRODUCTION FOR THE YEAR 1974, BY INDUSTRIES

<table>
<thead>
<tr>
<th>Name of Operating Company</th>
<th>Name of Controlling or Parent Company</th>
<th>1974 Coal Production</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>STEEL</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. United States Steel Corp.</td>
<td>United States Steel Corp.</td>
<td>16,389,000</td>
</tr>
<tr>
<td>2. Bethlehem Mines Corp.</td>
<td>Bethlehem Steel Company</td>
<td>13,347,625</td>
</tr>
<tr>
<td>3. Republic Steel Corp.</td>
<td>Republic Steel Corp.</td>
<td>2,951,169</td>
</tr>
<tr>
<td>4. Youngstown Mines Corp.</td>
<td>Lykes Resources, Inc.</td>
<td>2,606,800</td>
</tr>
<tr>
<td>5. Inland Steel Co.</td>
<td>Inland Steel Co.</td>
<td>2,469,434</td>
</tr>
<tr>
<td>6. Kaiser Steel Corp.</td>
<td>Kaiser Steel Corp.</td>
<td>2,049,950</td>
</tr>
<tr>
<td>7. Cannelton Coal Co., Divs.</td>
<td>Algoma Steel Co., Ltd.</td>
<td>1,952,220</td>
</tr>
<tr>
<td>8. National Mines Corp.</td>
<td>National Steel Company</td>
<td>1,934,967</td>
</tr>
<tr>
<td>9. Mathies Coal Company</td>
<td>(Lykes Resources, Inc.)</td>
<td>1,868,538</td>
</tr>
<tr>
<td></td>
<td>(National Steel Co.)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Consolidation Coal Co.)</td>
<td></td>
</tr>
<tr>
<td>10. Jones &amp; Laughlin Steel Corp.</td>
<td>Jones &amp; Laughlin Steel Corp.</td>
<td>1,807,514</td>
</tr>
<tr>
<td>11. Arco Steel Corp.</td>
<td>Arco Steel Corp.</td>
<td>1,494,700</td>
</tr>
<tr>
<td>12. Gateway Coal Co.</td>
<td>Jones &amp; Laughlin Steel Corp.</td>
<td>1,092,311</td>
</tr>
<tr>
<td>13. Beatric Pocahontas Co.</td>
<td>(Republic Steel Corp.)</td>
<td>870,316</td>
</tr>
<tr>
<td>14. U.S. Pipe &amp; Foundry Co.</td>
<td>(Inland Creek Coal Co.)</td>
<td>770,416</td>
</tr>
<tr>
<td>15. Mead Coal Co.</td>
<td>U.S. Pepe &amp; Foundry Co.</td>
<td>695,000</td>
</tr>
<tr>
<td>16. Harmer Coal Co.</td>
<td>Mead Corp.</td>
<td>631,991</td>
</tr>
<tr>
<td>17. C.F. &amp; I. Steel Corp.</td>
<td>(Consolidation Coal Co.)</td>
<td>625,000</td>
</tr>
<tr>
<td>18. National Coal Mining Co.</td>
<td>National Steel Co.</td>
<td>366,055</td>
</tr>
<tr>
<td></td>
<td>Island Creek Coal Co.</td>
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</table>

**OTHER INDUSTRIES**

<table>
<thead>
<tr>
<th>Name of Operating Company</th>
<th>1974 Coal Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Alabama By-Products Corp.</td>
<td>3,430,697</td>
</tr>
<tr>
<td>2. Semet-Solvay Div. Allied Chemical Corp.</td>
<td>1,187,000</td>
</tr>
<tr>
<td>3. International Harvester Co.</td>
<td>657,862</td>
</tr>
<tr>
<td>4. Union Carbide Corp. Metals Div.</td>
<td>730,000</td>
</tr>
<tr>
<td>5. United States Fuel Co.</td>
<td>331,424</td>
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</table>

**TOTAL** 52,012,156

**TOTAL** 6,336,983
TABLE 2
Continued

<table>
<thead>
<tr>
<th>Name of Operating Company</th>
<th>Name of Controlling or Parent Company</th>
<th>Production</th>
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<tbody>
<tr>
<td>Deck Derby Coal Co.</td>
<td>Pacific Pwr. Lt. Co.</td>
<td>6,786,000</td>
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<tr>
<td>Windsor Power House Coal</td>
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<td></td>
</tr>
<tr>
<td>Central Coal Co.</td>
<td>American Electric Power Co.</td>
<td></td>
</tr>
<tr>
<td>Southern Ohio Coal Co.</td>
<td>Pacific Power &amp; Light Co.</td>
<td></td>
</tr>
<tr>
<td>Central Ohio Coal Co.</td>
<td>Pacific Power &amp; Light Co.</td>
<td></td>
</tr>
<tr>
<td>Southern Appalachian Coal</td>
<td>Montanna-Dakota Utilities Co.</td>
<td></td>
</tr>
<tr>
<td>Central Appalachian Coal</td>
<td>Duquesne Light Co.</td>
<td></td>
</tr>
<tr>
<td>Pacific Power &amp; Light Co.</td>
<td>Montana-Dakota Utilities Co.</td>
<td></td>
</tr>
<tr>
<td>Knife River Coal Mining Co.</td>
<td>Pennsylvania Pwr. Lt. Co.</td>
<td></td>
</tr>
<tr>
<td>Greenwich Colliers Co.</td>
<td>Duquesne Light Co.</td>
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<tr>
<td>Duquesne Light Co.</td>
<td>Duke Power Co.</td>
<td></td>
</tr>
<tr>
<td>Eastover Mining Co.</td>
<td>Utah Pwr. Lt. Co.</td>
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</tr>
<tr>
<td>Bridger Coal Co.</td>
<td>Idaho Pwr. Co.</td>
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<tr>
<td>Ohio Edison Company</td>
<td>Ohio Edison Company</td>
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TOTAL-29,893,199

GRAND TOTAL-88,442,338

Source: Keystone Coal Industry Manual, 1974
### TABLE 3

Size of Underground Mines and Average Seam Thickness by Type of Company

1955

<table>
<thead>
<tr>
<th>State</th>
<th>County group</th>
<th>Company type</th>
<th>Weighted average seam thickness (in inches)</th>
<th>Annual tonnage per mine (Thousands of tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pennsylvania</td>
<td>I</td>
<td>Single</td>
<td>58</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Intrastate</td>
<td>75</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Interstate</td>
<td>72</td>
<td>304</td>
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<tr>
<td></td>
<td></td>
<td>Integrated</td>
<td>81</td>
<td>948</td>
</tr>
<tr>
<td>West Virginia</td>
<td>I</td>
<td>Single</td>
<td>76</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Intrastate</td>
<td>80</td>
<td>132</td>
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<td></td>
<td></td>
<td>Interstate</td>
<td>91</td>
<td>876</td>
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<td></td>
<td>Integrated</td>
<td>83</td>
<td>934</td>
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<td>West Virginia</td>
<td>II</td>
<td>Single</td>
<td>54</td>
<td>39</td>
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<td></td>
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<td>212</td>
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<tr>
<td></td>
<td></td>
<td>Interstate</td>
<td>55</td>
<td>441</td>
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<tr>
<td></td>
<td></td>
<td>Integrated</td>
<td>72</td>
<td>804</td>
</tr>
<tr>
<td>West Virginia</td>
<td>III</td>
<td>Single</td>
<td>46</td>
<td>65</td>
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<td></td>
<td></td>
<td>Intrastate</td>
<td>52</td>
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<tr>
<td></td>
<td></td>
<td>Interstate</td>
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<td>491</td>
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<tr>
<td></td>
<td></td>
<td>Integrated</td>
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<td>554</td>
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<tr>
<td>West Virginia</td>
<td>IV</td>
<td>Single</td>
<td>57</td>
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<tr>
<td></td>
<td></td>
<td>Integrated</td>
<td>56</td>
<td>572</td>
</tr>
<tr>
<td>V. Kentucky</td>
<td>III</td>
<td>Single</td>
<td>65</td>
<td>458</td>
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<td></td>
<td></td>
<td>Intrastate</td>
<td>66</td>
<td>477</td>
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<tr>
<td></td>
<td></td>
<td>Interstate</td>
<td>70</td>
<td>315</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Integrated</td>
<td>56</td>
<td>359</td>
</tr>
<tr>
<td>Illinois</td>
<td>I</td>
<td>Single</td>
<td>80</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Intrastate</td>
<td>N.A.</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Interstate</td>
<td>73</td>
<td>698</td>
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<tr>
<td></td>
<td></td>
<td>Integrated</td>
<td>none</td>
<td></td>
</tr>
<tr>
<td>Illinois</td>
<td>III</td>
<td>Single</td>
<td>77</td>
<td>53</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Intrastate</td>
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<td>707</td>
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<tr>
<td></td>
<td></td>
<td>Interstate</td>
<td>89</td>
<td>1242</td>
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</table>

FIGURE 1

Map of Part of an Underground Coal Mine
CHAPTER III

A MODEL OF ACCIDENTS AND THEIR REGULATION IN UNDERGROUND COAL MINING
A Model of Accidents and Their Regulation in Underground Coal Mining

Existing Studies of the Problem

The economic literature on coal mining accidents and regulation has all appeared since the passage of the Coal Mine Health and Safety Act of 1969. About half the articles have concentrated on the pre-1969 period, while the rest have studied the effects of the 1969 Act.

Andrews and Christenson published two articles in 1973\(^1\) and 1974\(^2\) that examined the effects of the Federal Coal Mine Safety Act of 1952 on injury rates in covered mines. In the 1973 article,\(^3\) the authors used three comparisons to attempt to see whether changes in injury rates after 1952 could be attributed to the 1952 Act. Since the 1952 Act placed emphasis on the prevention of mine disasters (accidents which result in five or more fatalities), they compared changes in fatality rates from disasters with changes in fatality rates from all accidents. Their hypothesis was that the act's emphasis should have reduced disaster fatality rates more than total fatality rates. They found that total fatality rates were essentially unchanged, while disaster fatality rates fell. The authors' second comparison was between fatality rates in covered underground mines (those with 15 or more workers) and uncovered mines. Before 1952, fatality rates in small, uncovered mines were twice those in larger
mines. After 1952, fatality rates fell about 15 percent in the small mines, while they did not change in the larger mines. While the first result is favorable to the hypothesis that the 1952 Act was effective, this comparison does not support that hypothesis. The third comparison was between fatality rates in underground mines and uncovered strip mines.* Here again, the results do not support the efficacy of the 1952 Act. Fatal injury rates in strip mines declined even more than in covered underground mines.

The evidence presented in Anderson and Christenson's 1973 article does not indicate that the 1952 Act has significant effects. The three comparisons produce conflicting results; but none of them indicate that total fatality rates were improved by the Act's enforcement. Feeling that the results of this article might be an artifice of looking at mines of different seam thickness, the authors, in a 1974 article, examined the effects of seam thickness on productivity. Comparing fatal injury rates among mines of different seam thicknesses, they found that mines with thicker seams had lower fatality rates. However, post-1952 changes in fatality rates were not associated with seam thickness. The act did not appear to have different impact on mines with thin or thick seams.

*Fatalities from disasters are not considered for strip mines and small underground mines, since disasters are extremely rare in both groups.
In a third paper, Andrews and Christenson used OLS regression techniques to explore the effects of the 1952 Act. In this paper, firm size and mechanization and a dummy representing the passage of the 1952 Act are used as independent variables. The coefficients of the regulation dummy are generally not significant in the different specifications used. If anything, they indicate a positive relationship between injury rates and the new Federal regulations. The authors comment on this: "The Bureau of Mines was handicapped to some degree by inadequate powers, but still more so by the lack of cooperation and support for any sharp crack-down on unsafe practices."

These three papers were followed by similar efforts by Howard and Andrews and Christenson to examine the effects of the 1966 amendments to the Federal Coal Mine Health and Safety Act. These studies, which looked at accident rates in Kentucky coal mines, were also unable to demonstrate any clearly positive effects of Federal regulation of injury rates. Howard comments that his equivocal results may have occurred because of the increased mechanization of the industry and the working of deeper seams. Both of these factors, in Howard's

*An extension of this work to 1970 by Witt, Palomba, and Palomba (1975) also produced an estimated positive relationship between the post-1969 year and injury rates.
opinion, offset the potential positive effects of the 1966 statutes. He offers, however, no hard evidence for his opinions.

