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Technological Progress and Environmental Regulation as Drivers of Productivity Growth: Evidence from the U.S. Coal Industry, 1972-1994

by

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ABSTRACT

Utilizing mine-level data collected from coal mine operators by the Mine Safety and Health Administration from 1972 combined with inspection and citation data collected by the same Administration since 1983, a detailed analysis of the effects of regulatory enforcement on coal mine productivity was performed. Inspections in and of themselves were found to have no effect on productivity, though a strong correlation exists between mines receiving high numbers of citations for dangerous conditions and low labor productivity. The size of an operation, measured by output, was found to have an effect on average levels and growth rates of labor productivity.

Several analytical issues are raised by this research. Of fundamental importance is separating out the effects of inspections from the underlying reasons for the inspection. The number of inspections is largely determined by mine size, conditions such as presence of methane, and past safety history. Additionally, a citation, which indicates non-compliance, arises from an inspection, which does not indicate, *a priori*, such a violation. The mechanism through which labor productivity and regulatory enforcement are related is not identified in this analysis, though further analytical techniques and sources of data which may shed light on the issue are introduced.

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My two years at MIT in general, and this thesis in particular, would not have been the rewarding and pleasant experiences they were without the camaraderie, support, and friendship of several people. Of course, an unknowable amount of gratitude is owed to my parents and family.

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More than any other single factor, the people I have met here have had the most influence on my enjoyment, what I have learned, how I have grown, and how I have changed. It truly has been the journey that has defined the destination, not just at MIT but in my whole life. All of one's friends are really reflections of one's own personality, and I thank them deeply for their friendship. So to the hapless romantic, my spiritual twin, the pragmatist, the clown, JB, the new father, and the person who knows you're *never* too old to ride a big-wheel plastic tricycle: thank you. When I grow up I want to be just like you.

"You have chosen not to be perturbed by great problems, having trouble enough to forget your own fate as a man. You are not the dweller upon an errant planet, and do not ask yourself questions to which there are no answers....
Nobody grasped you by the shoulder while there was still time. Now the clay from which you were shaped has hardened, and naught in you will ever awaken the sleeping musician, the poet, the astronomer that possibly inhabited you in the beginning."

-Antoine de Saint-Exupery
Wind, Sand and Stars

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1 Introduction

Coal mining in this country is part of a much larger set of issues and interactions regarding resource depletion, energy use, environmental concerns and economics. The mining practices vary considerably, as does the geological nature of the deposits being mined. Transportation of the coal is a serious concern, at time accounting for over half of the delivered price. To understand the changing nature of coal markets and mining, one needs to examine the mining industry not only at the point of extraction, but where the demand is located and where investment in new supply is taking place.

Central to the success of a coal mine and, indeed, to a coal-mining region is the cost at which it can deliver the coal to its customers. This is highly influenced by the cost of extraction and, even more important, whether this cost is rising or falling. Conventional resource economics identifies two key determinants to the cost of extraction: depletion and technological progress. The former will lead to rising marginal cost of supply, since the coal extracted early will be that which is easiest to mine. As mining continues, the working face will be ever farther from the mine mouth, entailing longer and more complicated structures to move workers, equipment and coal. Technological progress, on the other hand, is expected to counteract these scarcity concerns. By employing better equipment, more coal can be mined more cheaply, goes the argument. Even if existing mines cannot take advantage of new technology, improved information and equipment will make possible the prospect of starting a new mine with considerably lower supply costs, thus inviting investment.

Things are clearly changing, whatever the reason. Mines today are producing more coal with lower amounts of labor, capital or material usage: output which has come "for free" due to better or more efficient mining methods. This has been seen at the national and regional levels. Not all regions have improved at the same rate, however, and there are still very large disparities in supply costs across regions. More specifically, the growth in total factor productivity has not been uniform across the different mining sectors. Total factor productivity is the change in output after accounting for changes in the various inputs. For example, if an operator increases usage of all inputs by 20% and output rises by 30%, there is said to be a 10% growth in total factor productivity. It is the growth achieved at no cost.

Productivity has clear implications for the cost of supply for mines and the mining industry. Where productivity can be expected to increase, investment is attracted, as the more productive, lower cost supplier will be able to enjoy higher profit margins. If the new entrants are very large, as in the case of some western surface mines, they can capture market share away from other suppliers. Indeed, work done at the national level has shown productivity growth to be a principal determinant of the price of coal. The big question, then, is what determines productivity growth?

In the arguments about technological change, the passage of time is credited with providing for improved equipment, better information, and more efficient practices. In most industries, including coal mining, the process gets more efficient over time. How much of these improvements can actually be manifest into the industry depends on several factors. First is whether the state of the technological art is fixed once a mine is in place - if the technology is embodied. This is akin to the automobile engine: no matter how good today's engines may be, the performance of any one engine is fixed at the time it is cast. Alternatively, one may be inclined to believe that existing mines can benefit from improving technology and information. Certainly one would expect learning by doing improvements to be realized, especially in the initial quarters of production. The way in which existing mines can utilize technological improvements will greatly affect the rate at which improvements diffuse into the industry. If technology is truly embodied, then improvements will only come about through the replacement of mines with new mines, or through large-scale retrofitting of existing operations such as in longwall mines.

Seeking new ways to extract coal at lower cost is not the only focus of a mine operator's energies, however. In 1969, Congress passed the Coal Mine Health and Safety Act following a large and devastating mine collapse in Farmington, West Virginia, which resulted in large loss of life. The main focus of the Act was reducing the incidence and death associated with mine accidents, as well as improving the working conditions for miners, primarily by reducing the amount of dust and particulates which can be present in the working environment. Additionally, several states were enacting legislation to mitigate aesthetic and environmental deterioration associated with surface mining. These state programs lead to federal regulation in the 1977 Surface Mining Control and Reclamation Act.

The 1970's were a period of widespread productivity decline for the industry. The coal industry was not alone; economic activity in the nation as a whole grew at a rate far below that for the previous decades. While several ideas were put forward, government regulation was attacked by some as being a major reason for the decline in productivity.

The research in this thesis focuses on enforcement of the CMHSAct by the Mine Safety and Health Administration from 1983-1994. Beyond looking simply at enforcement effort, we will examine the impact on the productivity of mines in several different coal producing areas in the United States. The importance of this period is that it is an eleven year period of unambiguous growth in productivity, albeit at different rates for different regions. Secondly, it is far enough since the enactment of the regulations to make reasonable the assumption that expectations of operators and investors have come to fully incorporate the new regulatory structures. This allows us to look less at the initial-year impact on the industry, which would mostly have fallen on requiring existing mines to change their practices, and more on the running impacts of the regulation.

Organization of Thesis

The thesis is organized into five chapters and an appendix. Chapter 2 gives a more thorough background to mining in the United States, identifying production and labor trends for the various regions since 1972. It also delves deeper into understanding the structural as opposed to mine-level technological changes which affect productivity. Insight is given regarding the dynamics of the industry, looking especially at the differences across age or vintages of mines even within a particular region. Chapter 3 is a detailed discussion of the data upon which the later analysis rests. After describing the source and arrangement of the data, and explaining certain assumptions embodied in the manipulation of the data, a comparison is made with similar data available from other sources. Furthermore, it offers a justification for using labor productivity data to examine total factory productivity trends.

Chapter 4 is the principal analysis chapter. This chapter brings together information on inspections and citations under the Coal Mine Health and Safety Act and data on the operating performance of the mines. After a regional analysis of productivity and enforcement is found to be promising but inconclusive, a mine-level analysis is developed. Once the intuitive background for such an analysis is explained, a more formal econometric model is proposed, and results are briefly discussed. This issue of determining causation, and the inherent difficulties in doing so, is explored, as are additional methods and data which may help advance the research.

Chapter 5 is a discussion of the main findings. Additionally, it places the current research in the context of a fuller analysis of regulatory effects. Areas for further research are also summarized.

An appendix contains the output logs from the various regression models, as well as additional data to support the analysis.

Summary of Findings

The principal findings of this thesis is that mines which continue to employ unsafe mining practices, as evidenced by the most severe type of citation, are unambiguously at a productivity disadvantage. Even stronger is the relationship in the other direction: the high-productivity mines always have low numbers of severe citations. This is particularly true for underground mines, which we expect since the Act's primary focus was underground rather than surface operations.

The burden imposed on mines due to the intrusive nature of inspections was not found to have a significant negative effect on labor productivity. This is in contrast to some industry claims that inspections and recordkeeping divert sufficient resources away from the actual mining operation to depress productivity. While this claim may have had some validity in the initial years of the Act, there is every indication that mine operators have become quite efficient at working within the administrative requirements of the Act.

As a result of having to control for scale effects within the various regions, some insight was gained into the benefits to making mines of a particular size - is larger better? In the case of surface mines, the answer seems to be a strong "yes". In both Appalachia and the Interior, larger mines had higher levels of productivity. In the Powder River Basin and Lignite regions, the trend was less clear, but there was also more uniformity in the level of productivity. Western surface mines, a group plagued by falling productivity since the 1970's, seem equally dismal regardless of size, with the exception of the very largest mines, which appear to buoy the entire region with their high productivity levels. Growth rates display less clear scale effects.

The scale effects for underground mines are not as obvious as for the surface mines. In the Interior and Western regions, scale seems to play an important role in determining the level of labor productivity, though the Interior shows signs that, at the extreme sizes, this effect is somewhat negated. Appalachia shows little dependence on scale at all.

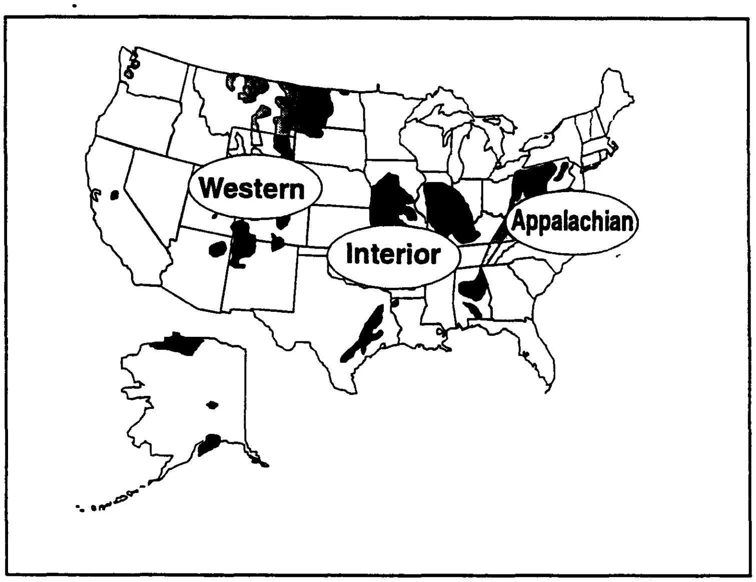
2 The Importance of Productivity in U.S. Coal

This chapter provides an overview of the coal industry in the United States: where is it mined, how is it mined, and the changing shares of national output. Additionally, labor productivity trends are presented for different coal-producing regions and methods.

The second aim of this chapter is to provide a background to the various factors which affect labor productivity. This includes a discussion of what affects aggregate (for a region or state) labor productivity as well as differences in productivity across different regions, methods, and vintages. This leads to a better understanding of the dynamic process through which mine-level improvements in labor productivity are realized for the region and, eventually, for the industry.

Overview of U. S. Coal

Coal is mined in the U.S. in three broadly defined areas, by either of two possible methods. The geographic areas are Appalachia, the Interior, and the West, as shown in the map, below. The West is not a well-defined region, but rather refers to all regions outside of the readily-identifiable coal-bearing areas of the Interior and Appalachia. Consequently, two sub-regions within the West are identified: Lignite and the Powder River Basin. These areas are either geologically uniform and tightly defined (PRB) or refer to a different type of coal (Lignite).



Mines can be either underground or surface mines. Underground mines involve drilling a network of shafts and adits (horizontal tunnels), complete with supporting transport within them for both workers and coal. The size can range from small, labor intensive operations to much more mechanized mines where the geology is more favorable. Longwall mining, a new underground mining method, is a further extension of mechanized sub-surface mining. Surface mines are employed where the coal lies in fairly uniform, thick seams near the surface of the ground. Very large machines are used to remove the non-coal earth, exposing the coalbeds. These can then be readily scraped down by earth-moving vehicles, the coal being shuttled to the processing plant by a continuous convoy of trucks.

Generally speaking, surface mining is dominant in the Western states, accounts for two-thirds of output in the Interior, and one-third in Appalachia, where underground mining is still dominant.

Figure 2-1 shows several interesting statistics which give a good picture of the mining industry in the United States. Appalachian and Western mines both produce about the same amount of coal, yet the Western region is home to far fewer mines. Beyond indicating that Western mines must obviously be several orders larger in ouput than their Appalachian counterparts, this difference indicates also where most of the labor force will be concentrated: in Appalachia, where most of the activity is in more labor-intensive sub-surface operations rather than large surface mines.

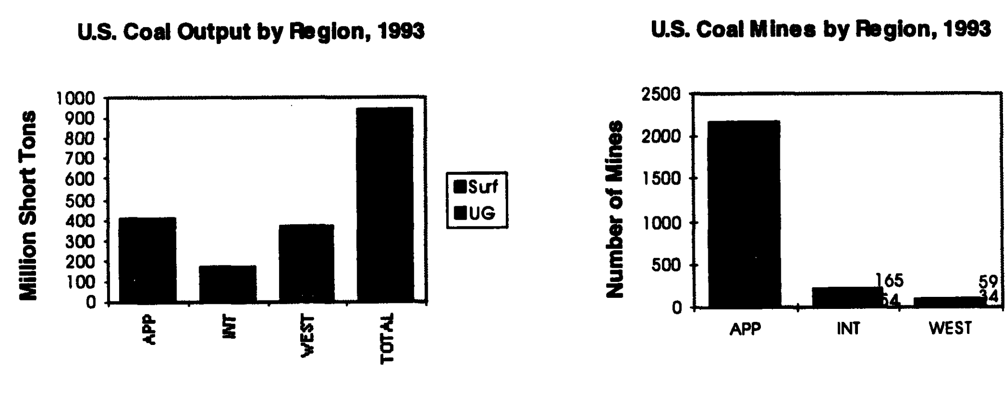


Figure 2-1

[1] Source: Energy Information Administration *Coal Data: A Reference* 1993.

Of course, coal is not traded in a homogeneous world or even national market. The delivered price of coal is, in large part, transportation costs. Second, coal is sold by various grades - BTU content, sulfur content, moisture, and others. Since the grade is often determined by physical location, not all grades compete for the same markets. One example is coal for electric utilities - the largest single consumer of U.S. coal. Utilities, under orders to reduce their sulfur emissions, have been buying more western-mined, low-sulfur coal. This has been possible, at least in part, due to the fall of railroad transportation prices following deregulation of that industry. The demand for coal is not homogeneous: distance from the source as well as individual grade requirements prevent it from being such. Nevertheless, some large and dramatic shifts do occur in the industry if a lower-cost region becomes a major producer, and the particular type of coal found there finds new appeal. Such was the case with the Powder River Basin.

The Powder River Basin

The Powder River Basin is an area in the northeast counties of Wyoming, extending into a few southern Montana counties. It is the site of the most intensive, large-scale surface mining operations in the country. In the twenty years between 1972 and 1992 the Powder River Basin went from negligible production to accounting for roughly 25% of the nation's output.

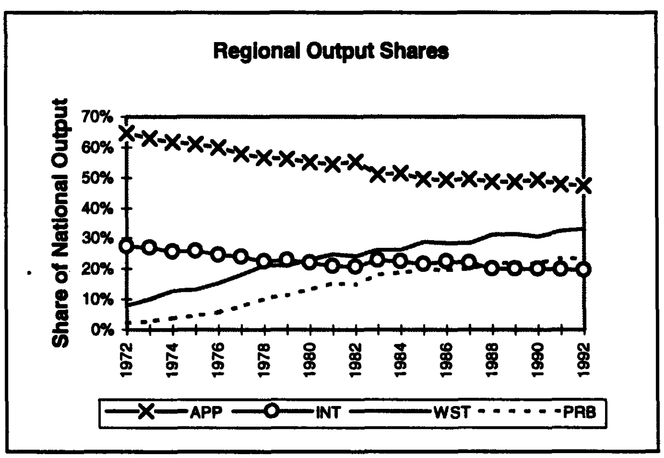


Figure 2-2

The Powder River Basin, with only a few dozen mines, has surpassed the entire Interior region with its many thousand mines. Why was this possible? The trivial answer is that vast amounts of coal from the region could be brought to market at a cost below the going price. This does not answer the real question, which gets at the underlying difference between Basin coal and coal from the other mining regions of the nation.

One great difference is geology. Massive strata of coal lie at shallow depth in the Powder River Basin area. This is in stark contrast to the intricate mine seams of the Appalachian states. The tremendous regularity of the geology makes it amenable to a highly mechanized method of extraction. Namely, strip mining, where the non-coal overburden is taken off, and large machines remove the coal. A third step, the replacement of the overburden, is performed for aesthetic and environmental reasons, though this was not always the case.

The difference between the two is the reliance on human labor. In the Basin, a mammoth machine is perfectly suited to deal with highly regular, large volume extraction of coal. Not so where the geology is more complex. This reliance on labor is measured in studies of productivity, the topic of discussion for the next section.

Labor Productivity

Simply defined, labor productivity is the number of tons of coal produced for each miner-hour of work. Figure 2-3 shows the relative labor productivities for the Appalachian and Interior states, as well as for the Powder River Basin.

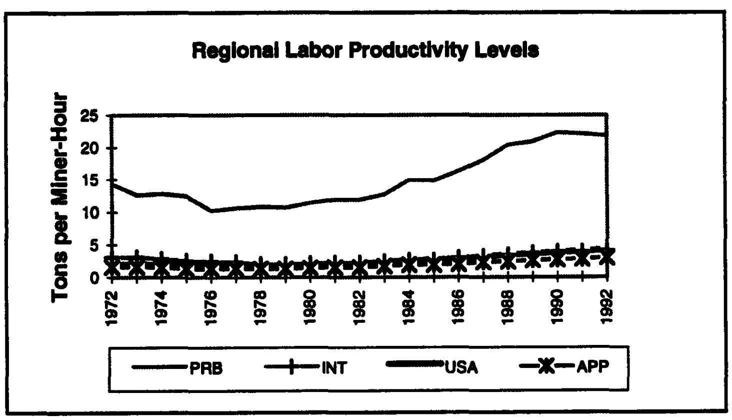


Figure 2-3

There is no obvious reason why labor productivity levels alone should be particularly important. After all, one can probably substitute capital or energy for labor if the price of labor becomes too high. In a sense, this single-input measure of productivity is a reflection of the prices and productivities of all inputs. If, for example, energy prices rise to the point that manual labor is cheaper, more workers will be hired to make up for the lower usage of machines. If output is kept roughly constant, then the increase in labor requirement is bound to be reflected as lower labor productivity. One cannot say whether this is a "good" or "bad" thing; it is simply a reflection of the shifting value of the different inputs.