Witt, Palomba, and Palomba\textsuperscript{9} have recently attempted to develop a model of coal mine accidents and regulation. Their model is more of a technological than an economic model. That is, they assume that for a given amount of labor and capital inputs, a given amount of coal output and accidents will result. The authors do not consider that a trade-off may occur between output and accidents. Their model, fitted to 1953-1969 data, estimates total man-days lost because of fatal and non-fatal injuries. For independent variables, it uses measures of mining technique (continuous mining and mechanical loading), man-days worked, and a dummy variable to represent the 1966 amendments. The dummy is not significant at the ten percent level. The authors then use their estimating equations to predict total days lost in 1970-1973. The estimates for each of these years overpredict days lost due to accidents.* The authors thus conclude that the 1969 act had a demonstrable impact.

Even though the above articles appeared in economics journals, they develop no economic models of regulation. Nor

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*The days-lost data for 1972 and 1973 were actually extrapolated from frequency rates, since severity (days-lost) rates had not been published for those years. See Witt, Palomba, and Palomba (1974), pp. 23-25.
do they test any economic hypothesis in their empirical work. Nelson and Neumann\textsuperscript{10} have taken a more self-consciously economic look at coal-mining accidents than have the above authors. They base their model of accident-generation on the profit maximizing behavior of the mine operator, who wishes to increase production, while avoiding the costs of accidents and injuries, as well as those of non-compliance with governmental safety regulations. Nelson and Neumann hypothesize that the coal miner's wage includes a risk premium. Since the risk premium should rise as conditions become more hazardous, it should act as a deterrent to unsafe conditions. The authors also include the riskless portion of the mine wage in their model, hypothesizing that an increase in this value will cause capital to be substituted for labor.\textsuperscript{*} Labor will therefore be used more intensively, exposing it to a higher risk of injury.\textsuperscript{11}

In their regression equations, Nelson and Neumann use a dummy to represent the effect of the 1966 Statute, and find a small relationship between the passage of the amendments and accident rates. This effect becomes smaller and statistically insignificant when the authors include a variable representing

\textsuperscript{*}They do not mention changes in the cost of capital, which could offset or intensify this effect.
the percentage of output derived from small mines. This leads Nelson and Neumann to hypothesize that the effect of the 1966 statute on accidents occurred through the decrease in the number of small mines.  

In order to test the effectiveness of the 1969 act, the authors predict total injuries in 1971 and 1972 on the basis of their regressions (which are based on 1950-1970 data). Their prediction equations underestimate the number of injuries in underground coal mining in those two years, seemingly indicating that safety has deteriorated in the face of the 1969 Act.  

Nelson and Neumann's model has two significant weaknesses. First, they pose a risk premium model without taking into account that a large majority of coal miners are paid the same wage, since they are all covered by the UMWA contract. But, more important, they present a model which is based on the demand for and supply of labor, but treat it as if it were a single-equation model. This ignoring of the identification problem makes it difficult to interpret the estimated coefficient and weakens their predictions.

**Other Studies of Government Regulation of Occupational Safety**

In the past several years, there have been a number of studies that attempted to measure the impact of OSHA enforcement on injury rates among covered employers. Research in this area
has been hampered by the fact that, during 1971, the definitions under which injury statistics have been collected were changed. This has meant that it has been difficult to use before-and-after comparisons of the type done by researchers to examine the effects of the Coal Mine Health and Safety Act.

Robert Smith was able to use data collected by states with their own injury reporting systems, which did not change in 1971. Smith looked at injury rates in industries inspected under OSHA's Target Industry Program (TIP). This program was designed to inspect the included industries much more intensively than others. Smith chose to look at the TIP industries on the basis that, if OSHA had any effect on injury rates, it should be evident in the most highly inspected industries. His model was, like those used in the coal studies, one that used a dummy variable to indicate the hypothesized effect. However, rather than simply comparing industry injury rates before and after the passage of the OSHAct, Smith estimated a model in which industry's post-OSHA injury rate was regressed on pre-OSHA rates, and on a dummy variable which was non-zero only for the TIP industries. Smith was unable to find any decrease in the TIP industries' injury rates relative to those in other industries.

John Mendeloff used the BLS injury statistics to compare pre-OSHA and post-OSHA injury rates. He assumed that, while injury definition changes have affected the level of reported injury rates, they have not affected percentage changes in those
rates (not including, of course, changes from before 1971 to after 1971). Mendeloff used a linear regression model to estimate yearly changes in the disabling injury rate for all manufacturing industries. His independent variables were the rate of new hires in the base year, and lagged one year, the percentage of male workers aged 18-24, and the average hourly wage of production workers. This model was estimated using data collected from 1948 to 1970. The coefficients were used, as in several of the coal mining injury studies to predict percentage changes in injury rates in the post-OSHA period (1972-3 and 1973-4). Mendeloff's predicted change in the disabling injury is slightly smaller than the actual change in 1972-3, and larger than the actual change in 1973-4. Neither difference is statistically significant. Mendeloff also estimated this model using California worker's compensation data, which does not suffer from the change in definition mentioned above. His results there were similarly inconclusive.¹⁶

Finally, using the California data, Mendeloff restricts his view to those types of injuries which safety engineers feel are most susceptible to regulation by government inspection. Using this approach, he was able to find some classes of accidents which exhibited large difference between predicted injury rates and actual injury rates. This has led him to conclude that California's disabling injury rate has been
reduced by 2 percent to 5 percent by government inspections.\textsuperscript{17}

Aldona DiPietro has recently completed a study that looked at firms covered by OSHA from a different point of view.\textsuperscript{18} Rather than attempting to discover OSHA's overall impact on accident rates, DiPietro attempted to estimate the impact of OSHA inspections on the accident rate of the inspected firms. Rather than assuming that OSHA had any deterrence effect (on uninspected as well as inspected firms), DiPietro assumed that only the injury rates in the two percent of covered firms that are inspected in any year will be affected by OSHA enforcement. Using OSHA inspection data and BLS injury data, she estimated the 1973 rate in a 2-digit SIC industry, using as independent variables the 1972 injury rate, the percent change in its employment, and a dummy indicating whether or not it was inspected in 1973. The model was estimated separately for each industry and for small, medium, and large establishments within the industry. She could not show that inspections led to decreased injury rates. In fact, her results tend to support just the opposite conclusion—or, at least that firms with high injury rates are more likely to be inspected than those with lower rates.

The "Crime and Punishment" Model

The basis of an economic approach to compliance with the law can be stated consisely: the would-be criminal weighs the
costs and benefits of compliance and chooses the action that produces the larger net value of his consumption stream. If the costs of prospective punishment outweigh the benefits of criminal activity, the crime is not committed.

We know that the motivation of those who violate laws is more complex than this model would suggest. Chambliss, for example, offers a typology of criminal motivation which includes expressive as well as instrumental motivations for criminals. Purely expressive behavior is performed without regard to possible consequences. Its motivation may have a strong neurotic or psychotic component and thus may not be amendable to analysis via the economic model. Instrumental behavior, on the other hand, is precisely the type of behavior that economists describe. Its motivation is the achievement of a goal. Murder and drug addiction are two crimes which often have significant expressive motivation. In this case, the criminal may act in an "irrational" manner, not considering possible punishment.* Many crimes have an expressive aspect, which complicates, but does not necessarily destroy, the usefulness of the economic analysis of deterrence. The greater the expressive component of a crime, the smaller will be the

*An equivalent explanation is that the utility of the act is so high for the criminal that no possible punishment would have any deterrent effect. Either assumption would vitiate the empirical usefulness of the economic model.
influence of legal sanctions on crime rates.

Chambliss also notes that some criminals have a significant commitment to crime as a way of life.\textsuperscript{22} For example, the professional thieves and murderers may not place a very negative value on their crimes or the threat of arrest. The civil rights, anti-war, or religious activist may actually place a positive value on arrest. For these examples, the contribution of enforcement to deterrence may be quite small. On the other hand, most citizens place a negative value on violating most laws, even if there is little or no probability that they will be caught. In this case, the mere passage of a law, with no enforcement provisions, may be sufficient to deter the prohibited activity.

On the basis of these observations, we would expect the greatest explanatory value of economic analysis to come in areas in which an illegal act is committed for purely instrumental reasons, and by people not committed to illegal activity. Crimes like income-tax evasion, anti-trust violation, minimum wage violations, and violations of environmental and occupational health and safety laws seem most amenable to this approach. In fact, recent empirical studies have almost exclusively examined crimes such as murder, rape, assault, robbery and auto theft.

The basic model used by economic studies of law enforcement can be summarized as Becker\textsuperscript{23} presented it:
\[ 0 = 0 (p, f, u) \text{ where} \]
\[ 0 = \text{the number of offenses committed} \]
\[ p = \text{the probability of conviction per offense} \]
\[ f = \text{the punishment per conviction} \]
\[ u = \text{other relevant variables} \]

The expected benefit of an offense is assumed fixed. Then, the expected costs will increase as the probability of conviction increases, and as the punishment for a conviction becomes harsher. In the case of a risk-neutral criminal, the variable affecting expected utility is simply \( pf \), the expectation of the cost of committing the offense. As \( pf \) rises, the number of offenses falls.

The next section presents an application of the "crime and punishment" model to government regulation of safety in underground coal mines. It describes mine operators' compliance with safety regulations as a function of two enforcement parameters—the probability of discovery and the penalty assessed per discovered offense. It follows the lead of Becker and others who have applied this analysis to felonious behavior. Since this approach is limited to examining the enforcement approach, however, it is more limited in its possible conclusions than the studies of mine safety reported in the first section of this chapter.

While those studies attempted to quantify the overall impact of government regulations and enforcement on injury rates, this
study focuses only on the effects of different levels of enforcement. Thus, for example, some compliance with the Coal Mine Health and Safety Act of 1969 would occur with very little or no enforcement. Either because of a belief that it is morally wrong to disobey the law or because of an irrational belief that they will be punished, some mine operators would obey MESA regulations without any real threat of punishment. This effect, which may be large, is specifically excluded from the scope of this study.

On the other hand, the effect of changing enforcement parameters is not a subject of the studies reported above, while it is the focus of this study. We hope to be able to measure the effect of increasing or reducing the resources devoted to inspecting underground coal mines. This along with future studies, will help to determine the appropriate level of government regulation of mine safety.

Accident Prevention and Government Intervention

1. Accident prevention with no government intervention.

The profit-maximizing firm will attempt to reduce accidents as long as the cost of preventing an accident is less than the costs incurred because it occurs. The cost of reducing accidents may be in the form of increased capital expenditure for safer plant and equipment. It may be in the form of using more workers on unsafe operations, more maintenance
personnel, or safety personnel. Increased training for workers is a third cost. Finally, equivalent to an increase in capital, labor and training per unit output, the pace of the production process may be decreased. For the purposes of this discussion, these safety inputs will all be considered part of the "safety factor" ($S$).

Accident costs to the firm also have a number of components. The accident may damage capital goods and disrupt production. Medical care for the injured worker may be paid for by the firm, as may some of the worker's lost wages. In addition, hiring and training costs may be incurred if the injured worker is replaced by another. As with safety inputs, these effects of accidents will be considered as a single entity, the "accident output" ($A$).

Using competitive assumptions, then, we can construct a behavioral model of the firm, with labor, capital, and safety inputs, and with product and accident outputs. The number of accidents decreases as safety inputs increase. ($\partial A/\partial S < 0$) With fixed safety inputs, an increase in either labor or capital used in production increases workers' exposure to hazards and therefore increases the number of accidents. ($\partial A/\partial L < 0, \partial A/\partial K < 0$)

(1).....Max: $\Pi = Q (K,L) - wL - rK - cA (K,L,S) - P_S S$

$\Pi = \text{profits}$
Q = quantity of output (price is normalized to 1)
K = capital
L = labor
w = wage rate
r = cost of capital
c = cost of an accident
A = number of accidents
S = safety input
Ps = cost of unit of safety input

At the maximum value,
\[ \frac{\partial \Pi}{\partial K} = \frac{\partial Q}{\partial K} - r - c \frac{\partial A}{\partial K} = 0 \quad \text{or} \]
\[ (2) \quad \frac{\partial Q}{\partial K} = r + c \frac{\partial A}{\partial K} \]
\[ \frac{\partial \Pi}{\partial L} = \frac{\partial Q}{\partial L} - w - c \frac{\partial A}{\partial L} = 0 \quad \text{or} \]
\[ (3) \quad \frac{\partial Q}{\partial L} = w + c \frac{\partial A}{\partial L} \]
\[ \frac{\partial \Pi}{\partial S} = -c \frac{\partial A}{\partial S} - p_S = 0 \quad \text{or} \]
\[ (4) \quad -c \frac{\partial A}{\partial S} = p_S \]

Equations (2) and (3) imply that, where accidents increase with rising production and constant safety input, the marginal product of capital must be greater than its cost. Similarly, the labor's marginal product must exceed the wage rate. This is so because the additional wage bill is more than the cost of hiring more labor. Workers are hired to increase production, and increasing production also increases accidents. The increased
income from higher sales must offset not only a higher wage bill, but also higher accident costs.

As with any other input, we expect the safety input to be used until its marginal cost equals its marginal product. Accidents decrease with increasing safety inputs, and we expect them to decrease more slowly at higher levels of safety input. From (5), we see that the safety input will be increased until its unit cost is equal to the marginal savings in accident costs.

2. Accident Prevention with Government Intervention.

We now introduce a government safety program into the above model. This program enforces a body of regulations designed to increase firm safety inputs. The regulations are enforced by unannounced inspections of workplaces. When the government inspector finds a violation of the safety regulations, the firm is penalized.

This system adds a new cost to unsafe working conditions. In addition to potential accident costs, the firm faces a risk of being penalized by a government inspector.

The potential cost of deciding not to comply with a regulation is determined in part by the probability of the infraction's being discovered by a government inspector. It is also related to the fine that will be imposed if the infraction is discovered. The higher the probability of detection and the
higher the potential penalty, the greater the loss in expected utility to the offending firm.

As in the case of accident costs, the argument for using a certainty-equivalence model here seems strong. Safety penalties are generally small compared with profits. This would seem to justify the assumption of risk-neutrality, at least for most firms.

As a model for the effects of government safety inspections, we add to our original model the expected costs of infractions of safety regulations.

\[(5)\quad \text{Max: } \Pi = Q(K,L) - WL - rK - cA(K,L,S) - PFI(K,L,S) - PsS\]

Where

- \(P\) = probability of an infraction's being discovered
- \(F\) = fine, or penalty, assessed per discovered infraction
- \(I\) = number of infractions

Here, PF represents the expected value of the cost of not complying with safety regulations. With a constant safety input, the number of infractions increases as production increases. Conversely, at a given level of output, increased safety inputs will enable the firm to increase its compliance with the law.
At the maximum:

\[(6) \quad \frac{\partial Q}{\partial K} = r + c \frac{\partial A}{\partial K} + PF \frac{\partial I}{\partial K} ; \frac{\partial A}{\partial K} > 0, \frac{\partial I}{\partial K} > 0\]

\[(7) \quad \frac{\partial Q}{\partial L} = w + c \frac{\partial A}{\partial L} + PF \frac{\partial I}{\partial L} ; \frac{\partial A}{\partial L} > 0, \frac{\partial I}{\partial L} > 0\]

\[(8) \quad -c \frac{\partial A}{\partial S} - PF \frac{\partial I}{\partial S} = p_s ; \frac{\partial I}{\partial S} < 0, \frac{\partial A}{\partial S} < 0\]

As in the case without government intervention, the marginal products of labor and capital are greater than the wage rate and the cost of capital. Now, in addition to the extra accident costs of increased production, the firm must absorb the cost of a greater number of penalties for infractions of safety regulations. Increased sales must offset all additional costs of increased production.

It may be interesting to see if, as we would suspect, an increase in penalties would increase the firm's safety effort for a given level of production. To see this, we derive \(\frac{dS}{dP}\) from (8) above:

\[-c \frac{\partial^2 A}{\partial S^2} dS - f(dP \frac{\partial I}{\partial S} + P \frac{\partial^2 I}{\partial S^2} dS) = 0,\]

or

\[(9) \quad \frac{dS}{dP} = \frac{-F \frac{\partial I}{\partial S}}{c \frac{\partial^2 A}{\partial S^2} + PF \frac{\partial^2 I}{\partial S^2}} > 0\]

Similarly, we can see that an increase in inspection activity, with a consequent increase in the probability that an infraction will be discovered, will increase the firm's safety effort.
Again, from (9) above:

\[
(10) \quad \frac{dS}{dF} = \frac{-P \frac{\partial I}{\partial S}}{c \frac{\partial^2 A}{\partial S^2} + PF \frac{\partial^2 I}{\partial S^2}} > 0
\]

We can also see that this model implies that an increase in inspection activity or penalties should decrease accidents:

\[
(11) \quad \frac{dA}{dP} = \frac{dA}{dS} \cdot \frac{dS}{dP} < 0
\]

\[
(12) \quad \frac{dA}{dF} = \frac{dA}{dS} \cdot \frac{dS}{dF} < 0
\]

To this point, we have examined safety behavior under conditions of constant output. Decreasing output is an alternative method of reducing infractions and accidents. If we allow variations in output, we can derive from (8):

\[
(13) \quad \frac{dS}{dP} (c \frac{\partial^2 A}{\partial S^2} + PF \frac{\partial^2 I}{\partial S^2}) + \frac{dQ}{dP} (c \frac{\partial^2 A}{\partial S \partial Q} + PF \frac{\partial^2 I}{\partial S \partial Q}) = -F \frac{\partial I}{\partial S}
\]

Note here that, for simplicity, we look at the effects on safety of changes in production, and not the separate effects of changes in the level of labor and capital used in production.

In (13), the sign of the coefficient of \(dS/dP\) is positive. If \(\frac{\partial^2 A}{\partial S \partial Q} < 0\) and \(\frac{\partial^2 I}{\partial S \partial Q} < 0\), the sign of \(dQ/dP\) is negative. The RHS of (13) is positive. The equality can be satisfied either through a positive \(dS/dP\)
or a negative $dQ/dP$ or both. The actual change in $S$ or $Q$ will depend on the relative costs of achieving a marginal reduction in the costs of accidents and infractions.
CHAPTER IV

MODEL SPECIFICATION AND
IMPORTANT ECONOMETRIC ISSUES
Model Specification

The specification of a model of accident prevention and government intervention proceeds in two stages. We first derive an equation to estimate accident rates, and then a relationship between enforcement parameters and an input to the accident rate equation. Together, these two relationships should allow us to infer the effects of safety enforcement on accidents.

The accident specification begins with a relationship between the number of accidents, coal output, and safety inputs:

(1) \[ A = A(S,Q) \]

\[ S = \text{safety inputs} \]
\[ Q = \text{output} \]
\[ A = \text{number of accidents} \]

As described in the previous chapter, "safety inputs" are simply labor and capital which reduce accidents and injuries. As such, safety inputs are not empirically well-defined entities. Many inputs that improve safety are not in the safety budget. They are not hard hats or machine guards or safety committeemen, and therefore are not easily measured. For example, with a fixed quantity of machinery, management may attempt to produce the same amount of coal as last year with 10% fewer workers. This
increased pace of work, which may result in more accidents, can be seen as a decrease in safety inputs.

In a sense, the distinction between safety inputs and production inputs is an artificial one. We are really dealing with the joint production of coal and accidents. Labor and capital are used for this purpose. A distinction between production and safety inputs is then made for analytical convenience.

For each combination of labor and capital inputs, one can derive a transformation curve, $T_n$, between production and accidents. (See figure 1.) At the point of maximum production, we can say that the safety input is zero. As we move down the transformation curve from right to left, safety inputs are increasing.

Suppose that a firm is producing at $(Q_o, A_o)$ on the $T_o$ transformation curve, which is derived from production possibilities using $L_o$, units of labor and $K_o$ units of capital. We derive a measure of safety inputs used by this firm by first solving:

$$\text{(2) } \min \quad wL + rK$$

s.t. $Q(L,K) \leq Q_o$

The solution, $(L_1,K_1)$, is the least-cost way of producing $Q_o$, with no inputs devoted to accident prevention. Our measure of safety inputs is, therefore:
(3) \[ S = w(L_1 - L_0) + r(K_1 - K_0) \]

This is depicted in Figure 1 by the transformation curve \( T_1 \), which is the transformation curve whose maximum output is \( Q_0 \) and which produces \( Q_0 \) at a lower cost than any other such combination of labor and capital.

Since we have no direct measures of safety inputs, our model specification will use several indirect measures.

One of these is output of coal per hour of work. If labor input consists of production input and safety input, as in (3) above, then a low output-labor ratio indicates that, \textit{ceteris paribus}, safety inputs are being used relatively intensively. This should imply a low accident rate. If infractions capture all important safety inputs, then output per hour should add nothing to the explanatory power of an accident equation. But, if there are safety inputs that do not affect infractions (as we are sure is the case), output per hour should be a helpful explanatory variable.

Another measure of safety inputs is the number of infractions of MESA regulations. We assume that many of the unsafe conditions and practices that occur as a result of low levels of safety inputs are infractions of MESA regulations. As safety inputs rise and levels of safety improve, we assume that numbers of infractions will de-
crease. Thus, infractions are a measure of safety inputs, with:

(4) ..... \( \frac{\partial S}{\partial I} \leq 0 \)

"Infractions" are not a measured quantity. An infraction occurs each time a regulation is not adhered to. But, not all infractions are observed by MESA inspectors. In addition, we cannot be sure that all observed infractions are cited. As in the case of assault, the crime has been committed even if the assault is not reported; or the criminal is not apprehended; or the criminal is not convicted. For coal mine health and safety, an infraction that is cited and not overturned upon legal contest by the operator will be called a violation \( (V) \). We observe violations, and not infractions. This problem will be discussed below, after we take up the second part of the specification, the relationship between government enforcement and the number of infractions.

Following this discussion, a first attempt at a specification of the accident relationship looks like:

(5) ..... \( A/L = d_0 + d_1 \frac{I}{L} + d_2 \frac{Q}{L} + e_0 \)

\( L = \) million hours of work

\( I = \) infractions

Here, we write the accident relationship so that the dependent variable is \( A/L \), the injury frequency rate dis-
cussed in Chapter I above. The injury rate is an intuitively appealing dependent variable, since it shows the degree of risk that miners experience better than the total number of accidents.

The measure of production per hour must be used with care, since different mining techniques have different associated ranges of production per section or per employee hour. A specific number of tons of coal per section per quarter may indicate a high level of production for conventional mining, but a low level of production for continuous mining. In order to take this into account, the coefficient of \( Q/T \) in (5) will be:

\[
(6) \quad d_2 = d_{21} X_1 + d_{22} X_2 + d_{23} X_3 , \quad \text{where}
\]

\[
X_1 : \text{percent of sections using conventional mining techniques}
\]

\[
X_2 : \text{percent of sections using continuous mining techniques}
\]

\[
X_3 : \text{percent of sections using longwall mining techniques}
\]

It is a common observation that, along the larger underground mines, injury rates tend to decrease with mine size. For example, Table I shows injury frequency rates for the 539 large mines used in this study. If we group them by average annual work-hours underground, we find
in seams of 30 inches and under, both production and safety are very difficult to achieve. In recognition of this problem, a variable for seam thickness, T, is included in the estimating equation.

Finally, there is a possibility that labor and management attitudes may play a role in affecting hazards that are either momentary in nature or occur as a result of work practices that can be altered in the presence of an inspector. In either case, we would expect a very small percentage of such hazards to be cited by inspectors. To indicate the magnitude of such uncited hazards, we include two proxies for positive influences on general safety practices not covered by MESA. These are a dummy for unionization and a dummy representing whether a mine is captive or independent.

As described above, the United Mine Workers of America is a safety-conscious union. It does not seem unreasonable to assume that its interest in safety and its collective bargaining strength will enable its local unions to have a positive effect on the safety practices at unionized mines. The coefficient of the unionization dummy, U, will measure this effect.

A final fact which may impact the safety behavior of the coal operator is whether or not the mine is vertically
integrated with the consumer of its coal. As was discussed in Chapter II, captive mines are reputed to be safer than their commercial counterparts. This study will attempt to test the validity of this widely held belief. We will see if the better safety record of captive mines can be traced to a combination of better mining conditions (e.g., seam thickness, size, and different methods of production) or if the captive mines are safer even after accounting for these other factors.

The above discussion enables us to modify (5) to its final form:

\[ A/L = d_0 + d_1 I/L + d_2 Q/L + d_3 L + d_4 T + d_5 U + d_6 K + e_0 \]

\( T \) = average seam thickness, in inches

\( U \) = unionization dummy, = 0 if not unionized; = 1 if unionized

\( K \) = captive dummy. + 0 if independent; + 1 if captive

The second part of the specification is a behavioral relationship determining the number of infractions at a mine. This follows from the model discussed in Chapter 2. Here we relate the decision to abate infractions of MESA regulations to economic and technological parameters, on the one hand, and to government enforcement, on the other.
In its simplest form, we can write:

(8) \[ I/L = b_0 + b_1 P + b_2 F + b_3 Q/L + e \]

- \( I \) = number of infractions this quarter
- \( P \) = probability of citing an existing infraction
- \( F \) = expected value of the penalty imposed for a discovered infraction

As discussed above, the threat of sanctions by MESA is a deterrent to operators' allowing their mines to be out of compliance with safety regulations. As the risk of being cited increases, and/or as the expected fine impose for a citation increases, the expected cost of the infraction increases. This increase in cost will induce operators to use resources to increase compliance. \( P \) and \( F \) are, of course, critical variables in this study. Their coefficients in (7) and (\( ^* \) indicate the ability of government intervention to alter the safety behavior of coal mine operators.