A better measure is total- or multi-factor productivity. A given amount of output can be produced from a nearly infinite number of different combination of four basic inputs: labor, capital, energy and materials. Different combinations may be more "efficient" than others: a long miner with a pick and shovel could almost certainly stand to gain from some small expenditure on power-tools, say. The crux of the matter is identifying shifts in input combinations which result in more efficient production from shifts which do not. The determination of single and multifactor productivity is futher addressed in Chapter 2. For now, the simple intuitive definition is enough to make our argument.

The Importance of Productivity

A large part of the motivation for this research comes, not surprisingly, from previous research. Recent studies on factors influencing the price of coal [Ellerman 1995] show the remarkable importance of total factor productivity. Whereas capacity utilization and output were not convincing explanations, the match between price and productivity were surprisingly good. Since TFP is a measure of how much extra output we get "for free", its relationship to total supply cost is not difficult to imagine. Higher TFP levels essentially shift the supply curve to the right: more firms become lower-cost producers than before. Figure 1-XX shows the relationship between the unit input, or the inverse of productivity, and the price of coal. The resounding lesson here is that, to understand the price fluctuations of the industry, knowledge of productivity trends is the single most important piece of information one should gather.

Getting Below the Aggregates

Until recently, productivity figures were only examined at the national aggregate level. While this is clearly an important metric, reflecting how efficiently the nation's coal industry delivers its product, it hides a much more compelling story. As explained previously, the markets for coal, both end-users and suppliers, are far from homogeneous. These regional variations are totally masked when aggregated to the national level. That is hardly the end of the story, however. Even within regions, the grouping together of underground and surface mines hides shifts in productivity specific to a particular mining practice. This is most notable in the Appalachian states, where underground mining productivity has surged, whereas surface mining productivity only recently regained its 1972 levels, as shown in Figure 2-4, below.

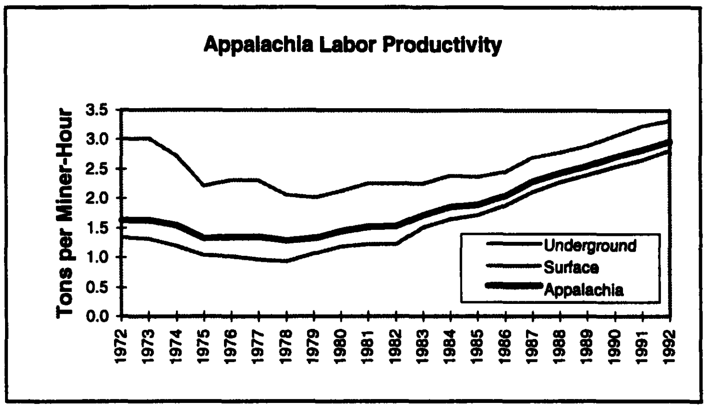


Figure 2-4

This raises some very interesting questions. For example, why has surface mining lagged behind underground mining in recovering from a fall in labor productivity during the 1970's? How did underground mining increase its labor productivity by 96% in the same time that surface mines managed only a 13% rise? Another feature from Figure 1-XX is the importance of share of output. There is clearly something quite different occuring in Appalachia's surface mining industry which is simply not captured in the regional trend. Needless, to say, this would be completely obscured in any national statistic. The face that surface mining accounts for only one-third of regional output and labor explains why its effect on the regional figures is small.

Do we see the loss of such trends in other areas? Yes, and the case of the Western states is even more revealing. While the mines of the Powder River Basin have been surging forcefully ahead, both in terms of productivity and in terms of share of national output, other Western mines have fared less well. Figure 2-5 shows productivity of surface mines in the Powder River Basin compared to Western mines outside of the Basin.

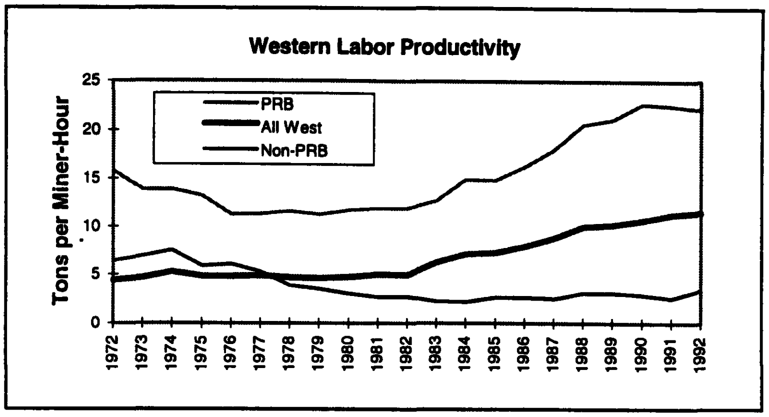


Figure 2-5

The Basin mines are simply overwhelming the non-Basin mines, which are clearly in dire straits regarding labor productivity. The Basin mines, however, have surged from being less than 25% of Western output to comprising nearly 80%. This has the effect of making the regional statistic resemble the Basin figure more each year. Notice that the prolonged decline and then stagnation of surface mining labor productivity in non-Basin mines has had almost no impact on the regional statistic.

It should come as no surprise, then, that national figures hide yet another vital aspect of the mining industry; that of dynamic entry and exit of mines. The Mine Safety and Health Administration has issued identification numbers for over 33,000 mines. Currently, there are about 3,000 active mines. Clearly there must be an underlying dynamic of old mines ceasing production and new mines entering the industry. Again, the national and regional aggregates hide this aspect of the industry.

Consider Figure 2-6, which shows the composition of mines in the Interior states. The mines are divided into three broad groups: the continuing mines, the exiting mines, and the vintages. The continuing mines are those that existed at the beginning of our period, 1972, and continued to produce through to the end of our records, in 1992. The exiting mines are those which existed in 1972, but ceased production before 1992. Finally, the vintage mines are grouped according to the year they entered production. For example, the 86 vintage shown in the figure are all mines in the Interior region which entered production in 1986. They have not been subdivided into mines from each vintage which continue producing through until 1992 and those that ceased: that can be inferred from the relative "fattening" or "thinning" of each vintage's output.

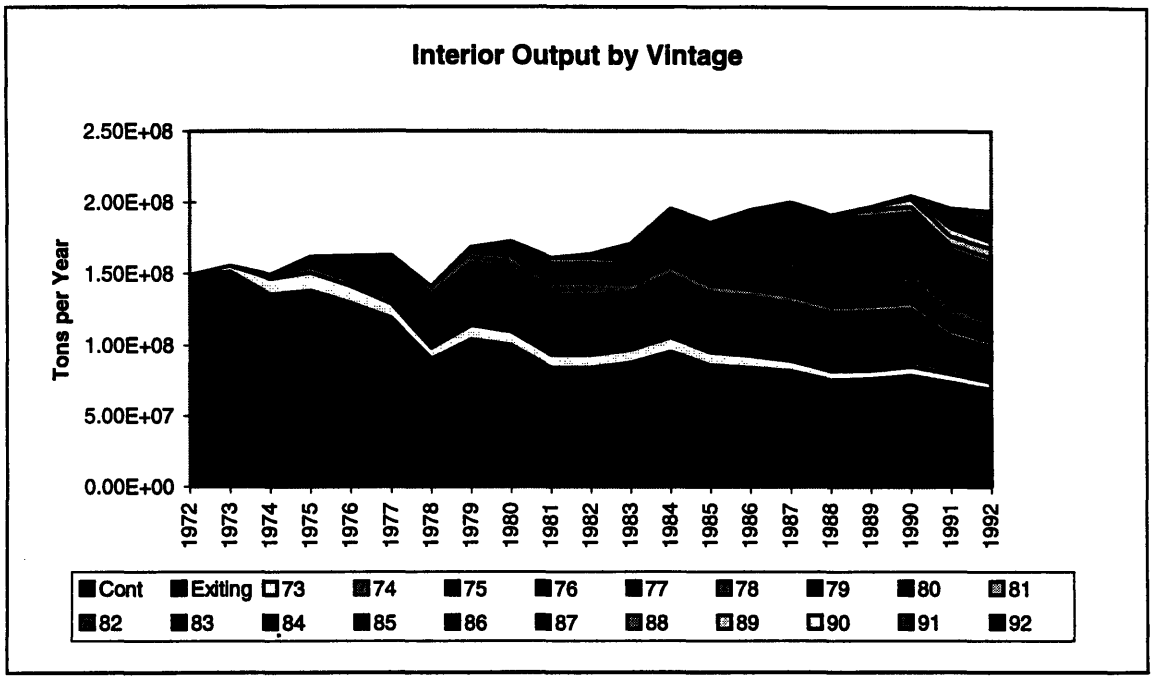


Figure 2-6

If one merely saw the total regional output figures, one would be led to believe that this was a relatively steady time for Interior mines: some increase in production, with only one real drop in output in 1978. A closer look at the mine composition reveals that, of all the 1972 production, over one half came from mines which would not survive another twenty years. Those mines that did survive the two decades managed to somewhat increase their output. Still, in 1992 only one-third of total output came from mines which existed in 1972. Far from the image of modest growth one would get from the aggregate picture, this was a period where many mines closed, and most of the growth of output came as old mines were replaced by new mines.

Similar figures can be produced for the Appalachian and Western states, though the compositional shifts are less dramatic. The West, in particular, has seen really no loss of mines at all: the fantastic growth of the Powder River Basin has allowed most mines which entered or were pre-existing to continue production.

The underlying dynamic of shifting importance of regions, mining methods, and vintage effects of mines lead us to go beyond the national or even regional figures. The question that immediately arises is whether labor productivity plays as important a role in compositional shifts and entry and exit as it does in prices. For this, a comparison of productivity between the various vintages, exiting, and continuing mines is illuminating.

Figure 2-7 shows labor productivity trends for the mines in the Appalachian states. The new mines are shown with a circle at the productivity level of their first year of production. In almost every year, the new mines outperform the old continuing mines. Not surprisingly, the low productivity levels of exiting mines were the very reason for their demise.

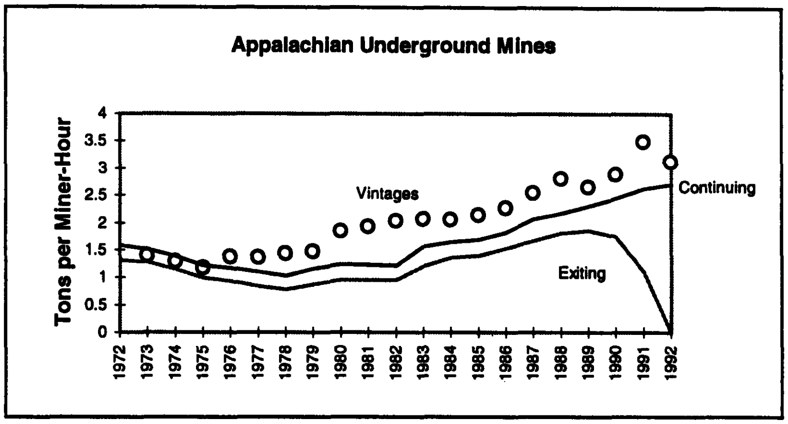


Figure 2-7

Environmental Health and Safety Regulation

There are two broad classes of environmental regulation which affect coal mining. The aim of this chapter is to introduce these regulations and provide an overview of how they may influence mine productivity. Furthermore, data is put forth which can be used to test more specifically how these regulations affect both the level and growth of labor productivity in coal mines.

The environmental laws most relevant to coal mining deal either with workplace safety concerns for the miners or with mitigating aesthetic and environmental detriment to the area surrounding the mining operations. The regulation primarily responsible for workplace safety is the Coal Mine Health and Safety Act (MSHA). The regulation focusing on environmental remediation is the Surface Mining Control and Reclamation Act (SMCRA).

Regulatory Impact on Surface Mines

While MSHA does apply to surface mines, the nature of the work is so different from underground mining that the brunt of the regulations affected the subsurface mines. Surface mines still were required to file with MSHA quarterly reports on output, labor and injury, however. The majority of regulation affecting surface mines stems less from a need to protect workers than from a need to lessen environmental damage to the area being mined. The source of these regulations is SMCRA.

SMCRA is quite different from MSHA in its history, as well. Whereas underground mining has always been recognized as a dangerous business, the pressure leading to passage of SMCRA arose mostly out of public dissatisfaction with the effects of strip mining. This lead to surface mining laws at the state level: initially in eastern states, later in western states as increasingly heavy mining moved there. SMCRA was enacted in 1977 as a federal effort to standardize and coordinate the various laws existing in 23 different mining states.

Small differences aside, surface mining laws generally require a certain level of "restoration" after mining is complete. Since strip mining involves the removal of non-coal surface material followed by the scraping of the coal, massive amounts of earth were displaced. The laws general call for replacing the overburden, as well as standards for how terrain is to be re-contoured.

The general impact on the mining operation is an increase in workforce and machinery to comply with the clean-up of the site after mining is complete. This involves not only additional earthmoving equipment, but equipment to grade and sort soil, as well as more administrative personnel to document compliance.

Regulatory Impact on Underground Mines

Underground mines are the main focus of the MSHA regulations. Enacted in 1969, partly in response to the 1968 Farmington, West Virginia mine explosion which killed 78 miners, MSHA seeks to minimize the occurrence of catastrophes as well as to reduce the fatality of these incidents. MSHA specifies with great detail requirements for ventilation, tunnel supports, coal dust suppression, and maintenance of mining machinery. Furthermore, MSHA required a greater level of detailed reporting by mines of output at various mining subunits, as well as worker-hours not just at the mine face but in processing plants, stock yards, shops and administrative offices. Worker injury data is also required, including non-fatal injuries, regardless of whether they lead to a loss of worker hours. Finally, MSHA requires inspections of each mine, and allows additional inspections for a variety of reasons.

The coal industry has long argued that the regulations imposed a large burden on the mines, leading to the loss of productivity seen in the years following the enactment of the regulation. Exactly how the law would affect productivity, and whether or not these would be permanent effects, merits some consideration.

MSHA can affect mine productivity in two general ways. First, the actual requirements of the law can impose conditions which.draw resources away from direct production activity. Second, the incidence of inspections itself leads to lowered productivity while the inspection is underway.

MSHA provisions which may hinder productivity by altering the way in which underground mining is carried out include roofbolting requirements, ventilation and dust suppression, and structural layout requirements. MSHA forbids miners working under unsupported roofs, thus limiting the advance of continuous mining machines to their length: about twenty feet. Prior to MSHA's enactment, many operators would advance nearly 100 feet prior to providing for support. The constant need to stop mining operation to put roofbolts in place would clearly hinder traditional mining operations. Ventilation and dust suppression requirement pose similar conditions. Operators routinely complain about having to maintain and replace nozzles which clog easily, being unable to advance the mine face without further extending the ventilation systems, and so on. Finally, the plans for mining layout and measures to be taken to provide appropriate support and ventilation must be revised with MSHA inspectors twice a year, usually. These measures are presumably the ones most necessary for the prevention of large mine catastrophes. If this disregard for safety resulted in higher levels of labor productivity - in itself a contentious point - it is not hard to see how restrictions on these practices would cut into productivity.

From a procedural standpoint, MSHA's many reporting, sampling, and inspection provisions diverted labor from the actual mining of coal to the process of complying with regulations. Quarterly reporting of output, labor and injuries meant an increase in administrative personnel. Requirements for constant monitoring of gasses and dust levels, quite apart from suppression and control requirements, also called for the hiring of people to carry out the various tests. Finally, the inspection of the mine by MSHA officials itself entails a reduction in productivity, as it will probably entail some disruption of work.

Measuring Impact of Environmental Regulations on Productivity

There are several possible ways in which we may look at available data to establish a relationship between MSHA and SMCRA and changes in labor productivity. First, and most simplistically, would be to look for any dramatic changes in labor productivity series around the time of enactment of these regulations. Second, one can try and discern a correlation between enforcement level and labor productivity. Third, the amount of labor going strictly to administrative work can be scrutinized for indication of the administrative burden of the acts. A brief discussion of the feasibility, value and limitations of each approach is merited.

To search for a discernible "kink" in a labor productivity time series is fraught with difficulties. The primary difficulty is the time scope of our data: no pre-1972 figures are available at the mine level. MSHA was enacted in 1969, and became fully implemented in the early 1970's. The formation of this dataset was one of their very obligations. In a sense, using an MSHA-derived dataset precludes, by definition, any data prior to the regulation. A second issues is that there is no such thing as a smoothly-evolving time series for labor productivity; certainly not at the mine-level. This frustrates efforts to identify any abnormal changes in labor productivity, as the backdrop of yearly changes is already quite large in most cases. In other words, the opportunity to find a change in productivity which is so pronounced and so close to the enactment date of either regulation as to rule out the possibility that it could be attributed to anything but the regulation simply does not exist.

The issues with SMCRA are different. We have data prior to 1977, the enactment date of SMCRA. However, most mine-producing states had their own surface mining laws prior to that. The extent of the state regulations, as well as their respective enactment dates and the dates of any amendments or reauthorizations vary considerably, complicating efforts. For a few large states, however, it would be worthwhile to explore this type of before-and-after analysis.

The second type of analysis, that of relating enforcement level to changes in productivity, is more promising. It primarily seeks to establish the productivity effect of actual enforcement and inspection, as opposed to compliance. One may tend to believe, then, that any productivity change resulting from the need to comply remains untested, since compliance usually entail longer-term changes than simply fixing up the mine on the eve of an inspection. One important piece of information on whether productivity is most affected by compliance or by inspections would be changes in fatal injuries. If it can be shown that these injuries - which are the focus of MSHA regulation - has unambiguously fallen, then it would strengthen the argument that it is actual inspections which are affecting productivity, compliance having already occurred as demonstrated by the improved safety data.

A slightly different approach to interpreting enforcement data comes from panel comparisons of mines. For a given year, mining method and region, we can compare the changes in labor productivity over the previous year for mines experiencing very little enforcement and those subjected the the heaviest enforcement. Since enforcement can reasonably be expected to be more extensive for big mines, as more people are affected, we would hope to compare mines of similar output but with different productivity levels. One limitation will be if enforcement is indicative of a totally different characteristic. If, say, enforcement is very heavy on mines operated by traditionally unsafe operators, then the comparison is really between safe and unsafe mines of similar size, which may lead to substantially different conclusions. For example, an unsafe mine which is constantly needing to satisfy MSHA inspectors with piecemeal improvements, with concurrent drops in labor productivity, might be said to suffer due to MSHA regulation. This is obviously a wrong conclusion, since it is suffering due to non-compliance with regulations, whereas the compliant mines are inspected less frequently, perhaps to the betterment of their labor productivity.