With increasing hourly production of coal, the infraction rate will increase. This occurs because there is a more intensive use of labor (and possibly capital) to produce greater output, and a corresponding decrease in the use of labor (and capital) as safety inputs.

The possibility of economies of scale in the provision
of safety has been discussed above. These scale economies may affect both conformance to regulations and other, unregulated safety practices. In order to capture their effect on infraction rates, production per quarter is included in the infraction estimating equation.

In the accident equation, the coefficient of $Q/L$ is modified to take into account the differing productivities of the different methods of production:

$$(9) \ldots b_3 = b_{31}X_1 + b_{32}X_2 + b_{33}X_3$$

In addition to mode of production, seam thickness will affect the relationship between production per employee hour and safety inputs in general, coal which is mined in thicker seams is easier to mine. Thus, with the same number of production workers a mine with an 84" seam will produce more coal than a mine with a 36" seam. Conversely, if both mines had the same output per work hour, the mine with the 84" seam would probably be devoting a larger percentage of work hours to safety (and obeying the law).

As an additional refinement of (9), we hypothesize that the unionized mines are likely to, ceteris paribus, have more resources devoted to correcting hazards. This can be caused either by the concern of the United Mine Workers of America union about safety conditions or by the fact that the costs per accident are increased wages and fringe benefits at unionized mines.
Finally, vertical integration may influence a coal mine's conformity to MESA regulations. Above, we pointed out that vertical integration may make it easier to achieve safe working conditions at captive mines. The same factors that encourage safety at captive mines may also lead to fewer infractions of MESA regulations at these mines. To the extent that this is true, the coefficient of a dummy variable for captive/independent status in the infractions equation will be negative.

The above considerations lead us to modify (9) to:

\[ (10) \quad I/L = b_0 + b_1 P + b_2 F + b_3 Q/L + b_4 Q + b_5 T + b_6 U + b_7 K + e_8 \]

When estimated, (7) and (10) give us information about three critical coefficients: \( b_1, b_2, \) and \( d_1 \). If more inspections (leading to the discovery of more infractions) induce mine operators to improve compliance, \( b_1 \) will be less than zero. If higher penalties lead to better compliance, \( b_2 \) will be less than zero. Low values of these two coefficients would indicate that the MESA enforcement program is effective in gaining compliance, while values close to zero would indicate that only large expected costs of illegal conditions will induce operators to shoulder the costs of correcting these conditions.
Note that the words "illegal conditions", rather than "unsafe conditions" have been used. We do not assume that compliance with MESA safety regulations actually reduces work hazards. The effectiveness of these regulations is measured by $d_1$, the marginal charge in the accident rate with respect to the infraction rate. The higher the value of $d_1$, the more unsafe are these illegal working conditions.

**Unobserved variables**

After estimating (7) and (10), we should be able to answer the questions which this study addresses. However, our data do not permit us to proceed directly with this estimation. This is because we observe neither $I$ nor $P$ nor $F$ -- three critical variables.

Our data sources do not permit us to observe infractions. We have data only on infractions which are cited by MESA inspectors. For the purposes of this study, when a notice or an order is written on an infraction, it becomes a violation, $V$. What we observe, then, is $V$, not $I$.

In addition, we do not observe $P$, the probability of an infraction's being cited. Since $P$ is the ratio of $V$ to $I$, and since we can observe $V$, knowing either $I$ or $P$ would enable us to derive the other.

Finally, we do not observe $F$, the mine operator's expected value of the penalty imposed when an infraction is
cited. We observe a distribution of penalties assessed and collected over time, and must infer a present expected value from this distribution.

In order to estimate (7) and (10), we begin by looking for an adequate index or instrument for both I and P. We do this by exploring the relationship between V and I. First, note that the number of violations is simply the number of infractions multiplied by the probability that an inspector will cite an existing infraction:

\[(11) \quad V \overset{\text{def}}{=} P \cdot I\]

Now, P is a function of how much the mine is inspected. That is, the more days in a quarter the mine is expected, the more likely it is that an infraction will be discovered.*

Of course, P depends on more than just the number of days of inspection. In a mine with 20 working sections and only 1 infraction per section, there is likely to be a lower yield of citations that in a mine with 2 working sections and 10 infractions per section. Even though both mines have 20 infractions, the larger mine will take longer to inspect.

In addition, the quality of the inspectors' training,

---

*MESA policy is to cite all infractions which are discovered. We assume, at the least, across mines, that a constant percentage of discovered infractions is cited.
MESA enforcement policies, etc., may influence the yield of an inspection. We will assume, however, that factors other than days of inspection and mine size have only random influence on $P$. then we can write:

$(12) \ldots P = P(D,S) + w$

$D =$ days inspected this quarter

$S =$ number of working sections in mine

In the estimation of this model, we assume that all inspection days are equally productive, so that doubling the number of inspection days at a mine is likely to double the number of infractions cited. Given this assumption, we can write (12) as:

$(13) \ldots P = k \ (D/S) + w$

From (13) and (11), we can derive:

$(14) \ldots V = I \ [k(D/S) + w]$, or

$(15) \ldots I = V \ [k(D/S) + w]^{-1}$

Then, let $I$ be an indicator of $I$, where:

$(16) \ldots I_o = V \ast (D/S)^{-1}$, from which:

$(17) \ldots I = k^{-1}I_o [1 + w/k(D/S)]$, or

$(17') \ldots I_o = kI[1 + w/k(D/S)]$

In addition, let $P_o$ be an indicator of $P$, where:

$(18) \ldots P_o = (D/S)$, from which:

$(19) \ldots P = k \ P_o + w$, or

$(19') \ldots P_o = k^{-1}P - w/k$

Since $I_o$ and $P_o$ can be directly inferred from the
observable variables V, S, and D, we can estimate (20) and (21) instead of (7) and (10):

\[ \text{INJ} = d_0 + d_1 k^{-1} \text{INF} + d_2 \text{PROD} + d_3 \text{HOUR} + d_4 \text{THICK} + d_5 \text{UNION} + d_6 \text{CAPT} + e_0 + v_0, \text{ where } v_0 = d_1 \]
\[ w(\text{KLINSP}) = -d_1 w \text{ INF/kP} \]

\[ k^{-1} \text{INF} = b_0 + b_1 \text{INSP} + b_2 \text{PEN} + b_3 \text{PROD} + b_4 \text{HOUR} + b_5 \text{THICK} + b_6 \text{UNION} + b_7 \text{CAPT} + e_1 + v_1, \text{ where } v_1 = w(b_1 + I/\text{KLINSP}) \]

Where: \( \text{INJ} = A/L = \text{injury frequency rate per million hours per quarter} \)
\( \text{INF} = I_o/L = V(D/S)^{-1} L^{-1} = \text{indicator of infractions rate} \)
\( \text{PROD} = Q/L = \text{production per hour in a quarter} \)
\( \text{HOUR} = L = \text{hours worked per quarter} \)
\( \text{THICK} = T = \text{average seam thickness} \)
\( \text{UNION} = U = \text{unionization dummy} \)
\( \text{CAPT} = K = \text{captive dummy} \)
\( \text{INSP} = D/S = \text{indicator of probability of an infraction's being cited} \)
\( \text{PEN} = \text{measure of present value of expected penalty per citation} = F \)

Using (20) and (21), we cannot identify the coefficients of the relationships expressed in (7) and (10). That is, we cannot know the true relationship between
accidents and infractions, or the true relationship between the probability of an infraction's being cited and the number of infractions committed at a mine. On the other hand, we are able to deduce most of the relationships that are of crucial importance to regulators and to their critics.

On the basis of estimates of $b_1$, $d_1$, and $d_2$, however, we can derive useful information about MESA's effectiveness in reducing injuries. We can compare injury rates predicted by these equations under current levels of enforcement with those predicted at much lower and higher levels. Using estimates of the coefficients of (21), we can predict INF assuming current inspection rates, much higher rates, and much lower rates. Using these predictions, we can then predict their effects on injury rates. The differences in predicted injury rates will be a measure of the magnitude of the effect of MESA inspections. Note that the difference between injury rates at current inspection rates and zero inspection rates does not necessarily measure the full impact of the 1969 Act. As discussed in Chapter 2, the regulations may be expected to have some impact even if there is no inspection/penalty process. This effect derives from the satisfaction that some operators will get from being in compliance with the law, independent of the economic impact of that compliance; or
from the educative aspects of MESA regulations and activities.

POSSIBLE MISSPECIFICATION IN THE RELATIONSHIP:

\[ I = V[k(D/S) + w]^{-1} \]

This model is made estimable by the assumption that every inspection is equally productive when applied to a given mine situation. This means that \( n \) times as many days of inspection at the same section will lead to \( n \) times the number of infractions as another section will result in \( n \) times the number of citations.

This assumption is not a reasonable one over the entire possible range of inspection. Suppose, for example, that \( k = 0.1 \). Then, for \( D/S = 1 \), we get from (14):

\[ E(V) = (0.1) \times 1. \times I = 0.1 \quad I \]

But, if \( D/S = 20. \), we get:

\[ E(V) = (0.1) \times 20. \times I = 2.0 \quad I \]

If the twenty days of inspection were spread out over five inspections, the total number of citations could easily be twice the number of infractions existing at any one time. It is possible that an uncorrected violation could be cited as many as five times in this situation. On the other hand, if the 20 days were all part of one inspection, \( E(V) = 2.0 \quad I \) is not a reasonable result. For (14) to be an acceptable simplification, we cannot be at
the extremes of that relationship, but rather in the middle portion of a relationship that may look like:

\[ V = I_1 \]
\[ V = I_0 \]
\[ V \]
\[ D/S \]

There is some reason to believe that, even if a mine were inspected a large number of days in a quarter, the inspector would not allow himself to make few enough inspections to be on the horizontal portion of the violations relationship. This is because the inspector would be more effective by coming to the mine more often, and remaining on the portion of the violations relationship that would produce more violations per inspection day.

Our assumption about the relationship between \( V \), \( I \), and \((D/S)\) does not allow for systematic differences in the efficiency of inspectors. Inspectors may not all cite the same number of infractions when inspecting a given section for a day. Some may be better trained or more experienced. Others may be more sympathetic toward the miners or toward the operators. Or there may be management differences among districts or subsdistricts that lead to different inspection postures.
Finally, our assumption does not take into account that different types of mines may incur different levels of inspection productivity. This may be caused by more or less good relationships with inspectors, concern by the inspectors for the economic viability of the mine (in the case of very small mines), bribery, etc. It may also be affected by the propensity of an operator to contest citations or fines. If the operator chooses to contest the citation, the inspector may be forced to spend time in court. If the inspector much prefers to spend time in the field, he may be dissuaded from citing some hazards by the threat of contest.*

Pooling Cross-section and Time Series Data

In estimation using pooled cross-section and time series data, ordinarily least squares us generally neither minimum variance nor asymptotically efficient. In addition, estimates of the variance-convariance matrix of the estimated coefficients are biased and inconsistent. These outcomes

*Many inspectors are former miners, with little formal education. Even though they know much about mining safety, they may write a citation poorly. Their writing may be ridiculed in the courtroom. Some inspectors feel that ridicule is the main purpose of the lawyers for the operators.

Also, the site of the legal contest may be far away from the inspector's home and may take him away for longer than he would like.
that all three categories of injuries show that frequency rates decrease with size. For fatal, disabling, and total injuries, mines below 250,000 work hours per year show approximately 50% higher rates than mines with over 500,000 work hours annually.

Decreasing injury rates for larger mines may be a result of geological differences. For example, larger mines tend to have greater seam thickness. On the other hand, there may be economies of scale in safety. If the effect of these economies of scale is captured by the infraction rate, there is no need for an additional scale variable. However, we are not certain that this is the case. In order to distinguish those differences in injury rates that are related to mine size and those that may be related to other factors, like seam thickness or unionization, we include production rate per quarter in the model of accident determination.

Even in mines of the same size, production intensity, and mining method, geological differences may make some more unsafe than others. One of these differences for which we have data is seam thickness. In "high coal", miners and machines can maneuver more easily. It is simpler for them to get supplies and take actions which enhance safety. Visibility is better, and the possibility of maneuvering to avoid an impending accident is greater. Especially
are the result of the fact that the residuals of the estimated relationships have both a transitory component and a permanent component, caused by individual variation among mines. The fact that the residuals have a permanent component implies that the residuals of the 12 observations for each mine are correlated. It is this correlation that weakens the efficiency of the OLS estimator.

More formally, let \( v \) be the residual of the estimated relationship. Also, let:

\[
(22) \ldots v_{nt} = u_n + w_{nt}, \text{ where}
\]

- \( v_n \): the residual in the \( t \)-th time period for the \( n \)-th mine
- \( u_n \): the permanent component of the residual for the \( n \)-th mine
- \( w_{nt} \): the transitory component in the \( t \)-th time period for the \( n \)-th mine.

Following Balestra and Nerlove,\(^1\) we assume that \( u_n \) and \( w_{nt} \) have zero means and are independent. Further, we assume that the \( w_{nt} \) are independent of themselves both across mines and across time. Finally, the \( u_n \) are assumed to be independent of themselves across mines, but to have constant covariance for the same mine across time, i.e.:
(23) \( E(u_n u_n) = \sigma^2_u \)

These assumptions imply a variance-covariance matrix of the residuals of:

\[
E(vv') = \begin{bmatrix}
A & 0 & \cdots & 0 \\
0 & A & \cdots & 0 \\
\vdots & \vdots & \ddots & \vdots \\
0 & 0 & \cdots & A
\end{bmatrix}
\]

\( \sigma^2 \begin{bmatrix}
1 & \lambda & \lambda & \cdots & \lambda \\
\lambda & 1 & \lambda & \cdots & \lambda \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
\lambda & \lambda & \lambda & \cdots & 1
\end{bmatrix} \)

where \( A = \begin{bmatrix}
. & . & . & \cdots & . \\
. & . & . & \cdots & . \\
. & . & . & \cdots & . \\
. & . & . & \cdots & . \\
\end{bmatrix} \)

and \( \sigma^2 = \sigma^2_u + \sigma^2_w \)

(25) \( \lambda = \frac{\sigma^2_u}{\sigma^2} \)

In order to improve the efficiency of our estimate, we use a GLS approach. First, we derive an estimate of \( A \). To do this, we use least squares to estimate (20) or (21). Then, we calculate residuals for each mine and average the mean squares and products of the residuals over all observations for each mine. This is our estimate of the variance-covariance matrix of the error terms for a single mine, \( \sigma^2 A \).

\[
\begin{bmatrix}
\Sigma e_1^2 & \Sigma e_2 e_1 & \cdots & \Sigma e_T e_1 \\
\Sigma e_1 e_2 & \Sigma e_2^2 & \cdots & \Sigma e_T e_2 \\
\Sigma e_1 e_T & \Sigma e_2 e_T & \cdots & \Sigma e_T^2 \\
\end{bmatrix}
\]

(26) \( \sigma^2 A = \begin{bmatrix}
\Sigma e_1^2 & \Sigma e_2 e_1 & \cdots & \Sigma e_T e_1 \\
\Sigma e_1 e_2 & \Sigma e_2^2 & \cdots & \Sigma e_T e_2 \\
\Sigma e_1 e_T & \Sigma e_2 e_T & \cdots & \Sigma e_T^2 \\
\end{bmatrix} \)
T: the number of time periods during which observations occur.

From this matrix, we obtain an estimate of $\lambda$.

Once we know $\lambda$, the calculation of the Aitkin estimator is straightforward. From each observed value, we subtract a fraction, $g$, of the mean of each mine's observations. This value is chosen so that the variance-covariance matrix of the new estimated relationship will be $\sigma^2 I$. The appropriate value of $g$ is:

$$g = 1 - \frac{1}{1 + T^{-1}\lambda^{-1}(1 - \lambda)^{-1}}$$

The Problem of Errors in Variables

Using indicators for the infraction rate and the probability of an infraction's being cited introduces the problem of errors in variables into our estimation. In (20), the error term, $v_o + e_o$, is correlated with the independent variable INF. In (21), the error term, $v_1 + e_1$, is correlated with the independent variable INSP. The correlation of an independent variable and the error term in a regression implies that the OLS estimate is neither unbiased nor consistent. In the case of equations (20) and (21), the use of indicators for $I$ and $P$ means that the OLS estimates of $d_1 k^{-1}$ and $b_1 k$ will be biased.
The potential for bias in the estimates of the coefficients of (20) and (21) invites the use of an instrumental variables approach. If we can find an instrument for INF in (20), and if the instrument is not correlated with either \( e_0 \) or \( v_0 \), the resulting estimate of \( d_kk_1 \) will be consistent. Similarly, if we can find an appropriate instrument for INSP in (21), the resulting estimate of \( b_1k \) will be consistent.

**Possible simultaneous determination of endogenous variables.**

In specifying our model, we have assumed that the frequency of inspection for a mine is exogenously determined. Thus, although (20) and (21) are simultaneous equations, they are in the recursive form. OLS estimation thus would not present the issue of simultaneity bias. However, if MESA decides to inspect mines on the basis of their infraction rates or their injury rates, we have:

\[
(28) \quad \text{INS} = s_0 + s_1 \text{INF} + s_2 \text{INS} + ... + e_2
\]

Unless \( s_1 \) and \( s_2 \) are both zero, the OLS estimation of (20) and (21) is no longer either unbiased or consistent.

As a matter of policy, MESA does inspect more often those mines which it considers excessively dangerous. It is not, however, clear that MESA's increased inspection of dangerous mines is based on current infraction or injury
rates. For example, in 1973, MESA initiated an Accident Prevention Program\textsuperscript{2}. This program initially covered the 150 largest underground mines, and 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. The existence of the Accident Prevention Program suggests that inspections and accident rates are simultaneously determined. Whether simultaneity actually exists depends on the extent to which the inspection rate under this program depends on current or past accident rates.

Given the possibility of simultaneity, the use of two-stage least squares seems attractive. In addition, the fact that two-stage least squares uses instruments for \( \text{INF} \) in (20) and \( \text{INSP} \) in (21) will help to eliminate the bias in the estimates of their coefficients caused by the errors in variables problem.

**Problem of Unobserved, Unchanging Differences Among Mines**

We may find that past history of investment, or management outlook, or unchanging unmeasured geological
conditions, leads to the level of accidents being higher in certain mines than would be predicted by our model. Such unobserved variables would bias the coefficients of (20) and (21). What would be the direction of the bias of these coefficients? This is explained in Theil (1971)\(^3\).

Suppose, for example, we omit the fact that the mine has outdated equipment, or is excessively gassy. Theil says that we must look at:

\[
E(b_j) = b'_j + P_{jk}b'_k
\]

* \(b_j\): the coefficient of variable \(j\) in the incorrectly specified question

* \(b'_j\): the correct coefficient variable \(j\)

* \(P_{jk}\): the coefficient of variable \(j\) in the auxiliary regression of the excluded variables on the included ones.

* \(b'_k\): the correct coefficient of the excluded variable, \(k\).

\[
X = P_{0x} + P_{1x} \text{INS} + P_{2x} \text{FEN} + P_{3x} \text{PROD} + \ldots + P_{kx} \text{CAPT} + e_x
\]

Let us look at the direction of the possible bias in the coefficient of \(\text{INS}\) in (21) from omitting the fact that some mines have more outdated equipment than others. First, we must ask what the sign of \(P_{1x}\) is likely to be. Will more inspections be made at mines with older equipment? There is some chance that MESA will consider such mines more
dangerous and inspect them more often, so $p_{lx}$ is probably greater than zero. The second question is what the sign of $b$ is likely to be.

Will there be more or less infractions in mines with older equipment? Again, the answer is that $b'_1$ is likely to be positive. If $p_{lx}$ and $b'_1$ are both positive, we expect that the coefficient of the incorrectly specified equation will be greater than the "true" coefficient, i.e., $b_1$ will be biased upward.

We also expect an upward bias in the estimate of $b_2$, the coefficient of PEN in (21). Again, there are likely to be more infractions in mines with older equipment. In addition, the MESA formula for determining the size of penalties increases penalties for mines with higher infraction rates. These two factors should result in an upward bias in the estimate of $b_2$ if the unobserved variable is omitted.

The fact that an upward bias in $b_1$ and $b_2$ may exist will strengthen our confidence in any negative estimates of these two coefficients.

Finally, we expect an upward bias in the estimate of $d_1$. This will be true if there are both more infractions and more accidents at mines with older equipment. This means that the OLS estimate of (21) will overstate the effect
of infractions on accident rates. This will weaken our ability to interpret a positive $d_1$ as an indicator of the effect of obeying MESA regulations. A positive $d_1$ will not necessarily imply that reducing infractions of MESA regulations will reduce accident rates.

One possible check on the size of the bias in estimating $d_1$ is a direct estimate of the effect of inspections on accident rates:

\[(31) \ldots \text{INJ} = c_0 + c_1 \text{INSPI} + c_2 \text{PEN} + c_3 \text{PROD} + c_4 \text{HOUR} + c_5 \text{THICK} + c_6 \text{UNION} + c_7 \text{CAPT} + v_2\]

Equation (31) is simply the direct estimate of the effects of enforcement activity on injury rates. It combines the effects of enforcement activity on infractions, as separately estimated by (21), and the effects of infractions on injuries, as separately estimated in (20). Therefore, we would expect that:

\[(32) \ldots \text{E}(c_1) = \text{E}(b_0) \text{E}(d_1)\]

Applying the above analysis, we can see that the probable bias in $c_1$ is positive. It is therefore a conservative estimate of the effect of inspections on accident rates. If we are concerned about the bias in our estimate of $d_1$, we can use $c_1$ as an estimate of the effect of inspections on accident rates. In doing this, we forgo the more detailed understanding of the enforcement process offered by (20) and (21), but may have a more conservative estimate of the effects of inspections on injury rates.
<table>
<thead>
<tr>
<th>Average Annual Hours Worked Underground</th>
<th>Average Annual Number of Injuries</th>
<th>Injury Frequency Rates, per Million Work-hours</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatal</td>
<td>Disabling Plus Fatal</td>
</tr>
<tr>
<td>0 - 125,000</td>
<td>5.6</td>
<td>509</td>
</tr>
<tr>
<td>125,000 - 250,000</td>
<td>13.0</td>
<td>1201</td>
</tr>
<tr>
<td>250,000 - 500,000</td>
<td>20.0</td>
<td>2178</td>
</tr>
<tr>
<td>500,000 +</td>
<td>33.7</td>
<td>3043</td>
</tr>
<tr>
<td>TOTAL</td>
<td>72.3</td>
<td>6931</td>
</tr>
</tbody>
</table>
A = Accidents

Q = production

FIGURE 1
Accident-Production Transformation Curves
CHAPTER V

DATA AND RESULTS
Data and Results

Data

The model presented in Chapter IV has been estimated using data largely gathered from the files of MESA for the years 1973 - 1975. The sample of mines chosen is the 539 underground bituminous coal mines which produced at a rate of 100,000 tons of coal per year during at least one year of that period. The mines in this sample constitute approximately one third of all underground mines and employ about 85 per cent of all underground miners. Where possible, data were collected on a quarterly basis. This means that, for most variables, we have 12 quarterly observations.

Injury data are dept by MESA on tapes produced from the "Coal Accident, Injury, and Illness Report," which is required of the coal operator for each accident and/or injury that occurs. For the purposes of this study, we were able to compile a quarterly record of the number of fatal, disabling, and non-disabling injuries that occurred to underground workers in our sample.

MESA also has records of production, employment, and hours worked, compiled from the mandatory monthly "Employment and Production Report." From these records, we have derived data on quarterly production, number of people employed underground and number of hours worked underground.

Information on violations cited and penalties came from
the data base of the MESA Assessments Division. Each violation is stored on a record that includes information on the date of violation, the assessed penalty, the date of payment, and the amount actually paid. From this, the number of violations and average penalty were derived on a quarterly basis. (See Appendix for a discussion of problems with this data and of how average penalty was derived).

Mining technique (conventional, continuous, longwall) information was provided on an annual basis by the MESA Division of Health. This division collects data on coal dust exposure, listing the job description of each person whose exposure was sampled. Since some job descriptions are unique to a specific technology, MESA was able to write a program that transformed sampling information into data about the number of sections and mining technique, and provide this information to me.

Information on parent company and unionization was provided me by the research department of the United Mine Workers of America, from their files. Seam thickness data was collected on an annual basis from the files of the Subdistrict offices of MESA. Number of inspection-days was collected from the files of MESA divisions of Assessments office, Wilkes-Barre, Pennsylvania, where they are kept for purposes of determining assessed penalties.
Results

Equations (20) and (21) of Chapter IV were estimated for the pooled cross-section, time series data representing the 539 mines in our sample during the 12 quarters of 1973 - 1975. Some modification of the standard TSLS approach was made to account for the fact that the observations were both cross-sectional and time series in nature, and for the existence of heteroskedasticity.

The first step in the TSLS process was choosing appropriate identifying restrictions for (20) and (21). The MESA enforcement districts have varying inspection resources, and the inspection rate at underground mines can be expected to vary according to the MESA district mine is in. On the other hand, it seems that geographic region should not have a significant impact on a mine's accident or infraction rate, independent of the predetermined variables already in (20) and (21). Thus, we use dummy variables representing the nine MESA districts to identify these two equations.