The third approach mentioned above would be aimed at examining the claim that regulation's primary effect is to increase the amount of administrative and compliance paperwork, leading to increased labor devoted to non-mining activity. It is fairly straightforward to examine growth in administrative labor for mines. Again, this can be compared over time, seeking correlation with enforcement vigor, or across mines.

As can be seen from the above discussion of methodology, some measure of enforcement level for SMCRA and MSHA is required. Likely candidates for enforcement effort are: enforcement budget, total civil penalties collected, number of inspections, and number of citations or violations. The first two are strictly aggregate numbers: no information exists which provides the total amount spent on inspecting each individual mine. As such, they would be useful only compared to productivity levels aggregated to the same level. The latter two proxies are more useful: they are available for each mine for a long but not exhaustive time-period (1983-1994 as opposed to 1972-1994). Furthermore, they could be aggregated in the same manner as input and output data are: by region, mining method, and by year. Data at this level is available only for MSHA enforcement and citation, however. SMCRA data is available at the state level and, obviously, is exclusive to surface mining.

In Chapter 4, we will discuss the actual methods employed in analyzing the impact of regulation on coal mines. The efforts focus exclusively on MSHA regulation and enforcement, as this is where data is most extensive. Regional aggregates, as discussed above, pose several additional problems which tend to make any results inconclusive.

Summary

In the U.S. coal industry, productivity has terrific importance. It is primarily important in determining the price of coal, as it represents shifts in a significant component of the cost of production. It furthermore is the engine of change for the composition of the industry. Whether a mine will survive or perish seems to depend a great deal on its level of labor productivity compared to other similar mines in the region. When examining the coal industry, whether one looks at labor productivity or output, it is essential to look at a less aggregated level than the usual national figures. At the very least, one should distinguish between geologically different coal-producing regions and mining method. This will go a long way to ensure fair comparison of more homogenous groups of suppliers than regional or national aggregates.

Environmental and health concerns about coal mining resulted in two primary pieces of federal regulation in the 1970's. These regulations have the effect of mandating certain mining practices and setting standards for working conditions. To the extent that resources devoted to compliance could have been used elsewhere in the process, productivity may have been affected. The effects can be broken down into three broad types. First, the immediate impact on existing mines which are now faced with implementing new practices and equipment. Second, the administrative burden of complying with the recordkeeping, testing and inspection requirements of the regulations. Finally, the permanent effect of constraining the design and operation of new mines which must meet with standards of practice that may be less efficient from an operational point of view. Different methodologies must be employed to identify each of the three effects. Our efforts will be focused on the period 1983-1994, long after the initial impacts of the Act have dissipated. Of the two federal regulations, we rely primarily on data regarding MSHA enforcement, as the data is more compatible with the operational data at the mine level.

3 The MSHA Dataset

As a result of the Coal Mine Health and Safety Act (1969), the Mine Safety and Health Administration was created. The role of this agency is, among others, to maintain records of mine activity in the United States. The data is gathered from each mine on a quarterly basis, and comprises a wealth of information. This chapter will provide an overview to the dataset, including definitions for particular terms. As a check on the validity of the dataset, a comparison is made with established industry-wide data.

Structure of the Dataset

Every mine in the United States is issued an identification number, referred to as the MSHA ID. The number is unique, and is not re-issued upon closure of the mine. Until the early 1990's, if a mine changed its mining method from, say, surface operations to underground mining, it would receive a new identification number. The number of cases where this occurs is quite rare, and the current practice is to allow the continued use of the same number. A new number is not issued simply for the expansion of an existing mining operation. The drilling of a neighboring shaft in an underground mine would not be considered a new mine, so long as it is still part of the same general mining operation. There appears to be some subjectivity here, and the decision usually rests with the state MSHA official. Generally speaking, as long as the extension is owned by the same company, is in the same general location, and the mined coal goes to the same preparation areas and loading areas as the rest of the mine, it is considered part of the same mine. This is actually beneficial to our analysis, as we are interested in a mining company's ability to deliver coal from a particular coal deposit, and less interested in whether this entails deepening existing adits or sinking new shafts.

The MSHA data contains information about the geological nature of the mine: the seam height, amount of overburden, and other information. This is not part of our analysis, as we are interested in how the mining operation evolves over time rather than in identifying promising geological characteristics for mining.

In addition to the geological data, the MSHA dataset contains information on the mining method. For our analysis, we have grouped all mines into "surface" or "underground" operations, though the MSHA data gives more exact descriptions about the specific surface or underground method.

At the heart of the dataset is the quarterly information on production and labor usage. This is given for the various subunits, or stages of the mining process. While output can be expected to come mostly from the mine-face work (subunit codes 1-4), clearly there is labor involved in other stages as well. The preparation plant (subunit code 30) , the stockyards (subunit code 17), maintenance crews, truck convoys (in surface mines), and administration (subunit code 99) all serve a purpose and require labor. Additionally, there may be coal from non-face operations, such as culm bank (subunit code 5) or dredge operations (subunit code 6).

For our study, we have included non mine-face labor in the calculation of labor input. This is due, again, to our interest in a mining operation's ability to provide sellable coal, of a particular grade, heat content, sulfur content and moisture, while at the same time ensuring compliance with applicable laws and running the business. This is the essence of productivity: the amount of product which is brought to market - not just extracted - for a given amount of input.

Originally, the data contained over 1.3 million observations, one each for each subunit of each mine for each quarter of every years from 1972 to 1992. This rather unwieldy amount of data was made more manageable by summing total labor and output for all the subunits in each mine, and summing all quarters to yield one observation per mine per year. This made the data easier to handle, avoiding the need to extract excessive sub-sets of information, while still retaining all the information necessary for our analysis. This condensed dataset contains approximately 500,000 observations.

Partitioning the Data

The main premise of this work is that industry aggregates hide a wealth of information. It makes sense, therefore, to consider a functional partitioning of the data. Since examining each mine on its own is impracticable, some grouping is necessary, but should still be small enough to identify microlevel trends. In this analysis, we have grouped the data in three ways: by geographic area, by mining method, and by vintage.

The smallest geographic grouping that could be performed would be by county. One level up from this would be groupings by state. Both these groupings were tried in early analyses, but it quickly becomes clear that, like all natural deposits, coal does not sit nicely within political boundaries. A better approach is to seek grouping by geological boundaries rather than county or state groupings. Three very clear areas emerge.

The traditional mining areas of the United States are in the eastern and mid-western states. The Appalachian[2] states have by far the greatest number of mines, and account for about 40% of all output today. The Interior[3] states, account for about 20% of production, and consist of generally larger mines than Appalachia, and a higher fraction are surface operations. The Western[4] region is heterogeneous mix of mining conditions, spreading from Arizona to Alaska. There is relatively little underground mining compared to the other regions. Surface mining is concentrated primarily in Wyoming and Colorado. Within Wyoming is the Powder River Basin[5], which consists of such massive and unique mines that it is treated as a separate region. Lignite[6] mines - exclusively surface operations - are also treated as a distinct region.

This serves as a good working grouping of mines. Further breakdowns would be possible, especially in Appalachia where there are different grades of goal, and one might expect that different mines there are serving different markets. For our purposes, however, the above geographic groupings are sufficient.

When studying the operation of firms in an industry, it is necessary to determine whether or not certain firms can be grouped at all. While the above geographic groupings can be expected to group mines facing similar transportation issues, regulations, demand or even some geological features, we need to further break down the groups according to mining method. The very different nature of the two principal mining methods - surface and underground - make treating them as if they were the same completely misleading. Surface mines, for example, usually have much lower amounts of mine-face labor, since the process is highly mechanized. It essentially involves one operator of a large machine which strips of layers of earth. Underground mining, however, usually entails several operators working along a coal seam. It does not lend itself as well to large-scale mechanization. The two very different methods seem to require that the mines be further grouped accordingly.

Finally, if we are to study the effect of technical progress, we need some measure of the degree of technological sophistication of a mining operation. This is very difficult to do, and certainly the MSHA

[2] Appalachian Region states are Alabama, Georgia, Eastern Kentucky, Maryland, Ohio, Pennsylvania, Tennessee, Virginia and West Virginia.
[3] Interior Region states are Arkansas, Illinois, Indiana, Iowa, Kansas, Western Kentucky, Louisiana, Missouri, Oklahoma, and Texas, except for Texas lignite mines.
[4] Western Region states are Alaska, Arizona, California, Colorado, Montana, New Mexico, North Dakota, Utah, Washington, and Wyoming, except for Wyoming and Montana surface mines within the Powder River Basin
[5] PRB mines are surface operation in the Northwest counties of Wyoming, plus a few mines in Southern Montana.
[6] Lignite is mined in Texas, North Dakota and Louisiana, plus one mine in Montana. All are surface mines.

data contains no "technology index" for the given mines. A useful proxy is the year in which the mine came into operation. If technology progresses in a fairly time-dependent fashion, then the passing of time becomes a useful indicator as to the amount of technological knowledge associated with the mine. Since, however, we seek to examine whether technology is somehow fixed in a mine, then the simple passage of time is not enough: we must vintage each mine, on the possibility that technological progress favors new mines rather than old mines, as discussed in chapter 2.

So aside from the geographic and mining method breakdowns for the coal mines, we also identify each mine with a particular vintage, and can (but do not have to) group mines of a particular vintage together. The vintage of a mine is determined by the first year in which the mine recorded any output, not the first year it was issued an MSHA ID or the first year some labor was recorded for it. Furthermore, mines which recorded output in the very first observation of the dataset, 1972, are classified as "pre-existing" mines, and their vintage cannot be determined.

Test on the Validity of the Data

The data with which we are working is, in essence, the labor and output information at its most basic level of collection: the individual mines, and subunits therein. As a check on the validity of this data, we can sum labor and output for comparison with industry-reported aggregates. These are available on a regional and national basis, also broken down by mining type.

Figure 3-1 shows output aggregates derived from the MSHA data for our three regions and by mining method for the years 1972-1992, as well as the values reported by the Energy Information Administration in their Monthly Energy Review. While the numbers are in close agreement, there is a seemingly constant discrepancy. Investigations into the EIA's methodology reveals that their figure is the result of the number of railcars loaded with coal reported by the Association of American Railroads "...converted into tons of coal by EIA by using the average number of tons of coal per railcar loaded reported in the most recent [statistics]." This explanation seems not to consider coal transported by truck or conveyor to ships, though the assumptions utilized which would lead to consistent overestimation of output are unclear.

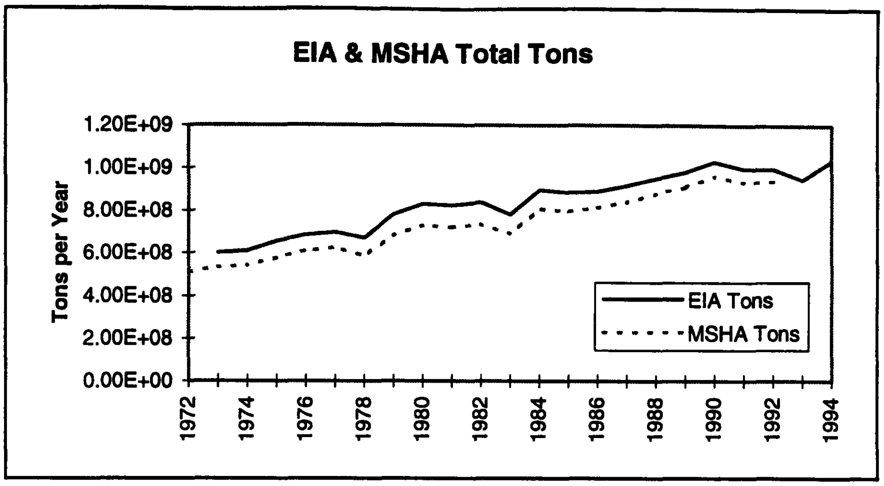


Figure 3-1

Figure 3-2 shows that the major source of discrepancy is in the estimate of surface mining output.

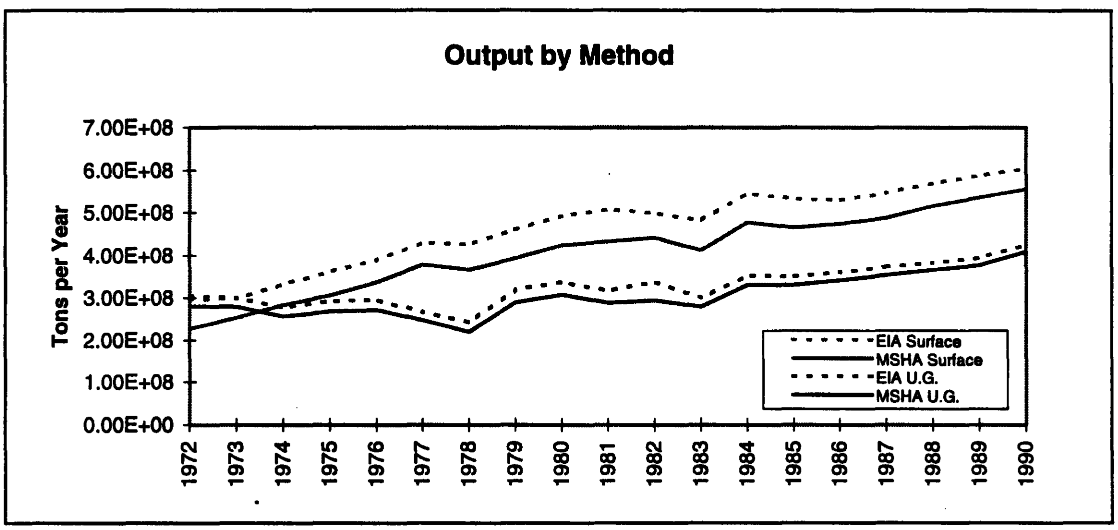


Figure 3-2

Figure 3-3 illustrates the discrepancies by mining region.

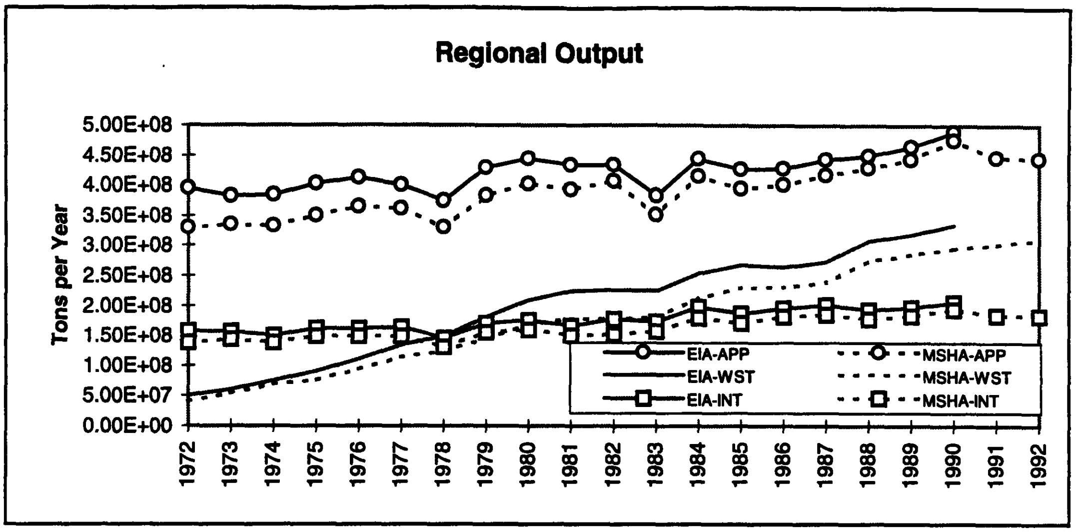


Figure 3-3

Beyond comparing output, it is possible also to compare differences in computed mine productivity. This comparison, again with EIA data, is shown in Figure 3-4.

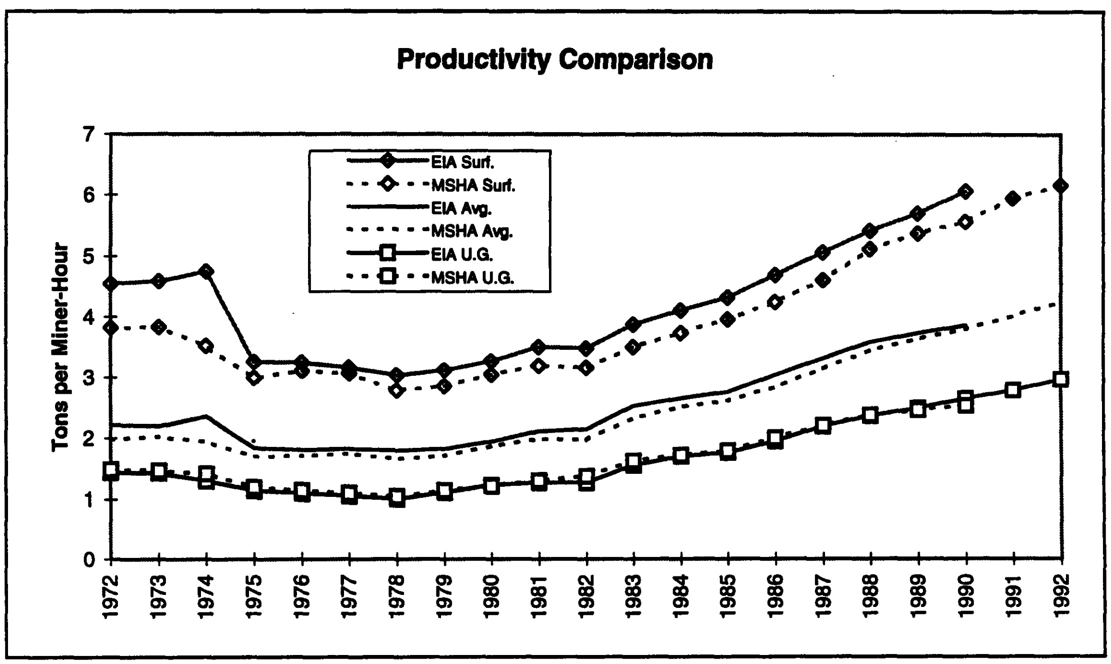


Figure 3-4

Whenever an empirical analysis of available data is undertaken, one must be aware of the limitations of the data. Having compared the MSHA data with the best data otherwise available, it appears that, while some discrepancies do exist, the same trends and relative movements appear in both sets of data. Furthermore, there is no reason to believe that the EIA data is inherently more accurate, noting as we have that these data are derived from a series of estimates, rather than from actual mine-level reporting of production.

MSHA Enforcement Dataset

Obtained separately from the principal dataset on mine location, description and operating data was the enforcement dataset. Having already collected the substantial data relating actual mines to ID numbers, this second dataset needed only to have the unique MSHA ID to allow easy matching to the existing data. The enforcement data contains information on inspections and citations from 1983 to the present. Since the primary dataset ends in 1994, enforcement records for 1995 and the first months of 1996 were discarded.