After deciding on the exclusion restrictions to be used, TSLS estimates were derived. At both stages of the TSLS procedure, the residuals exhibited a pattern of heteroskedasticity. The variance of the error term decreased as the number of hours worked increased. This pattern should be expected, since there are an integral number of infractions and injuries at each mine. The difference between N injuries
and (N+1) injuries translates into a difference of 100 in
the frequency rate of a mine with 10,000 hours worked, but
a difference of only 10 in the frequency rate of a mine with
100,000 hours worked.

The degree of heteroskedasticity in the TSLS equations
was estimated by regressing the square of the error term (the
dependent variable minus its predicted value) on HOUR\(^{-1}\) and
HOUR\(^{-2}\), e.g.,
\[
(1)\ldots \text{INF}^2 = a_0 + a_1 \text{HOUR}^{-1} + a_2 \text{HOUR}^{-2}
\]
INF: TSLS estimate of INF

The original regression was then re-estimated, dividing all
observations by:
\[
(a_0 + a_1 \text{HOUR}^{-1} + a_2 \text{HOUR}^{-2})^{0.5}
\]

In order to obtain an efficient estimator of the co-
efficients of (20) and (21) and to obtain consistent estimates
of the variance-covariance matrix of the coefficients, we
nest estimate of \(A\), the variance-covariance matrix of the
TSLS residuals over the 12 time periods. Following the dis-
cussion in Chapter IV, the TSLS estimates were recomputed
using a value of \(\lambda\) chosen after examining the estimate of \(\lambda\),
\(\lambda = 0.2\). The results are shown below and in Table 2. Stand-
are errors are in parentheses.
(2) $\text{INF} = 84.59 - 2.460 \text{INS} + .00726 \text{PEN} + (-1.319 \text{CON V} - (8.72)(0.84) + (0.017)(1.46)
2.176 \text{CONT} - 19.33 \text{LONG} \text{PROD} - .0965 \text{HOUR} - .1670 \text{THICK}
(1.45)(9.05) + (0.012)(0.063)
+ 2.975 \text{UNION} - 10.56 \text{CAP T}
(5.01)(2.08)

(3) $\text{FAT} = .0137 + .0070 \text{INF} + (-.00102 \text{CON V} - .0132 \text{CONT} + (7.2)(0.007)(11)(10)
.2126 \text{LONG} \text{PROD} - .000390 \text{HOUR} + .0591 \text{THICK} - .1690 \text{UNION}
(.85)(.002)(.47)(.30)
- .1078 \text{CAP T}
(.20)

(4) $\text{DIS} = 41.33 + .2300 \text{INF} + (5.802 \text{CON V} + 4.279 \text{CONT} + (9.41)(.09)(1.39)(1.35)
69.4 \text{LONG} \text{PROD} - .0701 \text{HOUR} - 2.313 \text{THICK} + 7.789 \text{UNION} -
(11.1)(0.022)(0.63)(4.02)
13.59 \text{CAP T}
(2.60)

(5) $\text{TOT} = -17.46 + 1.008 \text{INF} + (19.99 \text{CON V} + 20.41 \text{CONT} + (17.2)(.17)(2.41)(2.38)
64.79 \text{LONG} \text{PROD} - .00561 \text{HOUR} - 3.163 \text{THICK} + 35.28 \text{UNION}
(21.0)(.043)(1.13)(6.75)
-14.37 \text{CAP T}
(4.93)
Where:  INF:  infraction per million hours worked in a quarter
INSP:  inspection-days per section in a quarter
PEN:  present value of average penalty payment per violation
CONV:  fraction of sections using continuous mining methods
CONT:  fraction of sections using continuous mining methods
LONG:  fraction of sections using longwall mining methods
PROD:  average production per hour worked underground in a quarter
HOUR:  thousands of hours worked underground in a quarter
THICK:  average seam thickness, in feet
UNION:  union dummy, = 1 if mine is a UMWA mine
CAPT:  captive dummy, = 1 if mine is captive
DIS:  disabling and fatal injuries per million hours worked underground
TOT:  total injuries per million hours worked, underground
FAT:  fatal injuries per million hours worked, underground
Equations (2) through (5) support some of our expectations, while casting doubt on others. We can summarize the results on the basis of whether or not the following hypotheses are supported:

1. Infraction rates will decrease as inspection rates increase. **SUPPORTED.** This is one of our fundamental hypotheses. It suggests that frequency of inspection is a deterrent to illegal safety practices. Since the average infraction rate is 73 infractions per quarter per million hours worked, and since the average number of inspection-days per section is 7.8, increasing the number of inspection days by fifty percent would decrease the number of infractions by about 13%. At the mean values for INS and INF, the elasticity of INF with respect to INS is 0.26.

2. Infraction rates will decrease as penalties increase. **NOT SUPPORTED.** In fact, there is a positive but insignificant coefficient of the penalty variable in (2). This seems to imply that higher penalties might lead to more infractions, an implausible result. One possible explanation for such a perverse result is that there are unobserved, unchanging differences among the mines in our sample that lead both to higher infraction rates and to MESA's assessing higher penalties. Two candidates for such unobserved variables are geological differences making the mine unsafe and poor management. In either case, we could see a spurious positive
coefficient of the penalty variables in our estimate of infraction rates.

It is worth noting that the size and variation in MESA penalties is not great enough for us to expect any dramatic deterrence effect in our estimates. Our estimate of the mean present discounted value of assessed penalties is only $65. This is small compared to the costs of many safety-improving activities. This leads us to believe that the major threat of enforcement comes from the fact that the operator must disrupt production schedules in order to comply with the demands of an inspector who finds a violation. In the case of serious hazards, or of non-compliance with instructions to improve safety conditions, the mine, or an area of the mine, may be closed by MESA.

3. Injury rates will increase as infraction rates increase. SUPPORTED. In all three equations estimating injury rates, infractions seem to have a positive impact on injury rates. At the mean, a fifty per cent decrease in the infraction rate would decrease the fatal injury rate by 57 per cent*, the disabling injury rate by 19 per cent, and the total injury rate by 48 per cent. This implies that there is a meaningful impact of infractions on injury rates.

* Although there is a large standard error of the estimated coefficient of INF in (3), the regression result is still the best estimate we have of the relationship between infractions and fatality rates.
4. Infraction rates and injury rates will increase as production per hour increases. PARTIALLY SUPPORTED. Infraction rates do not increase as production per hour rises. In fact, they seem to decrease. This may occur because of conflicting relationships between the two variables. The original hypothesis is that production and safety are joint outputs and, ceteris paribus, if one rises, we expect the other to fall. On the other hand, unobserved variables may make it possible for some mines to be more productive and also to obey MESA regulations more easily. For example, unmeasured favorable geological conditions fall into this category.

It is also possible that when the pace of production is increased, many of the unsafe conditions or practices that occur are not prohibited by MESA regulations. Indeed, this is the reason that the hourly production variables were included in (3), (4), and (5). If all unsafe practices were MESA infractions, the hourly production rate would have no effect on the injury rates as estimated in these regressions. As hypothesized, the coefficients of the hourly production variables in the injury regressions are generally positive.

The effect on injury rates of increasing hourly production is particularly large in the case of longwall mining. (The excess of injuries indicated by the coefficient of LONG*PROD is diminished only slightly by the fact that these
mines have lower infraction rates than mines using other mining techniques.) This is contrary to our original expectations which were that the coefficient of LONG•PROD would be lower than the coefficients related to the other two production methods. There are two reasons for this. First, longwall production requires less labor per ton of output than the other two methods. In addition, it is reputed to be safer than the other two (although this reputation may be more deserved for fatal injuries than for non-fatal injuries).* This is again an example of where unobserved, permanent mine characteristics could cause misleading results in our estimates of infractions and injuries.

5. Infraction rates and injury rates will decrease as mine size increases. SUPPORTED. It is generally assumed that there are economies of scale in both coal production and safety. Our estimates generally confirm that this is true.

All other things equal, we can compare expected infraction rates in mines using 250,000 hours of underground labor tons with those using 25,000 hours quarterly. On the average, the larger mines will have 21.8 fewer infractions per million hours worked, 0.24 fewer fatalities per million hours worked, 20.8 fewer disabling injuries per million hours worked, and

* Communication from John Higgins, Safety Director, Eastern Associated Coal.
24.0 fewer total injuries per million hours worked.

6. Mines with thicker seams will have fewer infractions and injuries than similar mines with thinner seams. PARTIALLY SUPPORTED. Seam thickness has no significant effect on the rate of infractions, as is indicated by equation (2). It also has no relationship, or even a small positive relationship, with fatal injury rates. On the other hand, there is a significant negative relationship between seam thickness and rates of disabling and total injuries. According to (4) and (5), an increase of two feet in average seam thickness would mean a reduction in disabling injury frequency rates of 4.6 and in total injury rates of 6.3.

7. Unionized mines are safer than others, as reflected in lower infraction rates and injury rates. NOT SUPPORTED. Unionization does not change the infraction rate (or has a small positive impact). It may lead to a diminishing of the likelihood of a fatal injury. The unionization dummy has a high negative coefficient in the fatal injury equation; however, the coefficient is not significant at p = 0.3. In the case of disabling and total injuries, however, the unionized mines have, ceteris paribus, more disabling and total injuries. In fact, while the number of excess disabling injuries is rather small, the number of excess total injuries is very large.

This result seems quite perplexing. However, there are
three possible explanations for unionized mines' having
greater accident rates. The first explanation rests on the
fact that injuries tend to be underreported,¹ and that
the greatest underreporting occurs with the least important
injuries. That is, few if any fatal injuries are not re-
ported. However, some disabling injuries and a larger per-
centage of non-disabling injuries are not reported. The
underreporting of less serious injuries is especially acute,
since many employers believe (or act as if they believed)
that only accidents leading to at least several days of lost
time must be reported.

If the UMWA were concerned that mines report all re-
portable injuries and the union monitored the reporting of
injuries, a unionized mine might have more complete reporting
than a non-UMWA mine. If this were true, union mines would
report more injuries, and the excess of reported injuries
would be concentrated in the least serious group - non-
 disabling injuries. This would explain why the estimated
excess injury rate for union mines was largest in the total
injury group.

Another possible explanation for the union excess of
non-fatal injuries is the fact that there has been a great
deal of labor-management strife in underground coal mining
during the last five years. If this strife led to more
hazardous working conditions and practices, we would expect
injury rates to be highest in the mines which were represented by the UMWA.

A third explanation would argue the possibility of unionized mines actually being less safe. Suppose that mine operators choose a combination of wages and safety in order to attract an adequate supply and quality of mine labor. Then, the non-union mine operator will choose the combination of safety and wages \( (S_o, W_o) \) for which the marginal cost of any increase in safety will equal the marginal benefit of that increase - including any decline in wage payments that may occur. On the other hand, the operator at a unionized mine cannot make this trade-off. Therefore, if the wage rate \( W_o \) is below the union wage rate, the unionized mine will not improve safety to the level of the non-union mine. The author does not believe that the market conditions necessary for safety levels to be determined in this way exist in coal mining. This is because this paragraph implicitly assumes that unionization produces only a higher wage at a mine. Even if conditions of perfect information and costless job mobility existed, the package of wages and job conditions offered to unionized miners is surely superior in value to that offered miners in the non-union sector. Thus, an essential premise of the hazard wage argument presented here is false.

8. Captive mines are safer than others, as indicated
by both lower infraction and injury rates. SUPPORTED. Captive mines of similar size and other relevant conditions appear to have an average of fewer infractions, fewer fatalities, fewer disabling injuries, and fewer total injuries per million hours worked underground.

Direct Estimates of the Effects of Enforcement of Injury Rates

In Chapter IV, we discussed the issue of unobserved permanent differences among mines. There, the possibility was raised that the effect of infractions on injury rates might be overstated by an estimate of (20). It was suggested that estimating directly the effects of inspections on injury rates would avoid this problem. This estimation was performed, using the TSLS procedure outlined above. The results are presented here and in Table 2. (Standard errors are in parentheses.)