The structure of the data is, however, somewhat different. Whereas the principal dataset is organized by quarter, with each unit reporting tons and hours for that quarter, the second dataset reports each inspection and citation event as it occurs. Therefore, a mine that had seven inspections in a given quarter will have seven entries in the enforcement dataset, each inspection record indicating the exact beginning date of the action.

The picture gets even more complicated when dealing with citations. Since multiple citations can arise from a single inspection, and each citation is reported separately along with the date of the inspection which lead to the action, several entries may exist which relate to multiple citations resulting from one inspection.

To make this record structure congruent to that used to track labor productivity requires some manipulation. First, the number of unique inspection dates within a given year were counted for each mine. In some instances, this resulted in inspections which are separated by only one day to be counted as two different inspections. Since we have no *a priori* knowledge about whether the inspections were part of a single battery of inspections, we have preferred not to make assumption about whether closely spaced inspections should really count as a single event. As in other instances where strict rules had to be written to reflect somewhat subjective categorizations, we have chosen to articulate the rule and apply it as unambiguously as possible.

There are four different grades of citations indicated in the records. These are codified as 104-A, 104-G, 104-D-1 and 104-D-2, in order of severity of violation. 104-A citations are notices of minor violation. They are by far the most common of all the citations, and nearly every inspection results in a citation of this kind. They are issued administratively and are for what is generally characterized as "housekeeping" offenses. 104-G citations are for the improper training of workers, or for using workers in a capacity for which they were not trained.

Citations coded 104-D-1 or 104-D-2 are referred to here as "severe citations". They are two different kinds of "unwarrantable failure" citations. The difference between the two is a function of other conditions in the mine: a 104-D-2 citation applies if elsewhere in the mine a withdrawal order has been issued, whereas 104-D-1 is a "first offense" citation. Both are for practices or conditions which imply the existence of a dangerous condition, which would pose an imminent danger if uncorrected. Examples can include improper dust suppression, inadequate venting of hazardous (toxic or explosive) gases, insufficient roofbolting ahd other situations which warrant the closure of the affected section of mine.

We believe that these citation grades are key to establishing the effect of improved safety on mine productivity. Therefore, for each time period, the number of each type of citation was summed for each mine.

Finally, this restructured dataset was merged to the existing records. Since the inspection data goes back only to 1983, a large amount of the data was unaffected. There were a few odd instances where there existed enforcement data where no production data existed. In some cases, this occurred when a non-producing mine was inspected, leading to an absence of operating data for that particular year. In a very small number of cases, the enforcement data was for a mine which was "unknown" to the primary dataset (i.e. an ID number not encountered anywhere else in the record). Rather than probe possible clerical errors such as transposed numbers, and given that this occured in fewer than a dozen observations in a dataset of 120,000 records, these records were discarded.

Summary

The records collected from MSHA represents a wealth of information, as well as a truly challenging data management task. The information includes descriptive data on the mine such as location, name, operator, and some guide to the geological conditions such as depth and thickness of seam. For each subunit within the mine, quarterly data on tons of coal output and person-hours of labor input is recorded.

This data was aggregated on a yearly basis to make the numerical analysis more manageable, and to make the data more readily comparable to similar data from other sources.

As a check on the validity of the data, the output was compared on a national and regional basis with data available from the Energy Information Administration. While some discrepancies do exist, the trends match very closely and, we believe, are an accurate reflection of the operations of the industry.

Finally, as a validation of the applicability of labor productivity data to gain insight into total factor productivity trends, we offer a comparison of TFP and labor productivity from national data compiled by Dale Jorgenson. Labor productivity tracks the movements in TFP very closely, though the actual amount of growth in TFP is smaller than in single factor labor productivity.

The impetus for this research stems from questions which surfaced during aggregate-level studies of the coal industry. To proceed to a less aggregated analysis, two requirements had to be met. First, a robust dataset must be assembled. Second, the results from this micro-level analysis must be readily comparable to aggregate TFP studies. The data we have gathered from MSHA is not only robust, but the labor productivity analysis which it is used to perform has direct and easily appreciated implications for total factor productivity.

4 MSHA Enforcement and Productivity

A principal allegation against government regulation stems from the belief that inspections required under the law reduce productivity in coal mines. This argument is quite distinct from the argument about whether safe mines are inherently more or less productive. Rather, it alleges that the bureaucratic burden imposed by government on industry is, irrespective of whether or not a mine is in compliance, a drag on productivity.

The inspection data which we have from the Mine Safety and Health Administration allows us to supplement the production information discussed in Chapter 3 with data on the number of inspections each mine received in a given year, as well as any resulting citations. The inspection records do not go back as far as the production data, unfortunately - only from 1983 through 1994. This prevents us from looking closely at the initial-year effects of the Act, during a period of dramatic productivity decline in the industry. It does, however, offer data during a period of unambiguous growth in productivity. This makes for quite a compelling piece of analysis: when nearly all sectors of the coal mining industry are improving steadily, it is easier to isolate effects than during a period like the 1970's which saw massive regional shifts as well as disparities in productivity.

The first part of this analysis examines the inspection patterns of the Mine Safety and Health Administration. This is an attempt to discern a rationale for allocating scarce inspection resources. One would expect more frequent inspection of large mines, as more workers will be affected by the conditions there. Furthermore, MSHA has directions to increase the frequency of inspections in mines with high levels of methane gas.. The law calls for inspections as often as every week in mines venting more than 1 million cubic feet of methane per day. Other possible factors influencing the frequency of inspection may include: mine safety history, operator safety history, productivity level, mining method and geographic region.

The analysis then turns to examining, at the mine level, inspection frequency, citation incidence, and productivity level. This can be accomplished by looking at various mines in a given time period, and identifying any relationships that seem to exist between the factors. As far as possible, we should compare mines which are as similar as possible with regard to size, mining method, and geographic region to better isolate the effect of inspection effort.

Care must be exercised when specifying the regression model to better quantify the relationship. Specifically, scale effects and the dependence between citations and inspections make it more difficult to include in the model variables which represent only one effect. For example, all citations require an inspection - hence implicit in the effect of a citation will be the burden imposed by the inspection alone. These issues of choice of specification are discussed more fully in this chapter.

As the analysis of the impact of inspections and citations on mine productivity requires an understanding of scale-related effects on inspection effort and productivity, some insight is also gained into what, if any, advantages are realized by making mining operations a particular size. As expected, this will depend on mining method as well as the geological conditions.

Inspections Under MSHA

The Coal Mine Health and Safety Act rose out of concern about collapses and explosions in underground mines. Given the nature of the Act, it is hardly surprising that the vast majority of inspections are concentrated in the Appalachian region - home to the greatest number of underground mines. The Interior has the second-highest number of underground mines, and this is reflected in the number of safety inspections in that region's mines. The West has the fewest underground mines of all, whereas both the Powder River Basin and Lignite mines are exclusively surface mining operations, and consist of relatively few mines. Figure 4-1 shows the incidence of MSHA inspections in each of these regions.

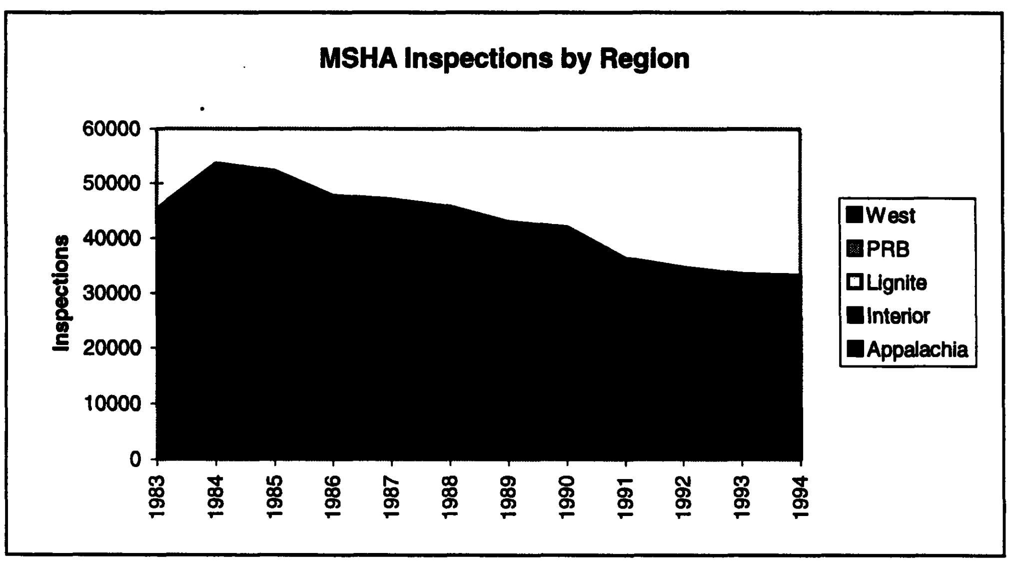


Figure 4-1

Looking at the number of inspections by method, we again see the great priority given to underground mines. They make up fully 73% of all inspections under the Act. This is shown in Figure 4-2, below.

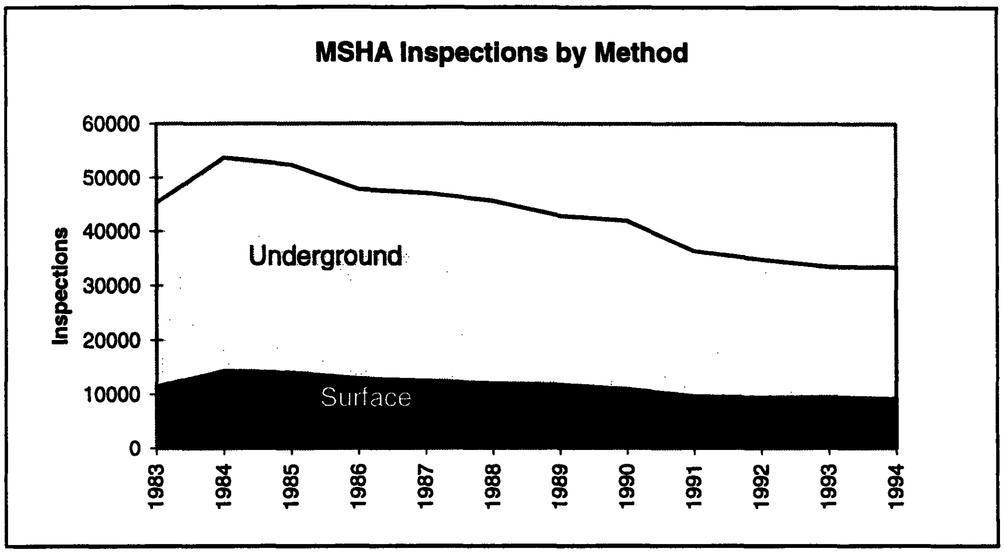


Figure 4-2

Different Measures of Inspection Effort

While comparing total inspections in a given region will tell us something about the spatial allocation of inspection effort by MSHA, it does not say much about any effects on the mining process. One way to approach the issue of inspection burden is to look at the number of inspections at a given mine. This measure is shown for the eight regions in Figure 4-3.

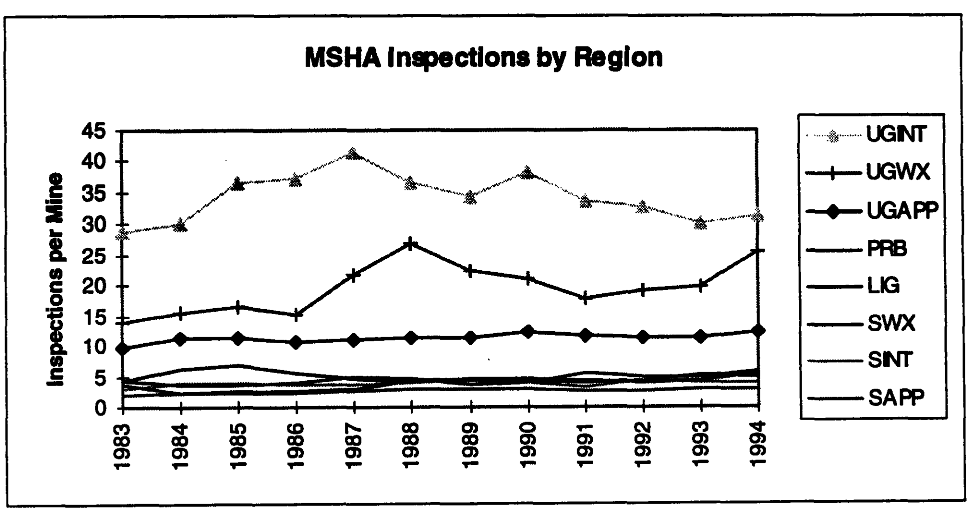


Figure 4-3

Unlike the initial impression that Appalachia has the heaviest amount of inspection, this calculus indicates that it is the underground mines in the Interior and West which are inspected most heavily. Appalachian underground mines receive about one-third the number of yearly inspections that their Interior region counterparts get.

This is clearly not the whole story, however. It merely says that inspection effort is not equal on a per-mine basis. Nor is there any reason to think it should. Appalachian mines are usually smaller than those in the Interior, which tend to be large operations. In 1985, for example, underground mines in Appalachia had an average output of 86,600 short tons per mine compared to 727,000 short tons for those in the Interior - a difference of approximately 8:1.

The comparison above suggests a second way of looking at the allocation of inspections effort: inspections per ton of output. Figure 4-4 shows this comparison.

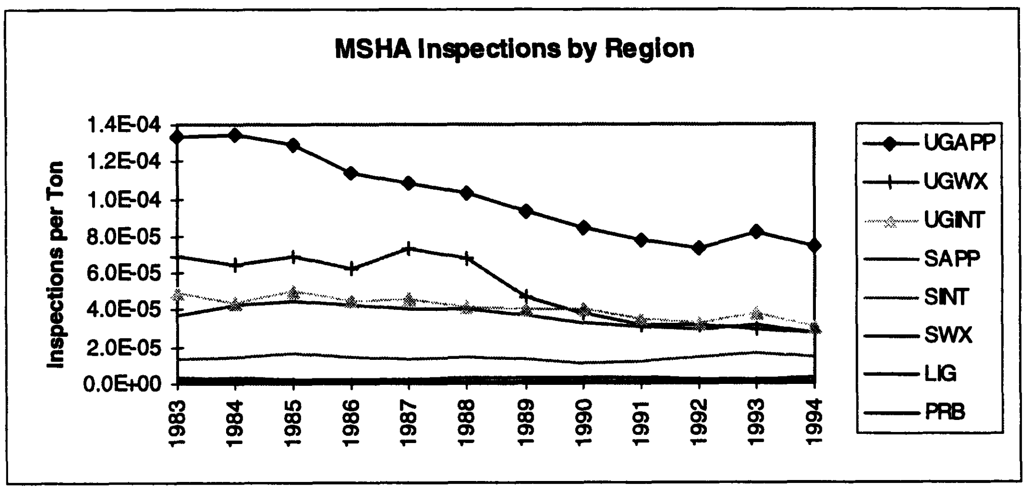


Figure 4-4

The pattern seen here is quite different from the per-mine measures. First of all, Appalachian underground mines seem to bear the brunt of the inspection. Second, this figure falls dramatically during the eleven years under study for the Appalachian mines, and less dramatically for the other underground mining regions.

We now encounter a problem of causality. Are the MSHA inspectors "backing off" the Appalachian underground operators during this time, or is rising average per-mine output the real reason why per-ton inspections are falling? Clearly, the answer is a mix of the two.

We can look at inspection concentrations in yet another way: inspections per hour of labor. This is somewhat analogous to the per-ton measure in that it captures increased inspection at bigger mines. It suffers from the same ambiguity as the previous measure, also - the exact cause for the variations cannot be discerned. Figure 4-5 shows the regional per-hour inspection trends.

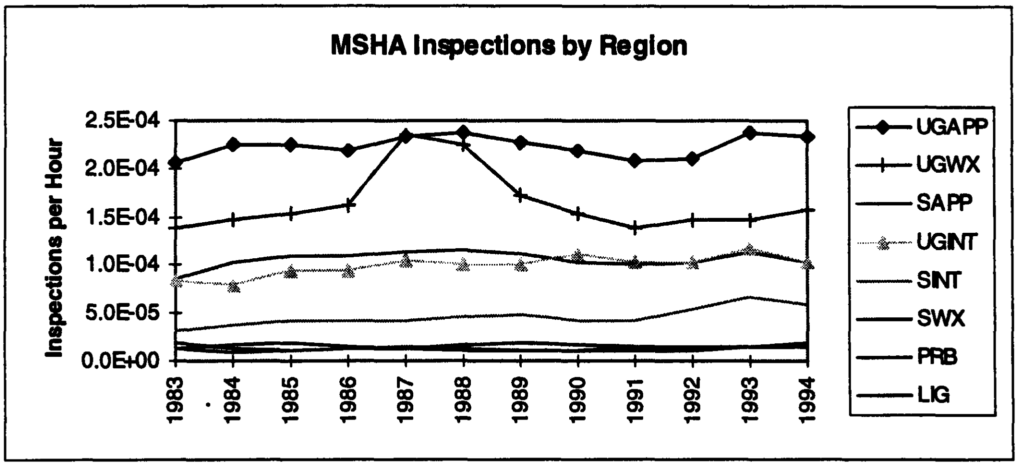


Figure 4-5

While trying to understand the logic behind allocation of inspection effort may be interesting, the central question remains unanswered - how is labor productivity affected? The question of which measure to use is one we will return to when specifying the regression model. For now, suffice it to say that underground mines usually have higher inspections than surface mines, and that larger mines receive more inspections than smaller mines. Keep in mind, also, that inspections can arise from complaints by workers, as a result of previous citations for certain problems, and due to particular hazards unique to a given mine (such as methane venting).

Regional Labor Productivity Figures

Having attained a good level of understanding about inspection efforts in the various coal-producing regions, we turn now our attention to labor productivity trends in the same eight areas. At this stage, we are still simply exploring the data, looking for indications about what may warrant further analysis.

Figures 4-6 through 4-8 show productivity trends for 1983-1994. The first two figures show absolute levels, though the second figure excludes PRB and Lignite mines in order to allow closer examination of the lower-productivity regions. The third figure normalizes all productivity levels to equal 1.0 at 1983. This allows comparison of relative growth rates as opposed to levels.

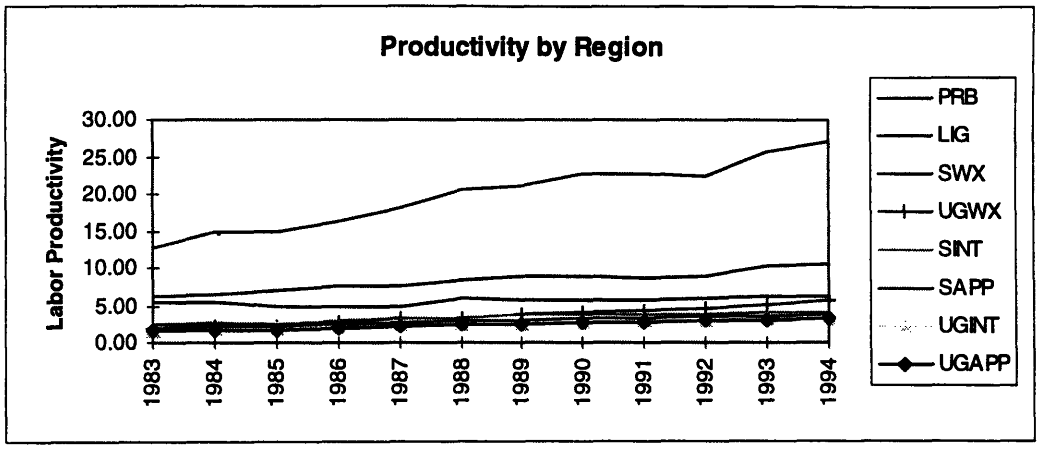


Figure 4-6

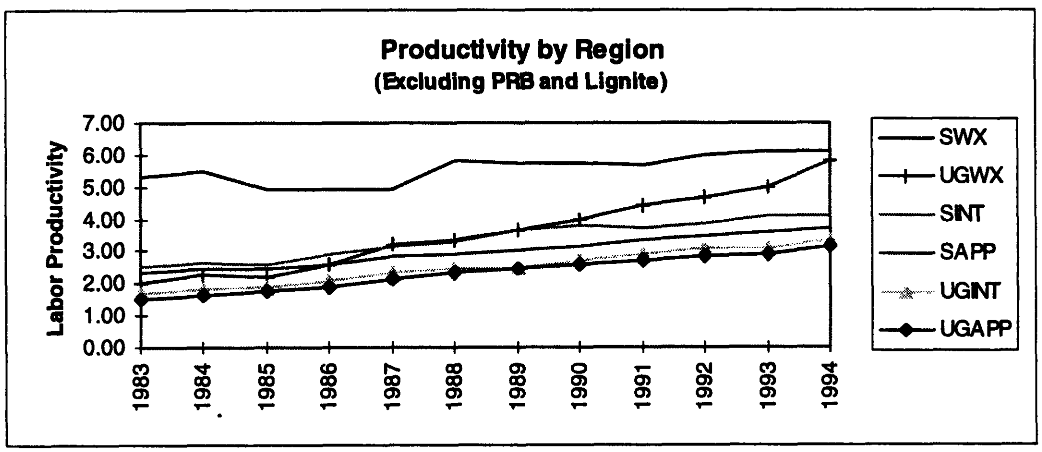


Figure 4-7

Productivity index (1983=1.0) by region

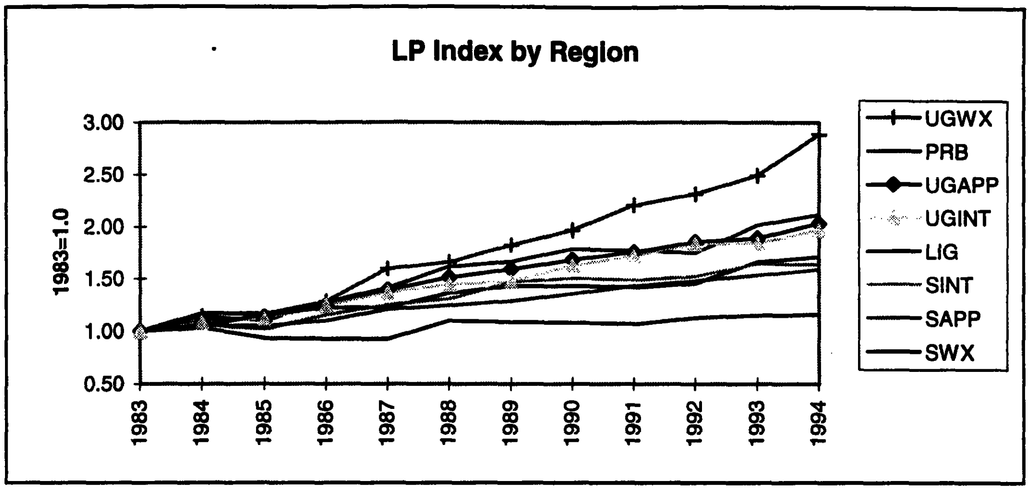


Figure 4-8

There are several interesting and potentially important features of the graphs above. Before delving into any kind of analysis, however, it is useful to examine the choice of metric which will be employed to measure inspection vigor on the part of MSHA. For this, it is useful to consider the following example.

Choice of Metric

A likely candidate for further examination is the underground Appalachian group of mines. While on a per-mine and per-hour basis these mines were subject to a relatively constant inspection rate, the growth in labor productivity lead to an ever-decreasing per-ton inspection burden. In fact, here the correlation seems quite good. Per-hour inspections fell in 1986, a year when productivity grew somewhat faster than previously. In 1993, the inspection rate per ton grew, reversing a long trend of falling rates. Interestingly, that same year productivity virtually stagnated.

While the Appalachian experience may seem to support the argument of productivity-dampening effects of inspections, it is really an unavoidable consequence of how the measures were constructed. If inspections in a given mine are roughly constant, then each time productivity surges, the per-ton measure of inspection effort will, by construction, fall. Since inspections *were* fairly constant for the Appalachian region during the years studied, and productivity *did* account for most increases in output (as opposed to increase labor usage), then the per-ton level of MSHA inspections *had* to track productivity change. Hence, this cannot be seen as evidence supporting any relationship between productivity or regulatory enforcement.

The above example raises the question of the appropriate measure of inspection effort. It is perhaps easiest to explain by looking at the order of production steps in coal mining. Labor is the key input controlled by the mine operator. Given a certain anticipated demand, the mine operator will devote the amount of labor believed to be required to produce the desired level of output. The link between the two is, obviously, labor productivity. If one is to look at the influence of inspection effort on labor productivity, one would want a measure relating to how inspection affected the inputs to the process, rather than some sort of *ex post* or realized measure. The difference is precisely that between per-hour and per-ton measures of inspection rates. A greater per-hour rate may indicate a greater burden on the production process, which will in turn be expected to affect labor productivity which will lead to an altered amount of output. The per-ton measure is a post-production measure, in itself dependent on the labor productivity which, it is argued, will be affected by that very rate. To better separate the factors influencing labor input and its productivity, it seems that the per-hour or per-mine measures provide a cleaner measure which is more representative of its perceived effects.

Some Observations

First, if we want to discern an effect on productivity of inspections, an obvious candidate is UGWX (underground Western mines), which experienced elevated inspection rates during 1987-1989. Both on a per-mine and per-hour basis, these years indicate inspection rates up to 30% higher than the apparent 1983-1994 levels for that region.

Interestingly, these years are not at all out of the ordinary regarding labor productivity. The eleven-year period shows steady growth, with some apparent cyclicality leading to accelerated growth in the years 1987, 1991, and 1994. The 1987-89 period of heightened MSHA inspection effort is not clearly reflected, and indeed is somewhat contradicted, by the productivity data. In 1987, the first year of higher inspection frequency, labor productivity increased 25%. In 1989, when inspection frequency returned to "normal" levels, labor productivity grew only modestly at 10% - compared to an eleven-year average growth of 9.6% per year. The evidence from this region seems to weaken the claim that increased inspection effort reduces labor productivity.

To more formally analyze the effects of inspection effort on labor productivity, a regression model was developed. The model is aimed at obtaining two effects related to inspections. First, to establish the relationship between changes in inspection level for a given region over time. Secondly, to examine the potential relationship between inter-region differences in inspection effort and differences in labor productivity.

Regional Analysis

In this first instance, we treat each method-region as a distinct set of observations, with no relation to the other regions. We simply seek to model labor productivity within that region over the eleven years 1983-1994. Explanatory variables are time, measured in calendar years and the number of inspections per mine. A constant is included in the regression, relating to the level of productivity in the absence of inspection (at some hypothetical year zero). A log-form specification is chosen, as growth is usually modeled as an exponential growth function

$$\text{Productivity} = e^{(\alpha t + \beta I + C)}$$

where t is time, I is inspection effort, and C is a constant such that e^C is some base level of productivity.

The simple regression then takes the form

$$\ln(\text{PRDCTY}) = \alpha \cdot YEAR + \beta \cdot INSPECT + CONST + \varepsilon$$

A summary of the regression results is given below.

Table 4-1 Regional Aggregate Regression Results

Region	YEAR	INSPECT	CONST	Adj-R^2	Obs.
SAPP	0.048	-0.020	-93.603	0.9863	12
	(17.444)	*(-0.956)*	*(-17.458)*		
UGAPP	0.066	-0.019	-129.927	0.9818	12
	(23.763)	*(-1.990)*	*(-23.763)*		
SINT	0.055	-0.034	-107.801	0.9564	12
	(13.758)	*(-1.394)*	*(-13.712)*		
UGINT	0.064	0.004	-126.422	0.9883	12
	(30.069)	*(2.085)*	*(-29.765)*		
LIG	0.046	0.007	-90.321	0.9371	12
	(11.220)	*(0.510)*	*(-10.917)*		
PRB	0.067	-0.026	-130.669	0.9450	12
	(12.213)	*(-1.030)*	*(-12.000)*		
SWX	0.011	0.022	-21.064	0.6066	12
	(1.144)	*(1.144)*	*(-1.453)*		
UGWX	0.094	0.002	-186.292	0.9807	12
	(23.024)	*(0.627)*	*(-22.935)*		

The most notable aspect of these results is that the number of per-mine inspections is only significant in one region, underground Interior, and here the relationship is weakly positive. The rest of the results indicate no clear effect of the number of per-mine inspections - even the sign of the relationship is highly questionable. Yet the adjusted-R^2 measure is very high.

An immediate suspect is the level at which the analysis was performed: essentially regional averages for output, labor, and inspections. As seen in the earlier figures, productivity measured at the regional level is fairly consistently increasing, and therefore easily fit to an exponential growth function such as was specified. Additional variations may be explained by enforcement effort, but the role of the explanatory variable inspections per-mine is not clear. At this aggregate level, inspections per mine is influenced not just by changes in the regional enforcement effort, but by changing composition of mines in the region. Furthermore, since we know that a determining factor in allocating enforcement effort is the size of the mine, an increase in per-mine inspections could actually be reflecting increasing mine size in the region. If there are scale effects of labor productivity - bigger mines are somewhat more productive - then a positive coefficient on inspections per mine would be reasonable in a region experiencing growth in average mine size. In the underground Interior region, this is exactly what occurred in the time period examined: output increased from 55 million tons in 1980 to 69 million in 1994, while the number of mines dropped from 84 to 68.

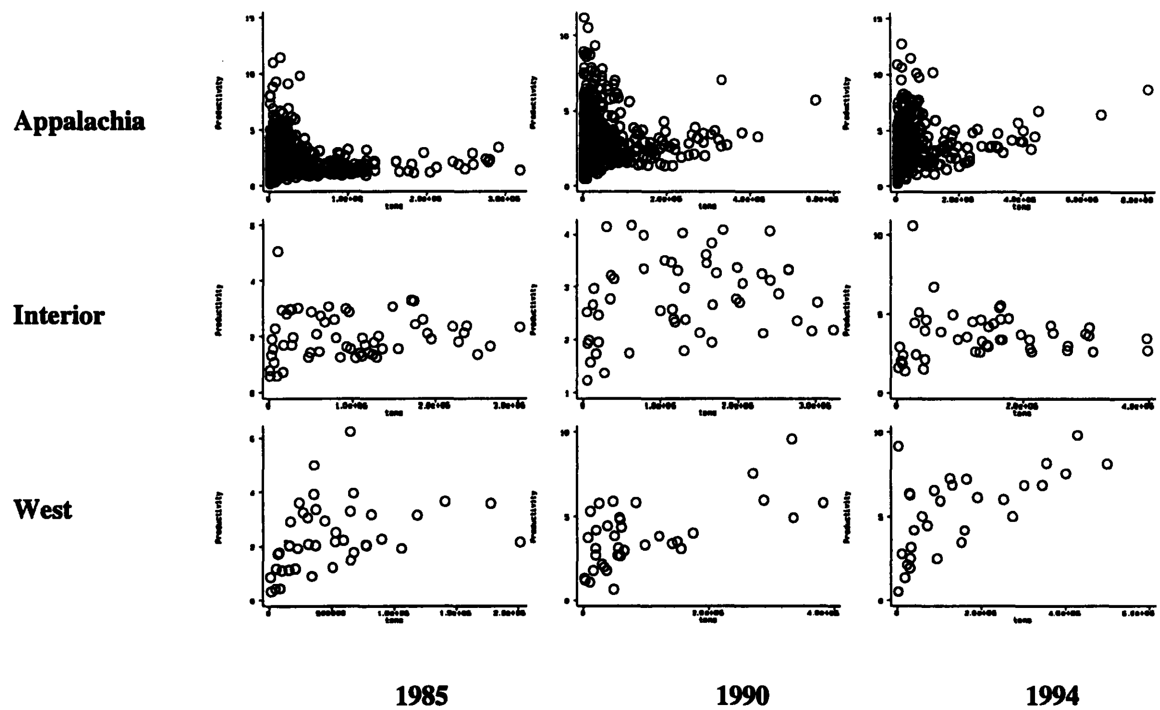
This is hardly a clear picture of how enforcement affects mine productivity, but rather an acknowledgment that productivity is tied up in a complex interaction of size, region, age, technology and possibly regulatory enforcement. To better clarify these interactions, two possibilities exist: account for compositional shifts in mine size (both in terms of output and labor), number of mines, and changes in inspection frequency, or conduct the analysis at the mine level. Performing the analysis at the mine level eliminates many of the compositional problems: there are no averages, and hence no need to separate the different ways in which an average can be affected, such as the enforcement per-mine metric. Some problems are left unresolved, however. For example, the relationship between scale and productivity will still be embedded in any figures of inspections per mine, since inspections are indicative of size.

Mine-Level Analysis

As we delve into a more complex analysis involving mine-level data, we must revisit the earlier issue of measuring inspection enforcement and the effect of scale. In particular, we seek a better understanding of how strong the relationship actually is, rather than relying on intuitive feelings that the relationship may be important.

Scale Effects on Productivity and Inspections

Below is a set of nine graphs, three years in each of three underground mining regions. The first set are scatterplots of productivity against mine output.



Figrue 4-9

The above figure shows, for the three underground coal-mining regions, the distribution of labor productivity against size for three years: 1985, 1990, and 1994. In the West there appears to be quite a clear relationship. The matter is less clear in the Interior and Appalachian mines.

Also important is the relationship between inspection effort and size of a mine. As for the productivity-scale relationship, above, a set of plots is given below. The relationship seems to be clearer here.

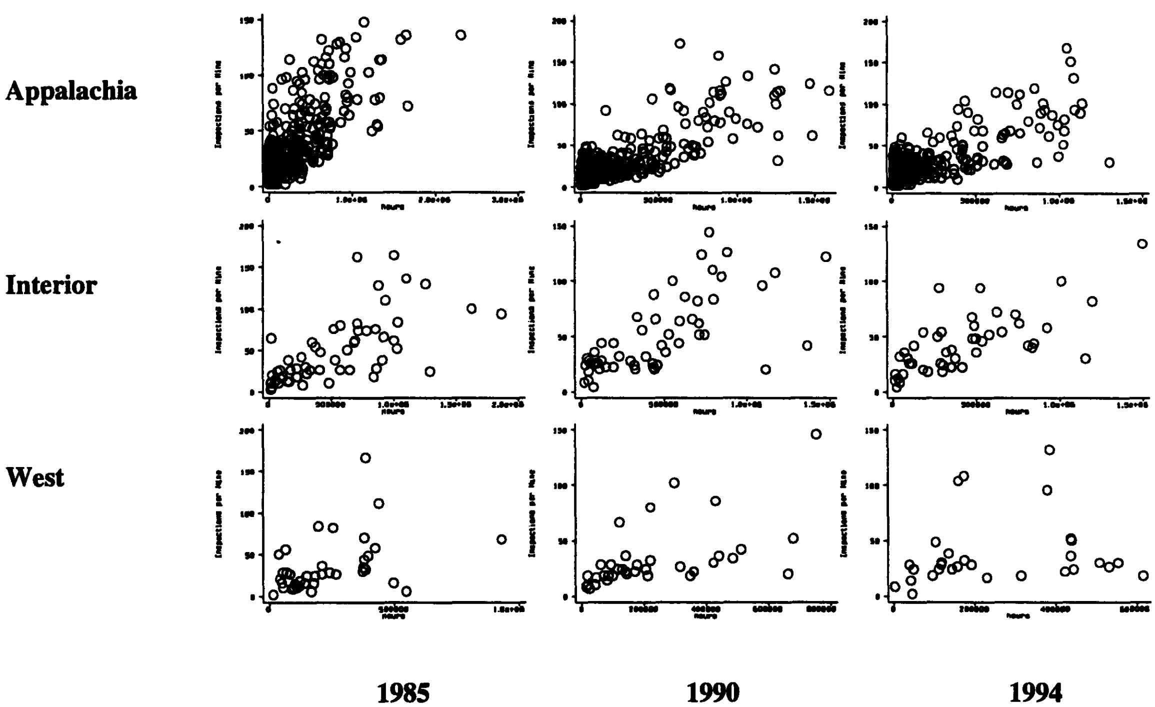


Figure 4-10

Developing an Econometric Model

It is most important to examine the different specifications of potential models, as the results, and hence the conclusions drawn, will be affected by the choice of explanatory variables.

A main concern is separating size effects from operational effects. Both tons produced and labor hours used can be used to gauge both effects. Since mines exhibit some variation in labor productivity with size, it may seem prudent to introduce tons of output into the model. However, productivity has been defined as tons per miner-hour. The positive returns to larger operation will not be separated from the algebraic fact that, all things being equal, productivity will increase if tonnage increases. Similarly for labor hours: bigger mines use more labor, implying a positive return to increased labor (due to scale), but negative returns since, for a given amount of output, higher labor usage implies lower labor productivity.

An alternative way to separate scale and operating effects is to use dummy variables to identify mines by their size. In this fashion, one could identify mines in, say, the 50th, 90th, 95th and 99th percentile by output. More specifically, these percentiles would be calculated for each year, by each of the three underground regions. In this manner, we incorporate scale effects with "labels" as opposed to using the tonnage or labor usage data. In Appendix A-2 the reader will find the relevant percentile brackets by tonnage, noting that these are shown for all years taken together, rather than on a year-by-year basis as was done for the calculations.

In this model, dummy variables are introduced for the constant (to account for different levels of productivity among sizes) and as intercepts on the year counter (to account for different rates of growth). The inspection effort and citations is treated as the same for all mines.

In the model as specified, we can separate and distinguish between the effects of inspections and that of safety. Safety is measured by CITSVR, which is the total of "unwarrantable failure" citations for a mine, issued in cases of imminent endangerment of workers. CIT1 and CIT2 are lesser offenses, with CIT1 being a very mild administrative citation for violations such as unremoved roof-fall - patently non-life threatening occurrences. CIT2 is a citation for the use of untrained workers in a particular area. More on the interpretation of the various implied relationships between the different citation grades is included in the discussion section, below.