(6) \[ \text{FAT} = -1.624 + 0.785 \text{INS}\text{P} + 0.0254 \text{PEN} + (0.0784 \text{CONV} + \text{CONT} - 0.0259 \text{LONG}) \text{PROD} - 0.0040 \text{HOUR} + 0.0309 \text{THICK} - 0.173 \text{UNION} - 0.0826 \text{CAPT} \]

(7) \[ \text{DIS} = 85.54 - 3.909 \text{INS}\text{P} + 0.0820 \text{PEN} + (4.681 \text{CONV} + 1.123 \text{CONT} + 65.86 \text{LONG}) \text{PROD} - 0.0798 \text{HOUR} - 1.843 \text{THICK} + 4.919 \text{UNION} - 16.64 \text{CAPT} \]
(8) \[ \text{TOT} = 137.58 - 9.899\text{INS} + 0.1049\text{PEN} + (13.94\text{CONV}) \]
\[ + (14.1)(1.54) + (0.3)(2.27) \]
\[ + 10.57\text{CONT} + 48.08\text{LONG}\text{PRODUCT} - 1.056\text{HOUR} - 2.487\text{THICK} \]
\[ + (2.45)(20.62) + (0.031)(1.15) \]
\[ + 31.05\text{UNION} - 25.47\text{CAPT} \]
\[ + (6.84)(4.83) \]

The effects of inspections on disabling and total injury rates are even stronger here than above. On the other hand, according to (6), more inspections seem to increase fatal injury rates.

The perverse sign of the coefficient of \text{INS} in (6) is probably the result of the upward bias caused by permanent unobserved differences among mines. We expect this bias induced by permanent unobserved differences to be greatest when there is a strong relationship between the excluded variables and both the dependent and independent variables. (See equation (29), Chapter IV.) This condition is met more strongly in (6) than in any of the other regressions in this chapter.

The conditions that most strongly influence MESA to inspect a mine are often geological conditions which are causes of fatal accidents, but which we do not observe. These include poor roof conditions, or excessive liberation of methane, potentially producing explosions. In 1970, roof falls and explosions led to over sixty per cent of all fatalities in bituminous coal mining, while accounting for
less than twenty per cent of all nonfatal disabling injuries. (See Table 4, Chapter I.) Omitting these variables from our fatality equation (6) biases upward the coefficient of INSP.

Unfortunately, the appropriate methods test this hypothesis, given the data problem, cannot be applied here. Both methods that this author is familiar with involve a process which, in effect, adds to the regression a dummy variable for each mine. The dummy variable approach, however, eliminates the restrictions necessary to identify the injury equations. The excluded predetermined variables are dummy variables, representing the MESA district of the observed mine. Since these variables are constant over all observations on each mine, they are indistinguishable from any dummy variable unique to that mine.

The increase in the estimated impact of inspections on disabling and total injury rates is not a very surprising result. We know that unobserved permanent differences among mines may cause a positive bias in the estimated effect of infractions on injuries. On the other hand, there is a bias in the opposite direction caused by the fact that INF measures actual infractions with considerable noise. By removing INF from the estimating procedure, the noise is reduced and the estimated relationship becomes stronger.

A second explanation for the larger impact of enforcement in the direct estimates is the possibility that some of
the impact of inspections on injuries may not result from a decrease in infractions. Suppose that the mine operator believes that mines with high injury rates will incur more inspections than mines with low injury rates. Then, improving safety conditions (whether through compliance with MESA regulations or other means) will decrease the frequency that a mine is inspected. Being inspected less often will mean fewer violations and penalties, even if the number of infractions does not change. It will also mean less management time spent handling inspections, abatements, and payment of penalties.

The reader may also note that the estimated impact of penalty size on injury rates is positive in (6), (7), and (8). In fact, at the mean values for penalty and injury rate, the elasticity of the fatal injury rate with respect to penalty size is 3.3. The enforcement model would lead us to believe that this number should be negative. The reason for the unexpected positive sign of PEN is that penalty size is determined in part by the hazardousness of the relevant violation. Of the eight factors used by MESA to determine the size of a proposed penalty, two are related to the probability of an accident's occurring and one is related to the severity of the resulting injury, should an accident occur.² This means that the size of the penalty reflects, to a large extent, the dangerousness of the vio-
lation. To the extent that this is true, we would expect injury rates to be higher when penalties are higher.

**Summary**

Our estimates of infraction and injury rates generally confirm the appropriateness of the government intervention model presented in Chapter III. For a number of reasons, described largely in Chapter IV, our estimates of enforcement on injuries are likely to be biased downward. Nevertheless, we show a significant effect of MESA enforcement on injury rates. This effect is almost entirely a result of the frequency that mines are inspected, not the level of penalty imposed (given the limited size and variation of that variable).

As a final exercise in this chapter, we derive estimates of the effects of increasing MESA inspections by fifty per cent for the mines in our sample. We use the injury data from our sample for 1973 - 1975, and apply the results of our estimation to derive estimates of changes in injury rates and number of injuries for those years. These are presented in Table 3. The estimated consequences of increasing the inspection rate by fifty per cent are that there would have been more than 11 fewer deaths, 350 - 2400 fewer disabling injuries, and 1500 - 6000 fewer total injuries.

The lower estimates of disabling and total injuries are derived from the indirect estimate of the effects of regula-
tion on injury rates. In this case, we estimated the effects of inspection frequency on infraction rates, and then estimated the effects of infraction rates on injury rates. The higher estimates were derived from directly estimating the effects of inspections on injury rates. For reasons discussed in the preceding section of this chapter, the direct estimates should be less biased than the indirect estimates. Therefore, our best estimates of the effects of increasing inspections by fifty per cent are: 11 fewer deaths, 2400 fewer disabling injuries, and 6200 fewer total injuries.
<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Constant</th>
<th>Infractions per MWh</th>
<th>Inspection Days</th>
<th>Average Penalty</th>
<th>Production per Hour (10^3)</th>
<th>Hours worked</th>
<th>Seam Thickness (feet)</th>
<th>Union Dummy</th>
<th>Captive Dummy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Conventional</td>
<td>Continuous</td>
<td>Longwall</td>
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<tr>
<td>Infractions per MWh</td>
<td>84.59</td>
<td>-2.460</td>
<td>0.0076</td>
<td>-1.319</td>
<td>2.176</td>
<td>-19.33</td>
<td>-0.0965</td>
<td>-1.670</td>
<td>2.975</td>
</tr>
<tr>
<td>(8.72)</td>
<td></td>
<td>(0.84)</td>
<td>(0.017)</td>
<td>(1.46)</td>
<td>(1.45)</td>
<td>(9.05)</td>
<td>(0.012)</td>
<td>(0.53)</td>
<td>(5.01)</td>
</tr>
<tr>
<td>Fatal Injuries per MWh</td>
<td>.0137</td>
<td>.0070</td>
<td></td>
<td>-.00102</td>
<td>-.0132</td>
<td>.2126</td>
<td>-.000390</td>
<td>.0591</td>
<td>-.1690</td>
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<tr>
<td>(0.72)</td>
<td></td>
<td>(0.007)</td>
<td></td>
<td>(0.11)</td>
<td>(0.10)</td>
<td>(0.85)</td>
<td>(0.002)</td>
<td>(0.47)</td>
<td>(0.30)</td>
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<tr>
<td>Disabling Injuries per MWh</td>
<td>41.33</td>
<td>.2300</td>
<td></td>
<td>5.802</td>
<td>4.279</td>
<td>69.4</td>
<td>-.0701</td>
<td>-2.313</td>
<td>7.789</td>
</tr>
<tr>
<td>(9.61)</td>
<td></td>
<td>(0.09)</td>
<td></td>
<td>(1.39)</td>
<td>(1.35)</td>
<td>(11.1)</td>
<td>(0.022)</td>
<td>(0.63)</td>
<td>(4.02)</td>
</tr>
<tr>
<td>Total Injuries per MWh</td>
<td>-17.46</td>
<td>1.008</td>
<td></td>
<td>19.99</td>
<td>20.41</td>
<td>64.79</td>
<td>-.00561</td>
<td>-3.163</td>
<td>35.28</td>
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<tr>
<td>(17.2)</td>
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<td>(0.17)</td>
<td></td>
<td>(2.61)</td>
<td>(2.38)</td>
<td>(21.0)</td>
<td>(.043)</td>
<td>(1.13)</td>
<td>(6.75)</td>
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<td>Dependent Variable</td>
<td>Constant</td>
<td>Inspection Days</td>
<td>Average Penalty</td>
<td>Production per Hour</td>
<td>Hours worked $10^3$</td>
<td>Seam Thickness (feet)</td>
<td>Union Dummy</td>
<td>Captive Dummy</td>
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<tr>
<td>--------------------</td>
<td>----------</td>
<td>-----------------</td>
<td>----------------</td>
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<td>---------------------</td>
<td>----------------------</td>
<td>-------------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>Fatal Injuries per MWh</td>
<td>-1.624 (0.59)</td>
<td>0.0785 (0.06)</td>
<td>0.0254 (0.001)</td>
<td>0.0784 (0.10)</td>
<td>0.0391 (0.10)</td>
<td>-0.0259 (0.81)</td>
<td>-0.00406 (0.001)</td>
<td>0.0309 (0.047)</td>
<td>-1.173 (0.29)</td>
</tr>
<tr>
<td>Disabling Injuries per MWh</td>
<td>85.54 (7.99)</td>
<td>-3.909 (0.84)</td>
<td>0.0820 (0.018)</td>
<td>4.681 (1.32)</td>
<td>1.123 (1.40)</td>
<td>65.86 (10.85)</td>
<td>-0.0798 (0.016)</td>
<td>-1.843 (0.64)</td>
<td>4.919 (4.07)</td>
</tr>
<tr>
<td>Total Injuries per MWh</td>
<td>137.58 (14.1)</td>
<td>-9.899 (1.54)</td>
<td>0.1049 (0.03)</td>
<td>13.94 (2.27)</td>
<td>10.57 (2.45)</td>
<td>48.08 (20.62)</td>
<td>-0.1056 (0.031)</td>
<td>-2.487 (1.15)</td>
<td>31.05 (6.84)</td>
</tr>
</tbody>
</table>
TABLE 3

Estimated Average Annual Changes in Injuries
Caused by Increasing MESA Inspection by 50%

<table>
<thead>
<tr>
<th></th>
<th>Indirect Estimate</th>
<th>Direct Estimate</th>
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<tbody>
<tr>
<td></td>
<td>Percent Change in</td>
<td>Average Change in</td>
</tr>
<tr>
<td></td>
<td>Injury Frequency</td>
<td>Annual Number of Injuries</td>
</tr>
<tr>
<td>Fatal Injury Rates</td>
<td>14.9%</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td></td>
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<tr>
<td>Disabling Injury Rates</td>
<td>5.1%</td>
<td>354</td>
</tr>
<tr>
<td>Total Injury Rates</td>
<td>12.6%</td>
<td>1546</td>
</tr>
</tbody>
</table>

* Inappropriate. See discussion of equation (6).
CHAPTER VI
DISCUSSION
Discussion

Enforcement and its Effects

MESA's performance in enforcing coal mine health and safety regulations has been subject to much criticism over its seven year history. Some coal operators have suggested that safety consultations should take the place of current enforcement activities, claiming that MESA should be "solving the real safety problems in the industry rather than trying to find the greatest number of non-safety (related) violations . . . in order to punish the operator." In terms of our model, they believe that infractions of MESA regulations have little causal relationship with accident rates. Others believe that most accidents are caused by bad work habits and lack of worker training, while MESA focuses on the safe deployment of equipment. On the basis of this belief, the state of Kentucky has instituted a program aimed at analyzing "work habits, practices, and procedures," and at training and certifying underground miners in job safety.

On the other hand, the United Mine Workers of America has consistently criticised MESA for inadequate commitment to its congressional mandate to enforce health and safety standards, for inadequate management and evaluation of its inspection activities, and for inadequate collection of penalties assessed against mine operators. Some of these
criticisms have been echoed by the Government Accounting Office, by the Congress, and within the Interior Department itself. Congressman Carl D. Perkins of Kentucky stated during the 1977 House Oversight Hearings on MESA that the "persistent inadequacies of coal mine health and safety enforcement rest more with haphazard and ineffective enforcement of the Act by the Interior Department, than with any significant flaw in the law itself."

This study was designed to determine whether, in spite of the putative weaknesses in the MESA program, its enforcement activities have had a substantial impact on underground mining injuries. Using the law enforcement framework developed by Becker and others, we have attempted to estimate the impact of mine safety enforcement on injuries. Two different specifications were used on our sample of 539 large mines.

The first specification estimated the effects of inspection frequency on infraction rates, and then estimated the effects of infraction rates on injury rates. Increased inspection rates were found to lead to diminishing infraction rates, as theory would lead us to believe. In addition, for fatal, disabling, and total injuries diminishing infraction rates led to lower injury rates. This second set of results supports the hypothesis that obeying MESA regulations improves safety. Using the estimated effect of inspections on infractions and the estimated effect of infractions on injuries, we
computed the marginal effect of increasing inspections on injury rates. The predicted effects of increasing inspections rates by fifty per cent are displayed in the first two columns of Table 4, Chapter IV. A fifty per cent increase in inspection rates is predicted to lead a decrease of 11 fatal injuries, a decrease of 354 disabling injuries, and a decrease of 1546 in total injuries.