The model used takes the following form:

$$\begin{aligned} \ln(\text{PRDCTY}) = {} & \alpha_1 T50YR + \alpha_2 T90YR + \alpha_3 T95YR + \alpha_4 T99YR + \\ & \beta_1 T50 + \beta_2 T90 + \beta_3 T95 + \beta_4 T99 + \gamma_1 INSPECT + \\ & \gamma_2 CIT1 + \gamma_3 CIT2 + \gamma_4 CITSVR \end{aligned}$$

where T(#)YR are the various coefficients on time for the four percentile divisions, T(#) are the intercept dummies for the four percentiles, and INSPECT is inspections per mine. CIT1, CIT2 and CITSVR are three different grades of citation.

The results, by region, are given in the tables below, first for underground mines, then for surface mines.

Underground Mines

Table 4-2 Regression Results for Underground Mines

Region	Percentile	YEAR	Intercept	INSPECT	CIT1	CIT2	CITSVR	Adj-R^2	Obs.
Appalachia	50	0.015 (9.51)	0.65 (57.91)	0.002 (3.14)	-0.005 (-5.24)	-0.048 (-3.35)	-0.011 (-3.71)	0.7762	14982
	90	0.043 (24.85)	0.75 (58.20)						
	95	0.081 (16.32)	0.39 (10.94)						
	99	0.071 (12.85)	0.44 (10.81)						
Interior	50	0.049 (7.60)	0.576 (11.96)	0.002 (1.08)	-0.006 (-2.70)	-0.073 (-1.28)	-0.032 (-3.43)	0.8362	659
	90	0.062 (8.72)	0.708 (11.07)						
	95	0.051 (2.53)	0.832 (5.31)						
	99	0.072 (3.098)	0.608 (3.52)						
West	50	0.076 (7.37)	0.386 (5.21)	0.003 (0.97)	-0.014 (-3.19)	0.023 (0.32)	-0.022 (-1.89)	0.8147	445
	90	0.095 (8.49)	0.864 (10.02)						
	95	0.110 (3.58)	1.076 (4.72)						
	99	0.067 (1.81)	1.360 (5.41)						

These results indicate a negligible effect of increased per-mine inspection effort. Citations, however, do seem to have a greater effect. In Appalachian mines, those with higher levels of citations, regardless of severity, have lower productivity. In the Interior, severe violations have a high correspondence with lowered productivity. In the West, citations again seem to influence productivity adversely, though the t-statistics are not as high.

Also interesting are the implications of scale for labor productivity. In the West, productivity levels are clearly increase with mine size. This is also true in Interior, except for the very biggest mines which are somewhat lower. No such clear pattern emerges in Appalachia.

Growth in labor productivity exhibits some increases in scale, though no clear relationship emerges indicating that larger mines will grow faster. In the Western underground mines, for example, the largest 4% of the mines (between the 95th and 99th percentiles) have the lowest rate of growth, lower even than the smaller 50% of mines. In Appalachia there appears to be a clearer positive return to scale, with the smallest 50% of mines growing, on average, 1.5% per year in terms of labor productivity, whereas the 90th and 95th percentile mines experienced growth in labor productivity of 4.3% and 8.1%, respectively.

It is only in the largest 4% of mines (between the 95th and 99th percentiles) that there appears to be a negative effect of size to labor productivity growth, as they grew at a more modest but still high 7.0% per year. The Interior offers a real puzzle with no discernible pattern present.

Surface Mines

Using the same specification as for the three underground regions, a similar analysis can be executed for the five surface mining regions. We anticipate more unexplained behavior in the surface mining regions than in the underground ones. One major reason is the relatively minor amount of inspection effort expended by MSHA on surface mines. This is expected and justified since the Coal Mine Safety and Health Act of 1969 was geared primarily towards underground mines. Additionally, surface mines are subject to additional regulatory requirements which are absent from underground mines. The lower applicability of our data, as well as the lack of what is quite possibly a major factor of surface labor productivity, make the analysis of MSHA regulation on surface mines less meaningful.

Once again, the data was partitioned into the 50th, 90th, 95th, and 99th percentiles by tonnage for each year and each region (Appalachia, Interior, West, Lignite and Powder River Basin). As before, this is to capture scale effects without relying on operational data which directly influences the labor productivity calculations. The regression results are shown below.

Table 4-3 Regression Results for Surface Mines

Region	Percentile	Year	CONST	INSPECT	CIT1	CIT2	CITSVR	Adj R^2	Obs.
Appalachia	50	0.016	0.781	0.000	-0.006	0.029	-0.005	0.7800	9796
		(6.42)	(43.50)	(-0.02)	(-0.95)	(1.31)	(-0.31)		
	90	0.033	0.900						
		(13.10)	(46.59)						
	95	0.057	0.969						
		(8.32)	(20.28)						
	99	0.057	0.984						
		(7.59)	(0.052)						
Interior	50	0.029	0.819	0.014	-0.034	0.035	-0.172	0.8081	1689
		(5.18)	(18.87)	(1.29)	(-2.62)	(0.86)	(-4.84)		
	90	0.058	0.919						
		(9.74)	(19.15)						
	95	0.053	1.116						
		(3.27)	(9.94)						
	99	0.050	1.133						
		(2.74)	(8.87)						
West	50	0.006	-0.334	-0.004	-0.027	0.088	0.047	0.9174	289
		(0.37)	(-2.64)	(-0.17)	(-0.94)	(0.85)	(0.59)		
	90	0.022	-0.402						
		(0.59)	(1.63)						
	95	-0.15	0.023						
		(-0.29)	(0.061)						

	99	0.020 (0.49)	1.991 (6.70)						
Lignite	50	0.095 (7.06)	1.303 (10.98)	-0.017 (-0.59)	-0.057 (-1.62)	-0.020 (-0.15)	-0.042 (-0.69)	0.9349	236
	90	0.030 (1.88)	2.230 (17.07)						
	95	0.089 (1.73)	1.872 (5.20)						
	99	0.023 (0.09)	1.818 (2.49)						
PRB	50	0.010 (0.38)	0.919 (4.38)	0.175 (2.06)	0.134 (1.57)	0.212 (0.76)	0.122 (0.51)	0.9129	263
	90	0.065 (2.80)	1.102 (6.12)						
	95	-0.017 (-0.37)	0.928 (2.70)						
	99	0.072 (1.70)	0.941 (2.89)						

As expected, there is scant evidence supporting the claim that either citations or inspection under MSHA reduces productivity for surface mines. The one notable exception is the impact of severe citations in the Interior. This seems amply countered by the Powder River Basin, where there is seemingly nothing that can be done to slow the pace of productivity growth in this extraordinary coal-producing region.

The effects of scale seem stronger than for underground mines. In Appalachia and the Interior, there is clear evidence that larger mines have higher labor productivity. The Lignite and PRB regions both have rather similar levels across all sizes. The Western surface mines are a true curiosity: the entire region is apparently buoyed by the largest mines, which are achieving modest growth in labor productivity at best.

Once again, the evidence linking growth rates in productivity to size is somewhat weak. Examples exist, as in Appalachia and the Interior, where scale does seem to affect the rate of growth. The other three regions, however, show no such link.

Determining Causation

The above analysis is strong evidence that their is a correlation between increased citation incidence and depressed labor productivity in underground mines. The mechanism through which this occurs is not clear. Indeed, the analysis does not speak at all about the direction of causation. The two competing explanations can be summed up as follows:

"The Benign Citation Hypothesis" - In this construction, a citation is an indicator of mining practice and nothing more. There is assumed to be complete independence between productivity and a citation, and any correlation between the two must lie in a third linkage: mining practice. Under this reasoning, the evidence that high-productivity mines have low citations shows that good operating practice is necessary to attain high levels of labor productivity. The same practices which lead to efficient mining also protect the health and safety of workers.

"The Citation Feedback Hypothesis" - This view of the production process holds that labor productivity is a realized measure given a bounded allocation of productive resources. While all mines must comply with the relevant laws, mines that have had citations - and especially those citations requiring some action on the part of the operator - will be further constrained in their ability to allocate labor and capital efficiently. Hence, lowered productivity in the presence of high citations has more to do with the regulatory burden of the citation rather than the operating conditions which lead to the citation in the first place.

While further in this section some analytical techniques are discussed which can further the investigation of causality, there are some first-attempt exercises which may shed some light on the question. First, one would want to establish the degree of independence between citations and inspections. While the data we have suggests that all inspections lead to some kind of citation, there are several cases of multiple citations arising from a single inspection. Furthermore, we have identified at least four different kinds of citation. These observations should be enough to allow citations to be distributed independently from the distribution of inspections, beyond the obvious fact that each citation must stem from an inspection.

The argument immediately becomes complicated when we re-visit the relationship with mine size. Recalling that there seems to be some labor productivity return to scale in mines, and that inspection effort is influenced by the amount of labor used in a mine, it is imperative that our analysis of citations be constructed in such a manner that we truly isolate the effect of the citation alone. That is, we must ensure that we are looking at the effect of a citation given that a given number of inspections have already occurred, rather than observing the cumulated effects of all actions leading up to a citation.

This again raises the crucial question of choice of metric. Clearly the use of citations per mine is inadequate, since this will have a lower bound equal to the number of inspections, which we already determined is largely a function of mine size. Citations per hour of labor input suffers from additional problems. First, MSHA carries out a minimum of four inspection in each underground mine. Hence there is a lower limit on inspections - and therefore citations - whereas no such lower bound exists for labor hours. This will lead to many smaller mines which receive the minimum number of inspections but have vastly different labor inputs reflected as a tremendous scatter in citations per hour for small mines. Furthermore, for a given level of citations per hour, it would be impossible to differentiate between a mine which achieved that level due to unsafe conditions, or a relatively safe mine which garnered many inspection due to its size. Most of these problems apply particularly to the 104-A, or CIT1, citations, which are the most common.

A third potential metric is citations per inspection. This allows us to explore the amount of auto-correlation between an inspection and a citation for the various grades, as well as controlling for size-effects which are embodied in the number of inspections. Additionally, it identifies mines which have a low number of citations due to low number of inspections rather than because it was particularly safe. Figure 4-11 shows the correlation between labor productivity and total citations for underground mines.

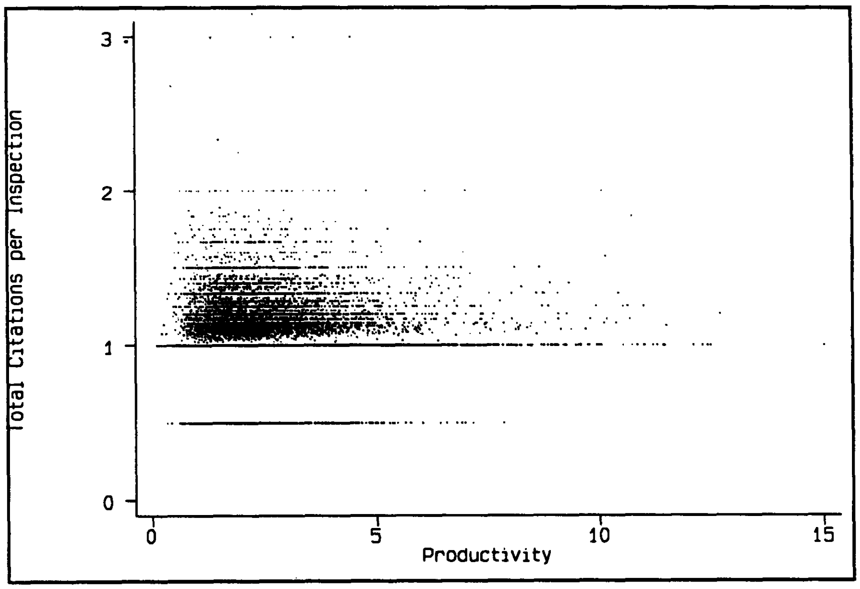


Figure 4-11

This is not particularly convincing either way. All it seems to say is that inspectors do not appear to be influeneced by the relative productivity of a mine in their determinations of citable offenses. More indicative, perhaps, is the distribution of severe citations, as shown in Figure 4-12 for underground mines.

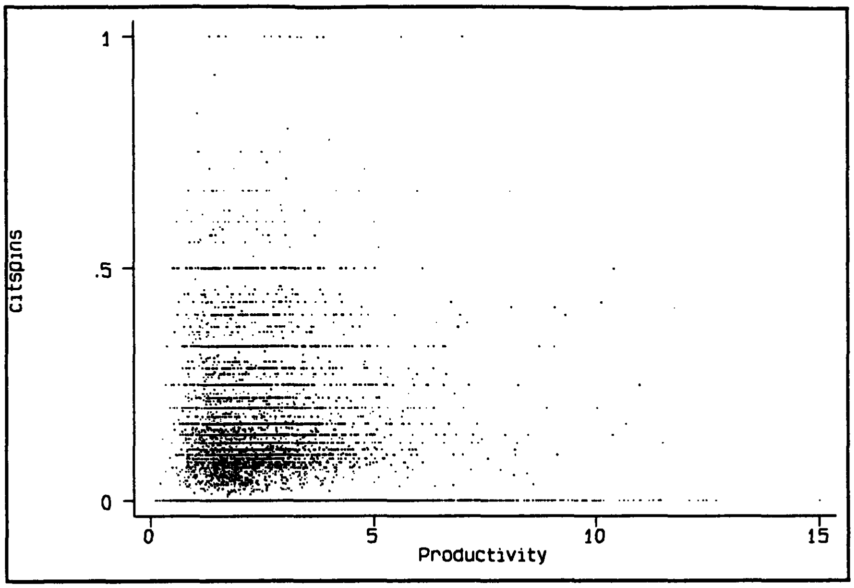


Figure 4-12

Again, this is not overwhelming evidence for either case. Simply put, mine productivity does not seem unduly affected by the number of citations arising from an inspection. We must now turn to the original allocation of inspections for possible explanations, shown below in Figure 4-13.

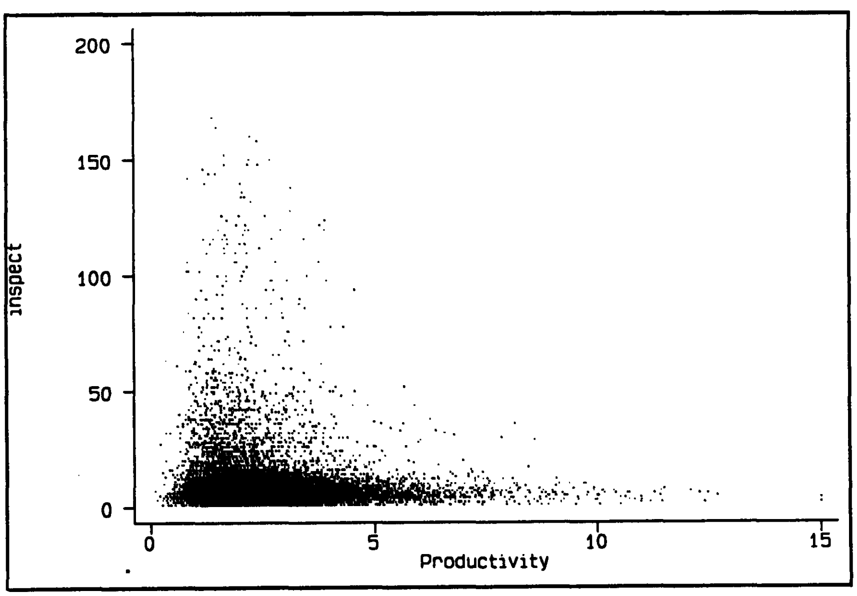


Figure 4-13

Figure 4-13 lends support to the idea that it is the frequency of inspections that identifies the heavily-cited mines. In other words, most of the variation is attributable to repeated inspections than highly variable citations per inspection. Unfortunately, this leaves us no closer to an answer. The relatively narrow range of severe citations per inspection could either indicate a certain "quota" mentality on behalf of the inspectors, or that all conditions in a mine that may be deemed dangerous are reported in some grouped fashion. In other words, no matter how dangerous the conditions in a mine may be, it might simply not be possible to issue dozens of citations on that one occasion. Recall also that conditions constituting an "imminent danger" are not cited in the procedure outlined here, but are dealt with under a separate part of the Coal Act.[7] Another point worthy of note is that the citations per inspection number is derived from dividing the sum of all citations for the year by the sum of all inspections. It is not an average of the actual citations per inspection for each inspection.

Other possibilities abound. Inspections are allocated, among other things, by the past history of violations. Indeed, a citation may often require a follow-up inspection. In a sense, then, inspections are as much a result of past inspections as they are of other factors already discussed. A regression of the number of inspections on several factors, including the number of severe citations experienced in the previous period, indicates this quite clearly.

Table 4-4 Regression of Number of Inspections

t50	t90	t95	t99	PRDCTY	Inspect (t-1)	Severe Cit (t-1)	Obs.	Adjusted R^2
2.612	4.373	7.466	13.89	-0.064	0.542	1.106	12075	0.7088
12.30	*17.48*	*17.65*	*28.15*	*-0.94*	*66.42*	*17.74*		

The occurrence of a severe citation in the previous year appears to increase the number of inspections in the current year by slightly more than one, with a very high level of significance. Interestingly, there is a great degree of serial correlation with the number of inspections in the previous period. This may be due to the fact that mine size and geological conditions do not change much, and hence there is little variation in the "base" number of inspections each year. Variations from this longer-term average, however, seem to be explained, at least partially, by the safety record of the mine. Notice, also, that labor productivity does not appear to contribute to the number of inspections.

The causation issue is far from resolved, then. What is clear is that the allocation of inspections seems to correlate more closely with the observed variations in productivity that do other measures such as citations per inspection. This appears to be due, at least in part, to the safety record of the mine in the previous

[7] §107 "Procedures to Counteract Dangerous Conditions" allows an inspector to immediately "...cause all persons...to be withdrawn from, and to be prohibited from entering, such area..." This is in stark contrast to the usual citation procedures which require an operator to correct a dangerous situation, failure to do so being possible grounds for a similar withdrawal order.

year. Inspection effort, then, is not a benign starting point, but rather an allocation which in itself reflects the relative safety of the mines in question. Both explanations for the productivity - citation relationship can still be asserted. The "benign citation" followers will then be encouraged to know that MSHA is being highly efficient in chasing up known unsafe operators, as the law requires. Alternatively, the "perpetual citation machine" advocates will point to the double-insult of being inspected often: it will inevitably lead to higher inspections.

Further Analytical Issues in This Research

The difficult conceptual and econometric modeling issues involved in establishing any kind of causal relationship between productivity and regulatory enforcement pose a variety of challenges for further research.

This analysis thus far does not support either of the two views set forth in the previous section regarding the causation mechanism surrounding enforcement of the Coal Act. The first hypothesis states that good operating practice is the key to high productivity, whereas the second theory bestows upon MSHA officials the key to mine productivity. Frankly, it is difficult to see how a citation which imposes almost negligible monetary penalties on an operator ($50 is the standard fine)[8] and entails no interruption of production could have a large effect on productivity, though one would hardly want to draw conclusion from an inability to envision a relationship.

Further analysis may shed light on the causation question. In particular, we would want to separate the function of the citation figures as an indicator of mine management practice from its potential role as a productivity drag. If the citation itself was the cause of productivity loss, then including a current citation counter as well as a counter of the previous period's citations would reveal the role of citations in determining productivity in the ensuing period. Since the temporal effects of citations are sought, using the original quarterly data for selected mines would be very beneficial. Second, one would want to include some measure of a citation frequency's deviation from the longer-term average. The underlying assumption is that management practice does not generally change much from quarter to quarter, and that the long-term management practice will be reflected in the long-run trend in citations. By including a linear and quadratic citation term in the regression, we would capture the effect of quarterly deviations from the longer trend. In other words, the linear term would reflect the citation level associated with operating practice, and the quadratic term would capture the more sporadic or capricious citation behavior of the inspectors.

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[8] MSHA Fact Sheet 95-4, http://www.msha.gov/MSHAFCT4.HTM

As the other kinds of citation entail more severe penalties and are for more dangerous practices, there is less ambiguity or scope for judgment or subjectivity on the part of the inspectors. The amount of training a worker has is a fairly precise measure[9], as is the nature of the work being done by that worker. Similarly, unwarrantable failures due to high levels of dust, toxic or explosive gas, or lack of structural support are subjected to measurable standards. The 104-G and 104-D citations, then, are less prone to abuse or variation from one inspector to another, and more likely to be true reflections of the conditions at a mine.

Nevertheless, the question remains as to whether it is inherently unsafe practices which are a drag on productivity, or the price MSHA extracts for non-compliance. Unlike the 104-A citations, the 104-D variety leads to a closure of a mine section[10]. The question is how much will this affect productivity? Since miners must be paid for their time at regular wages, perhaps the workers will simply be moved to an open section of the mine. The effect of a shutdown will also be determined by its duration and the relative amount of output for which that section accounts. Again, some further analysis on a quarterly basis with some more sophisticated choice of variables may be illuminating.

The role that mine injury data could play is very promising. It would be possible, for instance, so test whether there is a relationship between injuries and future inspection effort. Furthermore, one could establish whether mines receiving low numbers of citations were indeed safe operators or simply had slipped detection by MSHA. The data is available, and its integration into the analysis should be a top priority.

Summary

Inspection effort by MSHA is allocated with emphasis on underground mines, with the larger mines being subject to more inspections than smaller mines. Mines with particular characteristics, such as high presence of methane, will receive even more inspections. Mines also are subject to inspection if there has been a worker complaint, as follow-up inspections to previous citations, or if, in MSHA's judgment, the mine's safety record warrants more careful inspection.

When analyzed on a regional basis, results can be obscured by structural shifts in the industry within a particular region. All three measures of inspection effort - per-mine, per-ton, and per-hour - are a

[9] The Coal Act requires 40 hours for new underground miners (§115(a)(1)), 24 hours for new surface miners (§115(a)(2)) and eight hours of refresher courses at least every 12 months(§115(a)(3)).
[10] This is somewhat misleading. Repeated 104-A citations can lead to a withdrawal of workers, though this is rare.

function not only of inspection vigor on the part of the Administration, but also of changing composition - number of mines, average mine size, and productivity of these mines. Since the period examined has been one where some regions have experienced considerable growth in output, a general diminution of the number of mines, and increased labor productivity, the variations in the different inspection metrics make analyses based on regional aggregates unreliable. Mine-level analysis is required.

When specifying a mine-level regression model, care must be taken to separate operational effects (relating small changes in labor usage and output to labor productivity) and scale effects (where labor may have increasing returns to scale). In this analysis, the effects were separated by partitioning the mines in the given region into those falling below the 50th, 90th, 95th and 99th percentile. This non-uniform partitioning is due to the highly skewed distribution of mine output, where a traditional quartile would lead to grouping mines which differ in output by one or more orders of magnitude. Each size group is allowed an independent time coefficient and intercept. All mines are presumed to be equally affected by inspections and citations.

The results indicate that underground mines are significantly and adversely affected by increased citations, but inspections do not, in and of themselves, seem to affect mine performance. This is a result requiring some deeper thinking due to the fact that all citations arise from an inspection. In fact, one would expect perfect colinearity to exist were it not for the fact that one inspection can lead to multiple citations. What the coefficient on INSPECT really means, in this case, is that it is no worse to received a given number of citations from a large number of inspections than if all arose from a single inspection. In other words, for a given number of citations, the number of inspections is immaterial.

The more interesting result is the profound effect of citations on mine productivity. The severe citations seem to lower labor productivity by 1 to 3% per additional citation, depending on the region. The untrained worker and basic citations have varying degrees of effect. Recall, also, that the base citation, being the most frequent one, will also reflect the impact of inspection as well as the influence of operating practice on labor productivity.

For surface mines, inspections and citations under MSHA were rarely significant determinants of labor productivity. This may be due to MSHA's relatively minor role in surface mining operations, compared to the surface mining regulations which are more prevalent.

Causation remains enigmatic. There is every indication that citations do not come about as an independent result of observing mine practices, but rather depend on the initial allocation of inspection effort. In turn, this effort seems to be influenced by past safety and citation history. This is due largely to requirements for follow-up inspections when some citations are issued, as well as to the discretion allowed MSHA officials which permits consideration of general safety record when allocating inspection effort.[11] Further analysis utilizing quarterly rather than yearly data, coupled with more refined modeling of the effects of citation, may prove helpful in improving our understanding of the mechanism through which productivity and citations are related. An important body of information which would help resolve the issue is mine injury data.

The effects of scale on level and growth of labor productivity, too, are illuminating. The scale effect is most pronounced in surface mining, where both Appalachian and Interior surface mines show positive returns to scale. The Powder River Basin and Lignite mines also show some of this effect, but these regions consist of mines which are consistently very large: there simply are no small operations there. Growth rates do not follow scale quite as neatly, though in most regions the larger 50% of mines outperform the smaller half. The case for underground scale effects is less strong, but again the bigger half of mines tends to have higher levels and growth rates of labor productivity than the smaller 50%.

[11] §103 (a) "The Secretary shall develop guidelines for additional inspections...based on criteria including, but not limited to, the hazards found in mines...and his experience..."

5 Policy Analysis and Conclusions

In the arena of government regulation of industries rages an age old debate. Central to the debate are contending views regarding the best program for promoting health, safety, and environmental responsibility while limiting the interference of government in private industry. In the case of coal mining, the industry's inability to adequately protect the health and safety of miners in subsurface mines, and a failure to prevent aesthetic deterioration and contamination in surface mines lead to pressure at the federal and state levels to subject the industry to government regulation. The Coal Mine Health and Safety Act of 1969 (amended as the Mine Act in 1977) and the Surface Mining Control and Reclamation Act of 1977 are the regulatory creations that arose from that pressure.

In this chapter, we develop a broader picture of the effects of the Coal Act (1969), both in terms of impact on industry and its relative success in achieving greater protection for miners. Initially, two different ways of examining impacts on regulations are introduced: by type of impact and whether the events are expected to be permanent or not. Once this research is place in context, other areas meriting further work are discussed, and the results of this analysis summarized.

Industry Response to Regulation

The effects of the regulations can be analyzed chronologically or by category of effect. Broadly speaking, one would expect the initial effects of requiring existing mines to comply with regulation would differ in nature from the effects experienced by mines a decade later. This would be due to the penetration of compliance among the pre-regulation group, and the introduction of new mines since passage of the laws. These two effects are referred to as "transitional" and "continuous".

In addition to the temporal nature of the effects, one might describe at least two types of effect. First, the actual practice modification requirements imposed on the industry will required both time and resources to implement. Second, ensuring compliance will require a certain amount of intrusion and perhaps interruption of the mining operations to allow for full inspections. Furthermore, the mine operator does not have full knowledge or warning regarding the frequency, date, or extent of all inspections - if they did, one may expect an ability to anticipate and plan around these events. Indeed, the

Coal Act stipulates that spot inspections be conducted at irregular intervals[12] and provides for criminal and civil penalties against people who leak a notice of inspection to operators.[13]

To put things into a policy analysis framework, one would want to fully articulate, if not quantify, the effects of the regulation. This would, at a bare minimum, entail assessing the burden of compliance on the industry in terms of lost output due to inspection-induced "downtime", direct cost of altering operating practice and equipment to comply with the regulation, and the increased operating cost due to practices required by the law. Of course, one must also examine whether the goals of the regulation have been met, and to what extent. In the case of the Coal Act, one would look at figures for fatal accidents and respiratory problems, though the latter will often not manifest itself for many years. In short, one would seek a careful articulation of the altered performance of industry as well as the degree to which the policy goals were met.

Effects of the Transition into a Regulated Environment

This research has not addressed the question of how much the industry suffered during the transition, or what the mandatory changes in mining practice has meant as far as productivity. This would be very difficult to do within this analysis. Aside from the lack of data prior to 1972, when MSHA began collecting it, there are compositional hindrances. New mines have come in since 1972. In fact, new mines account for the vast majority of output.

Some of the best work on the transitional effects appears in a 1981 report by the US General Accounting Office. The GAO published a report exploring the causes and proposed cures for the prolonged slump in coal mine productivity. Among the issues studied was the effect of the Coal Act of 1969, cited often by mine operators as accounting for 22 to 40 percent of the decline[14]. In the report, GAO concluded of the effect of the Act:

> "While certain practices required by MSHA lowered productivity substantially, their impact was felt largely during MSHA's implementation and should not be a continuing source of decline."[15]

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[12] §103(i) of Coal Act

[13] §110(e), allows assessment of fines up to $1000 and a year imprisonment for such acts.

[14] US General Accounting Office *Low Productivity in American Coal Mining: Causes and Cures.* EMD-81-17, 1981. P.36.

[15] US GAO, *op cit.* Ref.1, P.36.

Indeed, the report stated that their analysis found that, in 1977, an increase of ten inspection days per year lowered underground mine productivity by 1.5 percent. The GAO analysis differs from this analysis in that total number of days of inspection was used to measure enforcement, as opposed to the number of inspections and resulting citations. Nevertheless, the reports conclusion - that the regulation's main impact was felt early on - is an important part of the impact picture. Furthermore, the report stated that "Our statistical analysis indicates that while the act was one cause [of productivity decline], it was certainly not the only cause, and was not as significant as the coal industry asserts."[16]

Even the GAO study does not help in deciding whether the coal industry *today* is better or worse off because of the regulation - that study was strictly a before and after study. The key to any such analysis is finding an appropriate comparison, or counterfactual, to what is actually observed. One would need to predict what the performance of the industry would be today had the regulations not been put in force. This would require assumptions about how much cheaper new mines would have been, how much investment would have been generated, and whether alternative reactions to continued working conditions may not have been worse.

The matter is further complicated upon the realization that some shifts in productivity are mirrored in other sectors of the economy[17]. Clearly, any predictions of the state of the mining industry in the absence of regulation is fraught with difficulty and subject to much uncertainty. Furthermore, it is not a terribly relevant question: Congress intended to improve worker safety with the Act, and fully anticipated it would come at some cost to industry. Perhaps a more sophisticated question than whether to abolish regulation is how to ensure or build upon the progress in a manner which minimizes the drag on the regulated industry.

Worker Safety Under the Coal Act

The safety record for mines after the Coal Mine Health and Safety Act show interesting trends. While fatal injuries (Figure 5-1) have fallen significantly since passage of the Act, non-fatal injuries do not appear much affected (Figure 5-2). Furthermore, we are quickly reaching a point where the effects of the dust-suppression requirements of the Act can be tested against incidence of respiratory disease in miners. The principal goals of the Act - to protect miners from fatal injuries and reduce the incidence of respiratory disease - have largely been met. It remains to be seen whether legislation will evolve to

[16] US GAO, *op cit.* Ref. 1, P 35.
[17] find them

address non-fatal injuries, which have not improved and were not the main focus of the 1969 and 1977 Acts.

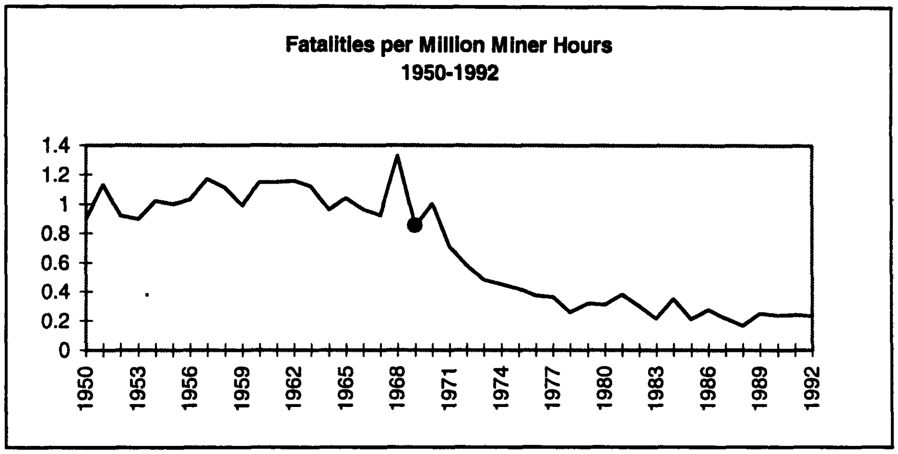

Figure 5-1

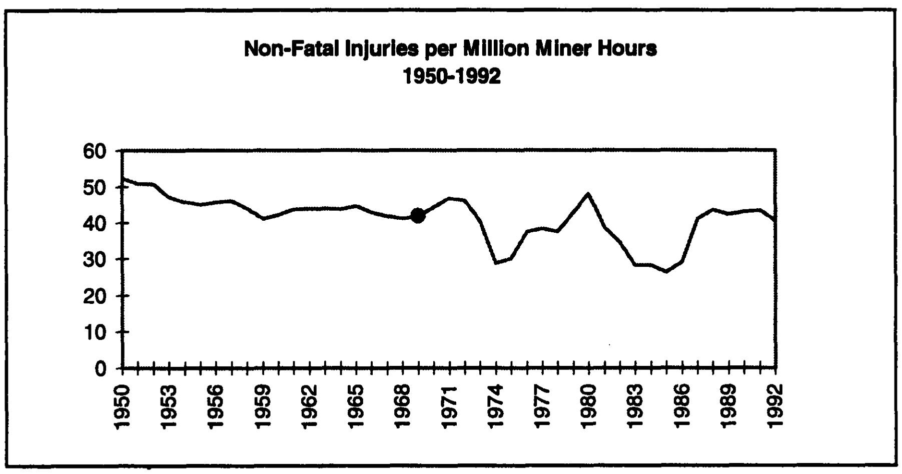

Figure 5-2

Conclusions

Industries are continuously evolving. New technologies arise which will improve performance of existing firms or, if they are unable to employ the new technology, new firms will enter. With each advance in the state of knowledge, age of capital becomes a bigger hindrance, and a dynamic is observed in which old producers are steadily forced out of production as newer firms enter. Due to the heterogeneity in the nature of coal, and the geological determination of these characteristics, changes in the demand for a grade of coal can cause large regional and methodological shifts in production, as was seen giving rise to the Powder River Basin mines. As discussed in Chapter 2, aggregation of production data masks these very important trends by lumping together non-similar mining regions and methods. It is important to get to a less aggregated level of information: the coal supply industry is dynamic and evolving, and technology is the driver.

Were it not for one important input to the production process - labor - that may well be the end of a very compelling story centered on "creative destruction" spurred by investment and knowledge. Labor, however, is not an input like capital, materials and energy. In essence, these other inputs are wholly owned by the producer: a purchased machine is wholly devoted to production. For a miner, his toil and working conditions have a direct bearing on other facets of life, in particular his safety at work and health over the rest of his lifetime. To the extent that private market transactions will not fully incorporate these indirect effects of the nature of the work, a set of limitations and rules are created to reflect society's standards for just and reasonable working conditions. The reasons for believing that markets are inadequate arenas to determine an efficient allocation of risk are several and well explained in the literature. Lack of information; inability to utilize information regarding low-probability, high-consequence risk; and imperfect competition due to low labor mobility for a typical miner's income and educational level are the more typical arguments[18]. From a social justice perspective, one may object to the fact that hazardous employment falls disproportionately on the shoulders of low-income persons, economically efficient as that allocation may be.

The Coal Mine Health and Safety Act was aimed at reducing the incidence of and injuries from the most disastrous mine incidents: collapses and explosions. While it has been successful in that role, no policy analysis would be complete without examining the costs associated with that success. At a minimum, one would want to ensure that such safety advances came about in the least expensive manner, even if one did not want to tackle the thorny issue of whether such protection was worth the price. This analysis examined the long lasting effects of the Coal Act. These are effects associated with the administrative burden of operating in a regulated environment, and the impact on productivity associated with non-compliance. Our evidence supports the notion that, to be a highly productive mine, compliance with the safety standards is a necessary condition. Furthermore, the purely bureaucratic burden of inspections on mines was shown to be rather small: for any given number of citations, it made no difference how many inspections were conducted during the year. What is not yet clear is the mechanism through which non-compliant mines suffer a loss of productivity: is it through excessive penalties associated with non-compliance, or are the unsafe practices which define non-compliance inherently inefficient?

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[18] Ashford, N. A. and C. C. Caldart. *Technology, Law, and the Working Environment* New York: Van Nostrand Reinhold. 1991. Chapter 5.

Areas for Further Research

Further analysis could help clarify some of these issues. For certain groups of mines, a quarterly time-series analysis coupled with a more sophisticated specification of explanatory variable would shed light on the causality issues. Additionally, incorporating mine-level injury data compatible with the current enforcement and operational data would help answer some of the questions regarding whether citations truly reflect mine safety conditions.

The research in this thesis focuses principally on federal regulation which concerns itself with underground mines. As mentioned in Chapter 2, surface mines are specifically addressed in the Surface Mining and Reclamation Act of 1977. Several factors conspired to frustrate efforts to aptly incorporate the enforcement of this act into our analysis. First, SMCRA is under the jurisdiction of the Department of Interior rather than Labor. This means, among other things, that the data gathering practices and procurement processes are different. Second, the primacy of states under SMCRA has lead to varying practices across states, as well as decentralized recordkeeping and data gathering. The best data available in time for this research was from the Office of Surface Mining, which reported federal inspections and citations, as well as funding levels to states. Neither offers the full detail of mine-level data available under MSHA's practices. This is not to say that the data is not available, and certainly some good research could be conducted without requiring data requisition from every state. Data from five large surface-mining states would provide a good start to examining some of the same issues discussed here.