The second specification directly estimated the effects of inspections on injury rates. By eliminating infractions from the estimate, the bias introduced by the errors in measuring that variable was also eliminated. In so doing, the estimate of the effect on disabling injuries rate of increasing inspections by fifty per cent increased to 2433. The estimated effect on total injuries increased to 6171. However, the direct estimate of the effect of inspections on fatal injury rates was positive, indicating that an increase in inspections would increase fatalities. We have suggested that this could occur if some variables which are strongly correlated with both fatal injuries and inspections were excluded from the specifications we have used.

Also, we were unable to demonstrate a deterrence effect for MESA penalties. This may be related to the fact that penalty size reflects the hazardousness of a violation, or to estimation bias in our regressions caused by unobserved variables or measurement error. In fact, it is likely that
the small average size of collected penalties provides little incentive for mine operators to make expensive changes in the production process.

As was discussed in the introduction, the limits as well as the implications of this study should be clearly understood. The study only covers the enforcement aspects of the Federal mine safety program, which also includes training, consultation, and research. Within the enforcement program, it does not examine the effects of health enforcement on the incidence of coal worker's pneumoconiosis (black lung). Also, the results are based on a sample of large underground mines, and do not purport to describe the effects of safety enforcement on mines producing less than 100,000 tons per year, or on surface mines.

Our estimates of enforcement effects are based on a crucial and untested assumption. In Chapter III, we discussed the fact that neither I (the number of infractions committed at a coal mine) nor P (the probability of a given infraction's being cited) are observed. Only the variable V (the number or cited infractions) is actually observed. Given this fact, it was necessary to make an assumption about the relationship among I, P, and V. For the purposes of this study, we have assumed that P is linearly related to the number of days devoted to inspecting each mine section in a calendar quarter. If this assumption is true, we can develop an index for I and P which is accurate up to a scale factor. Although our
assumption about \( P \) is a reasonable one, it is untested. Empirical research in this area should prove useful to further studies in this field. The issue of how inspectors enforce regulations is critical to an understanding of the regulatory process.

The issue of unmeasured permanent differences among mines is the second area where further study may reap significant rewards. We have noted above that unmeasured variables can contribute to bias in the estimated coefficients of all the enforcement-related variables. (See pages 105 - 109). For example, it hypothesized that the positive coefficient of \( \text{INS} \) in regression (6) in Chapter V is a result of this bias. Further study, including additional collection of data about mine ownership and geological factors, may help to clarify this problem.

**Two Remaining Mysteries**

There remain two puzzling results of the estimation of our model of coal mining injuries. The first of these is the fact that unionized mines have higher non-fatal accident rates than would be expected for non-union mines with the same characteristics. The second is the fact that, at the same levels of productivity, longwall mining seems to be more hazardous than continuous or conventional techniques.

We have hypothesized that the high accident rates of unionized mines may be caused by relative underreporting of
accidents by non-union mines. However, this explanation is speculative, since we have no data on the reporting of accidents in unionized and non-union coal mines. This finding clearly indicates the need for a study on underreporting of accidents among different types of mines.

The fact that longwall mining seems to be more hazardous than conventional or continuous mining also indicates the importance of more careful study in this area. It is commonly assumed that longwall mining is considerably safer; and limited use of this technique in the United States is given as reason that American coal mining is more hazardous than its European counterpart. Estimates of the hazardousness of longwall mining in this study do not support this assertion. We have mentioned above that longwall mining may tend to occur in mines that have hazardous conditions which are omitted in our model of accident causation. While this could account for our findings, further study seems necessary to clarify this issue.

**Evaluating MESA Enforcement**

During the course of this study, several people have asked whether the marginal costs of MESA enforcement were greater or less than its marginal benefits. This study is not directed at the question of the cost-effectiveness of MESA enforcement. Nevertheless, our results and currently available information about the resources used in the process of inspection and abatement of hazards are consistent
with the hypothesis that MESA's benefits are greater than its costs.

From 1965 to 1969, productivity in underground coal mining was increasing at an average annual rate of 2.8 per cent. In the four years after 1969, productivity has declined at an average annual rate of 6.8 per cent. (See Table 1.) This decline in productivity is an indication of the general increase in the cost of producing coal in the 1970's. The coal operators have claimed that a substantial amount of the increase in the cost of producing coal is a direct result of the enforcement of the 1969 Act. While there have been attempts to estimate the effects of MESA enforcement on production costs, these attempts have been flawed in obvious ways, and provide no useful guidance in this area. At this time, we do not know to what extent the decline in productivity in the 1970's is a result of MESA enforcement, and to what extent other factors, like labor-management disputes, a less experienced work force, and the mining of thinner coal seams, play a role. Developing and testing an appropriate model of production and safety would be useful in this regard, but is outside the scope of this study.

We have a somewhat better idea of the costs to the government of enforcing the 1969 Act. In 1976, the MESA enforcement budget for Coal Mine Health and Safety was $41.8 million. However, the activities of MESA include inspecting
both underground and surface mines, and inspecting for both
safety and health hazards. We would estimate that no more
than $20 million was spent annually on safety enforcement in
underground mines. In addition, the mines in this sample
consist of only one third of all underground mines, although
they employ about 85 per cent of all underground miners. A
reasonable upper limit to MESA expenditures for inspecting
these mines in $15 million. The costs of increasing inspections
by fifty per cent is not likely to be greater than half of
this, or $7.5 million.

The benefits of a fifty per cent increase in MESA in-
spections at the mines in our sample are estimated to be
3800 fewer non-disabling injuries, 2400 fewer disabling in-
juries, and 11 fewer fatalities. Disabling injuries include
temporary and permanent disabilities. We know that under-
ground coal miners with temporary total disability in 1970
averaged 36 days - about two months - of work lost. Also, the
average age of fatal accident victims in 1966 - 1970 was 43
years.9

Although we have some evidence on the costs and benefits
of MESA enforcement of underground coal mining safety regu-
lations, there is clearly not enough information to compare the
cost-effectiveness of this approach with other measures designed
to reduce morbidity and mortality. However, on the basis of
our results, we cannot conclude that the costs of this program
outweigh its benefits. For example, suppose that the compliance costs of MESA regulations are as great as its enforcement costs. In addition, assume an implicit value of $4000 for the average disabling accident (mean disability, more than two months). Then the marginal benefits of MESA enforcement exceed its costs unless we value saving a life at less than $540,000.*

While this study has focused on the effects of changing the amount of resources devoted to MESA enforcement, increasing MESA inspections is not necessarily the only way to improve its ability to prevent accidents. MESA may also profit from improved organization and administration of its enforcement activities. Davitt Macateer, representing the United Mine Workers of America union before the House Government Operations Committee in October, 1973 stated that MESA had "no system auditing or monitoring its inspectors," and that, in general, it had no management control system designed to help it evaluate the organization's success in meeting its goals. This type of problem was made clear to the author in the process of collecting the data for this study, much of which would be useful to an agency in evaluating its own effectiveness. The data was often costly and time-consuming to collect. In add-

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* The values assumed for disabling and fatal injuries are for convenience only. The reader is welcome to make different assumptions, or to attempt to compare the effects of MESA enforcement with other government programs designed to save lives.
ition, its collection and maintenance were scattered among three branches of MESA or actually only available in the 17 subdistrict offices. Other administrative problems with the MESA enforcement program, concerning assessment and collection of penalties, have received much attention during the past five years.\textsuperscript{11}

MESA may also be able to increase its effectiveness by concentrating more on those types of violations which are highly associated with serious accidents. While the Bureau of Mines has financed many engineering studies of safety problems, it has not sponsored any statistical studies of the relationship between infractions of specific standards and ensuing accidents. Such studies might simply be a more disaggregated version of this study and could point out areas which demand additional attention by MESA inspectors. If the information were available, MESA would want to deploy its inspection resources and penalty powers so that the marginal contribution to safety of resources devoted to compliance with each regulation would be equal to that of enforcing all other regulations.


<table>
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<th>Percent Change from Previous Year</th>
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<tbody>
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<td>1965</td>
<td>14.00</td>
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</tr>
<tr>
<td>1966</td>
<td>14.64</td>
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</tr>
<tr>
<td>1967</td>
<td>15.07</td>
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<td>1968</td>
<td>15.40</td>
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<tr>
<td>1969</td>
<td>15.61</td>
<td>1.4</td>
</tr>
<tr>
<td>1970</td>
<td>13.76</td>
<td>-11.9</td>
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<tr>
<td>1971</td>
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<td>-12.6</td>
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<tr>
<td>1972</td>
<td>11.91</td>
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<tr>
<td>1973</td>
<td>11.20</td>
<td>-6.0</td>
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</table>

APPENDIX

MEASURING THE EXPECTED VALUE OF
PENALTY PAYMENTS
Appendix: Measuring the Expected Value of Penalty Payments

The payment of assessed penalties has been a continual source of conflict during the years since the passage of the Coal Mine Health and Safety Act of 1969. Throughout this period, actual payments have been considerably smaller than original assessments. In addition, the average time between a violation and payment of the associated penalty has been over one year.

Economic theory suggests that the deterrence effect of a penalty will depend on the operator's expectation of the present discounted value of his payment. We assume that the operator is able to predict how much he will pay and when he will pay it (perfect foresight). With this assumption, we still must determine time to payment and the amount paid and decide on a discount rate.

For a discount rate, we use an estimate of 12 per cent as the after tax profit rate of coal mines, as suggested by Zimmerman. Our data base includes the date and amount of payment of those penalties that were settled by mid-1976. This means that, for all cases still open at that time, we do not know the date and amount of payment. Although over 90 per cent of the cases originating in 1973 and 1974 were closed, a considerably smaller percentage of 1975 cases were closed.

We estimate the time to payment of open cases from the
time to payment of closed cases from earlier periods. Time to payment is regressed on the original assessment, a captive dummy, and whether the violation occurred before or after January 1, 1974. The most important determinant of time to payment is the date of the violation. This seems somewhat surprising, but is actually reasonable. During the early years of enforcement of the CMHSA, there was a great deal of controversy over assessment procedures. The legality of these procedures was challenged early in the Act's history. The assessments guidelines were not revised to adequately meet legal objections until 1974, at which time the operators' recalcitrance about paying penalties diminished somewhat.

The results of the regression are displayed here (standard errors are in parentheses):

\[
(1) \text{TIME} = 1.024 + 0.00008\text{ASST} - 0.717\text{CAPT} + .871\text{YR73} \\
\text{(.0056)} \text{(.000011)} \text{(.61)} \text{(.0055)}
\]

\[R^2 = 0.25\]

TIME = time, in years, from the date of violation to the date of payment

ASST = amount of original assessment, in dollars

CAPT = 0, if the mine is commercial = 1, if mine is captive

YR73 = 0 if violation occurred after 1973, = 1 otherwise.

As we would expect, the larger the assessed penalty, the longer the time to its payment. In spite of long delays in payment, MESA has never penalized operators for overdue payments. Thus, the gain to the employer of postponing payment grows as
the payment increases. Finally, the captive mines tend to pay sooner than commercial mines. However, the difference in time to payment between captive and commercial mines is less than a month.

A similar procedure was used to estimate the fraction of the original assessment that was actually paid. The fraction paid was regressed on the original assessment, captive dummy and a variable representing whether the violation had occurred prior to 1974. The results of this regression are presented here:

\[(2) \quad \text{PCPAID} = 0.6660 - 0.0001572 \text{ASST} + 0.0260 \text{CAPT} - 0.1713 \text{YR73} \]
\[
\begin{align*}
&\quad \quad (0.0016) \quad (0.000023) \quad (0.0027) \quad (0.0021) \\
R^2 &= 0.14 \\
\text{PCPAID} &= \text{fraction of original assessment that is eventually paid.}
\end{align*}
\]
Footnotes, Introduction

7. See Becker (1968) and Ehrlich (1973 and 1975).

Footnotes, Chapter I.

1. For an excellent, although somewhat dated, discussion of the history of coal mine accidents in the United States, see Drury (1964).

2. Davitt Macateer (1972) presents some interesting observations about differences in safety practices between the United States and European countries.


7. Much of the following discussion is derived from Committee on Education and Labor (1970).


10. Communication from J.R. Zelonka, Management Science Staff Engineer, MESA.


Footnotes, Chapter II.


4. See Schroeder (1973) for a good description of the underground mining process.


6. Ibid., p. 17.


8. Ibid., p. 7.


Footnotes, Chapter III.
17. Ibid., pp. 61-84.
22. Ibid., pp. 710-712.

Footnotes, Chapter IV.

Footnotes, Chapter V.

Footnotes, Chapter VI.
7. Straton (1972a and 1972b) and Nelson and Neumann (1975), pp. 44-47.

8. Data from Thomas Brown, U.S. Department of Labor.


Footnotes, Appendix.


BIBLIOGRAPHY
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