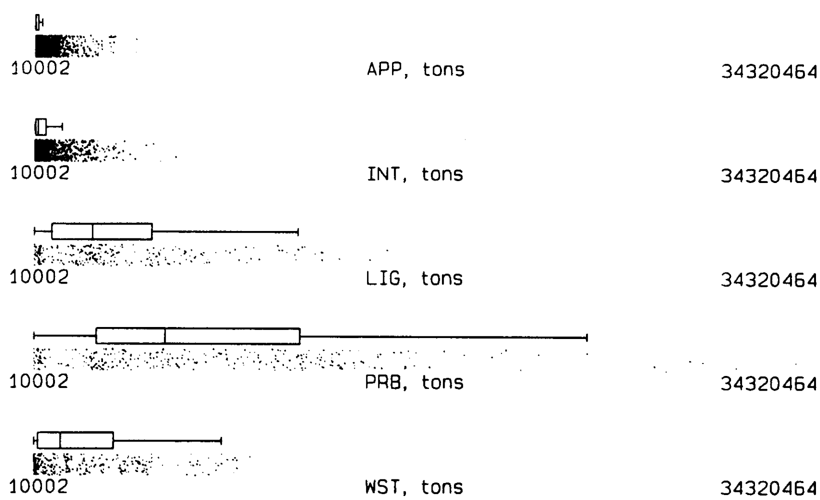
Surface mines have behaved differently than their underground counterparts in many ways. Some regions, like the West (excluding Lignite and PRB) have seen their level of productivity stagnate, reaching 1972 levels only in the mid 1980's (see Chapter 2). All surface mines have taken longer to regain their 1972 levels than underground mines, and the cause may be in the different regulatory regime governing them. If, as was the case in underground mines, the effects of SMCRA were largest during the transitional period, the relative newness of the surface regulations may explain the lag. If one accepts the view that new mines designed with knowledge of the regulation suffer less, and therefore the rate of turnover of productive capacity helps determine how long it takes for the industry to develop least-cost compliance strategies, then the lower turnover of surface mines, especially in the western regions, may contribute to the surface-underground lag. The door is wide open for combining such knowledge of the dynamics of the industry with regulatory enforcement data for surface mines, as this analysis has done for underground mines.

This thesis has made use, for the first time, of very detailed, mine-level data to study the evolution of mine labor productivity and the effects of federal regulations. It has identified some critical steps in developing a solid analysis, such as the drawbacks of excessive aggregation or the choice of explanatory variables. The results have been illuminating and well-supported. Inspections do not, by themselves, seem to have much of an impact on productivity. Mine labor productivity is much more seriously impacted by high levels of citations relating to dangerous conditions. There remain unanswered questions surrounding causation, and there seems to be a complex feedback of inspections, citations, and safety conditions in a mine. The impact of MSHA's regulatory efforts is minimal on surface mines, and further study on this group would be of particular interest given the stark productivity differences among this type of mining and its large share of national output.

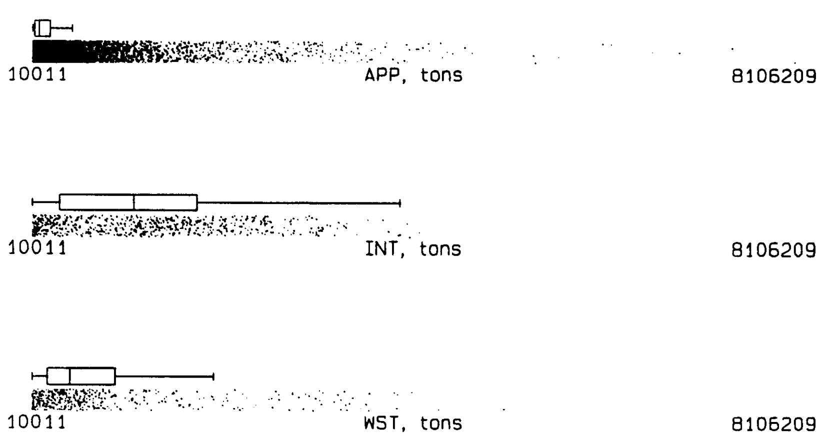
This analysis provides a useful and defensible description of the effects of current regulatory practice. It also shows the importance of understanding the regional, methodological, and temporal shifts in the industry which may escape detection by national aggregate measures. The possibilities created by the use of such a micro-level dataset are vast, and the understanding gained from utilizing such data should provide motivation for further research.

Output Distribution

Surface Mines

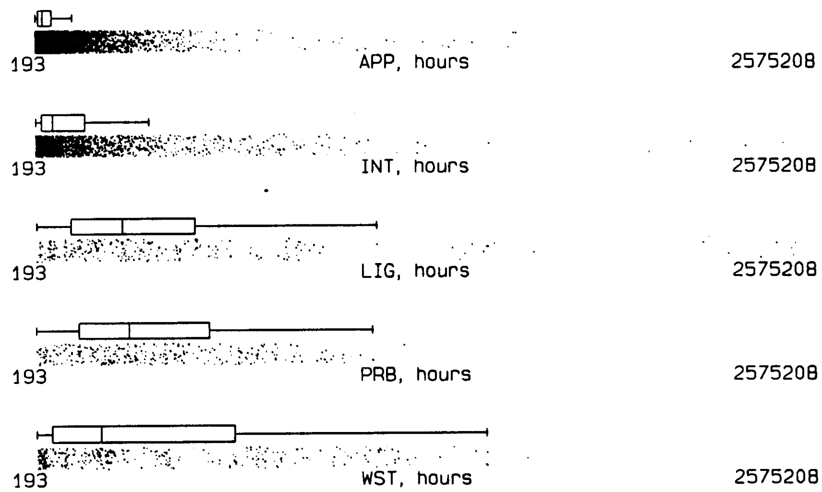


Underground Mines

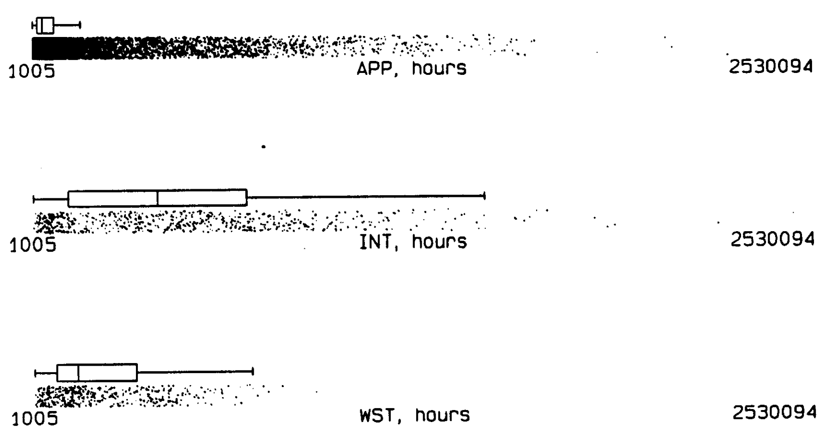


Labor Distribution

Surface Mines



Underground Mines



This is a copy of the STATA output for the principal regressions cited in the analysis. Recall that this is from the dataset which has been purged of mines producing less than 10,000 tons per year, as per EIA practice. Annotations, for clarity, are in italics.

```
. by regcode tchcode: regress lnprd t50yr t90yr t95yr t99yr t50 t90 t95 t99 ins
> pect cit1 cit2 citsvr if year>=1983, noc
```

Appalachian Surface

```
-> regcode=    1 tchcode=    0
 Source |    SS      df    MS          Number of obs =  9796
---------+------------------------------     F( 12, 9784) = 2894.93
  Model | 10000.9626   12  833.413551       Prob > F    = 0.0000
Residual | 2816.69103 9784  .287887472      R-squared   = 0.7802
---------+------------------------------     Adj R-squared = 0.7800
  Total | 12817.6536 9796  1.3084579        Root MSE    = .53655

------------------------------------------------------------------
  lnprd |   Coef.    Std. Err.     t     P>|t|    [95% Conf. Interval]
---------+--------------------------------------------------------
  t50yr |  .0155207  .0024165    6.423  0.000    .0107838   .0202575
  t90yr |  .0330802   .002526   13.096  0.000    .0281287   .0380317
  t95yr |  .0572119  .0068739    8.323  0.000    .0437377   .0706862
  t99yr |  .0573133  .0075552    7.586  0.000    .0425034   .0721231
    t50 |  .7809212  .0179533   43.497  0.000    .7457291   .8161133
    t90 |  .9004915  .0193289   46.588  0.000    .8626029    .93838
    t95 |  .9693963  .0478048   20.278  0.000    .8756891   1.063104
    t99 |  .9842825  .0524334   18.772  0.000    .8815022   1.087063
inspect | -.0001197  .0057578   -0.021  0.983   -.0114061   .0111667
   cit1 | -.0062065  .0065412   -0.949  0.343   -.0190287   .0066156
   cit2 |  .0292647  .0224178    1.305  0.192   -.0146788   .0732081
 citsvr | -.0052304  .0169768   -0.308  0.758   -.0385085   .0280477
------------------------------------------------------------------
```

Appalachian Underground

```
-> regcode=    1 tchcode=    1
 Source |    SS      df    MS          Number of obs =  14982
---------+------------------------------     F( 12, 14970) = 4330.87
  Model | 10652.3017   12   887.69181       Prob > F    = 0.0000
Residual | 3068.38028 14970 .204968623      R-squared   = 0.7764
---------+------------------------------     Adj R-squared = 0.7762
  Total | 13720.682 14982  .915811107       Root MSE    = .45273

------------------------------------------------------------------
  lnprd |   Coef.    Std. Err.     t     P>|t|    [95% Conf. Interval]
---------+--------------------------------------------------------
  t50yr |  .0149902   .001577    9.505  0.000     .011899   .0180814
  t90yr |  .0433634  .0017448   24.852  0.000    .0399433   .0467835
  t95yr |  .0805023  .0049338   16.317  0.000    .0708315   .0901731
  t99yr |  .0708657  .0055162   12.847  0.000    .0600533   .0816781
    t50 |  .6540993  .0112961   57.905  0.000    .6319576   .6762409
    t90 |  .7459398  .0128166   58.201  0.000    .7208178   .7710618
    t95 |  .3874083  .0354284   10.935  0.000    .3179643   .4568523
    t99 |  .4436843  .0410287   10.814  0.000     .363263   .5241056
inspect |  .0020043  .0006388    3.137  0.002    .0007521   .0032565
   cit1 | -.0050046  .0009544   -5.244  0.000   -.0068753  -.0031338
   cit2 | -.0476781  .0142313   -3.350  0.001   -.0755732   -.019783
 citsvr | -.0111949  .0030161   -3.712  0.000   -.0171069  -.0052829
------------------------------------------------------------------
```

Interior Surface

-> regcode= 2 tchcode= 0

Source	SS	df	MS		
				Number of obs =	1689
				F(12, 1677) =	593.77
Model	2043.72504	12	170.31042	Prob > F	= 0.0000
Residual	481.012579	1677	.286829206	R-squared	= 0.8095
				Adj R-squared =	0.8081
Total	2524.73762	1689	1.49481209	Root MSE	= .53556

lnprd	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
t50yr	.029437	.0056852	5.178	0.000	.0182862	.0405878
t90yr	.058029	.0059597	9.737	0.000	.0463397	.0697183
t95yr	.0528506	.0161808	3.266	0.001	.0211138	.0845873
t99yr	.0502729	.0183588	2.738	0.006	.0142643	.0862815
t50	.8192935	.043422	18.868	0.000	.7341264	.9044606
t90	.9185912	.0479817	19.145	0.000	.8244808	1.012702
t95	1.115809	.1122827	9.937	0.000	.8955799	1.336038
t99	1.133403	.1277723	8.870	0.000	.8827935	1.384013
inspect	.0144409	.0111802	1.292	0.197	-.0074878	.0363696
cit1	-.0342358	.0130746	-2.618	0.009	-.0598801	-.0085915
cit2	.0354174	.0411766	0.860	0.390	-.0453457	.1161804
citsvr	-.1721979	.0355787	-4.840	0.000	-.2419813	-.1024145

Interior Underground

-> regcode= 2 tchcode= 1

Source	SS	df	MS		
				Number of obs =	659
				F(12, 647) =	281.41
Model	530.784234	12	44.2320195	Prob > F	= 0.0000
Residual	101.695978	647	.157180801	R-squared	= 0.8392
				Adj R-squared =	0.8362
Total	632.480212	659	.959757529	Root MSE	= .39646

lnprd	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
t50yr	.0488652	.0064299	7.600	0.000	.0362392	.0614913
t90yr	.0624269	.0071626	8.716	0.000	.0483621	.0764917
t95yr	.0512142	.0202281	2.532	0.012	.0114936	.0909348
t99yr	.0722387	.0233167	3.098	0.002	.026453	.1180243
t50	.5762339	.0481921	11.957	0.000	.481602	.6708657
t90	.7082109	.0640071	11.065	0.000	.5825242	.8338976
t95	.8323976	.156786	5.309	0.000	.5245269	1.140268
t99	.6076384	.1726304	3.520	0.000	.2686548	.9466219
inspect	.0016168	.0014964	1.080	0.280	-.0013216	.0045551
cit1	-.0055718	.0020642	-2.699	0.007	-.0096251	-.0015185
cit2	-.0731726	.0569921	-1.284	0.200	-.1850843	.0387391
citsvr	-.0322685	.009399	-3.433	0.001	-.0507248	-.0138122

Western Surface (non Lignite or PRB)

-> regcode= 3 tchcode= 0

Source	SS	df	MS		
Model	739.333866	12	61.6111555	Number of obs =	289
Residual	63.5316777	277	.229356237	F(12, 277) =	268.63
Total	802.865543	289	2.77808146	Prob > F =	0.0000
				R-squared =	0.9209
				Adj R-squared =	0.9174
				Root MSE =	.47891

lnprd	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
t50yr	.0064525	.0174766	0.369	0.712	-.0279513	.0408563
t90yr	.0215026	.0367522	0.585	0.559	-.0508465	.0938516
t95yr	-.0154538	.0528906	-0.292	0.770	-.1195724	.0886648
t99yr	.0196303	.0405021	0.485	0.628	-.0601007	.0993614
t50	-.3336451	.1266124	-2.635	0.009	-.5828898	-.0844005
t90	-.4019172	.2462388	-1.632	0.104	-.8866543	.0828199
t95	.0228551	.3733118	0.061	0.951	-.7120334	.7577437
t99	1.991454	.2971984	6.701	0.000	1.4064	2.576509
inspect	-.0044621	.0269661	-0.165	0.869	-.0575465	.0486224
cit1	-.0271158	.0288098	-0.941	0.347	-.0838299	.0295982
cit2	.0880903	.103664	0.850	0.396	-.115979	.2921596
citsvr	.0473594	.0804795	0.588	0.557	-.1110698	.2057886

Western Underground

-> regcode= 3 tchcode= 1

Source	SS	df	MS		
Model	525.798151	12	43.8165126	Number of obs =	445
Residual	115.624214	433	.267030517	F(12, 433) =	164.09
Total	641.422365	445	1.44139857	Prob > F =	0.0000
				R-squared =	0.8197
				Adj R-squared =	0.8147
				Root MSE =	.51675

lnprd	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
t50yr	.0755972	.0102588	7.369	0.000	.0554339	.0957605
t90yr	.0947433	.0111574	8.492	0.000	.0728139	.1166727
t95yr	.1097563	.0306283	3.583	0.000	.0495576	.169955
t99yr	.0674747	.0372261	1.813	0.071	-.0056915	.140641
t50	.3856067	.0740216	5.209	0.000	.2401204	.5310931
t90	.8642789	.0862739	10.018	0.000	.6947112	1.033847
t95	1.075977	.2281623	4.716	0.000	.627534	1.524421
t99	1.360171	.2516537	5.405	0.000	.8655559	1.854785
inspect	.0033881	.0035076	0.966	0.335	-.003506	.0102821
cit1	-.0136263	.0042677	-3.193	0.002	-.0220143	-.0052384
cit2	.0229395	.0713513	0.322	0.748	-.1172984	.1631775
citsvr	-.0218609	.0115495	-1.893	0.059	-.044561	.0008392

Lignite Surface

-> regcode= 4 tchcode= 0

Source	SS	df	MS		
				Number of obs =	236
				F(12, 224) =	283.42
Model	942.56908	12	78.5474233	Prob > F =	0.0000
Residual	62.0788663	224	.277137796	R-squared =	0.9382
				Adj R-squared =	0.9349
Total	1004.64795	236	4.25698282	Root MSE =	.52644

lnprd	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
t50yr	.0948554	.0134368	7.059	0.000	.0683766	.1213342
t90yr	.0296364	.0158052	1.875	0.062	-.0015095	.0607823
t95yr	.0887988	.0512233	1.734	0.084	-.0121424	.18974
t99yr	.0234999	.2489979	0.094	0.925	-.4671781	.5141778
t50	1.303498	.1186983	10.982	0.000	1.06959	1.537406
t90	2.230134	.1306226	17.073	0.000	1.972727	2.48754
t95	1.872373	.3599894	5.201	0.000	1.162974	2.581772
t99	1.817747	.7305697	2.488	0.014	.3780785	3.257416
inspect	-.0165707	.0280905	-0.590	0.556	-.0719261	.0387848
cit1	-.0571474	.035195	-1.624	0.106	-.126503	.0122082
cit2	-.0202608	.1330731	-0.152	0.879	-.2824961	.2419746
citsvr	-.0420637	.0610234	-0.689	0.491	-.1623171	.0781897

Powder River Basin Surface

-> regcode= 5 tchcode= 0

Source	SS	df	MS		
				Number of obs =	263
				F(12, 251) =	230.74
Model	2080.50785	12	173.375654	Prob > F =	0.0000
Residual	188.596346	251	.751379866	R-squared =	0.9169
				Adj R-squared =	0.9129
Total	2269.10419	263	8.6277726	Root MSE =	.86682

lnprd	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
t50yr	.009793	.0261111	0.375	0.708	-.0416318	.0612177
t90yr	.0646721	.0230691	2.803	0.005	.0192386	.1101057
t95yr	-.0170591	.0462897	-0.369	0.713	-.1082249	.0741067
t99yr	.0720404	.0423932	1.699	0.090	-.0114513	.155532
t50	.9185917	.2096574	4.381	0.000	.5056798	1.331504
t90	1.101874	.1799525	6.123	0.000	.7474651	1.456284
t95	.9283736	.3443883	2.696	0.007	.2501146	1.606633
t99	.9406568	.3257438	2.888	0.004	.2991174	1.582196
inspect	.1745497	.0847053	2.061	0.040	.007726	.3413735
cit1	.1337555	.0854381	1.566	0.119	-.0345115	.3020225
cit2	.2116184	.2796498	0.757	0.450	-.3391407	.7623775
citsvr	.1218458	.2386405	0.511	0.610	-.3481471	.5918386

. log close

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