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Determinants of Coal Mine Labor Productivity Change

Published: November 1979

Prepared for:

U.S. Department of Energy
Office of Education, Business,
and Labor Affairs
U.S. Department of Labor
Employment and Training Administration
Office of Research and Development

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Oak Ridge Associated Universities
Oak Ridge, Tennessee 37830

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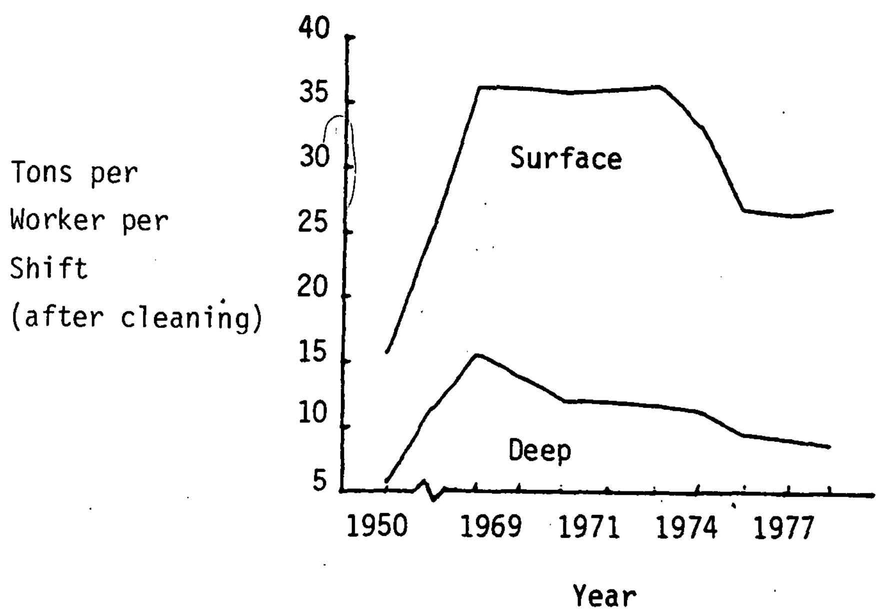
EXECUTIVE SUMMARY

Coal mine labor productivity (tons per miner-shift) has been falling yearly since 1970. Figure 1 details the historical trends in deep and surface mine labor productivity for the period 1950-1977. The decline in labor productivity since 1970 has implications for the coal industry's labor demand, cost of production, and injuries and could hinder the ability of the industry to meet the coal output goals of the National Energy Plan. The purpose of this research study was to identify and measure the causes of labor productivity decline in surface coal mines and deep coal mines. The executive summary provides concise answers to three questions: Why is coal mine labor productivity important? What are the causes of labor productivity decline in deep and surface coal mines? What are the implications of these findings for future coal mine labor productivity?



Source: Department of Interior, Bureau of Mines, *Minerals Yearbook* (Washington, D.C.: Government Printing Office, various years).

Figure 1. Deep and Surface Coal Mine Labor Productivity, 1950-1977.

WHY IS COAL MINE LABOR PRODUCTIVITY IMPORTANT?

Coal mine labor productivity is important for three reasons: (1) it affects the cost of coal production, (2) it affects coal industry labor demand, and (3) it affects injuries and injury rates in coal mining.

Declining productivity increases the cost of coal production because more workers are required to produce a given amount of coal. This increased cost of production requires a higher selling price for coal to maintain production. A higher selling price can limit coal's competitive position relative to other fuels, hindering expansion of the industry to the levels consistent with national energy policy.

Labor productivity is the link between output levels and employment requirements. The decline in labor productivity in the 1970s has increased substantially the number of workers required to produce a given amount of coal in spite of a shift to more productive surface mining in the western region. In 1969, the national average labor required to produce 100,000 tons a day was 5000 miners; in 1977, the average had risen to 6800 miners. From 1969 to 1977, deep mine production actually fell from 347 million tons to 272 million tons annually while the deep mine work force grew from 99,000 to 146,000. During the same period, surface output almost doubled from 213 to 416 million tons annually while the work force grew from 25,000 to 69,000. The increased labor requirements have made it more difficult to recruit and train workers to meet the industry's growth needs; the increased labor requirements have also increased the economic impact that an expanding coal industry has on the economy and on communities where coal-related growth is occurring. Because of uncertainty about the future of productivity trends, forecasting future industry labor requirements is difficult.

Declining productivity also affects injuries and injury rates by increasing labor requirements. Simply stated, more workers are exposed to the probability of an accident for each ton of coal produced, thereby increasing the total number of injuries society must bear to produce a given amount of coal.

WHAT ARE THE CAUSES OF LABOR PRODUCTIVITY DECLINE IN DEEP AND SURFACE COAL MINES?

The period of declining productivity in coal mining coincides with two major changes in the coal industry's environment: (1) change from a largely unregulated industry to a highly regulated industry (the Coal Mine Health and Safety Act of 1969; implementation of many state surface mine reclamation laws, etc.) and (2) change from a declining, marginal profits industry to a growing, profitable industry (increasing coal prices and demand in the 1970s). The introduction of regulation altered the way coal was mined in both deep and surface mines; labor services now had to be expended to ensure a safe working environment and to reclaim surface-mined land. The changing coal market conditions resulted in a rapidly increasing work force, entrance of new mines, changes in the regional and geologic characteristics of production, and changes in the amount of coal produced by different mining techniques. Work stoppages also increased during the 1970s. All of these factors have been cited as possible causes of productivity decline.

The results of this study indicate that the majority of the decline in deep mine labor productivity is a result of the Coal Mine Health and Safety Act of 1969 (CMHSA), work stoppages, and the increase in the demand for coal and coal prices. The CMHSA accounts for the majority of deep mine labor productivity decline from 1970 to 1973, with its strongest influence occurring in 1973 when the mine inspection work force began to level off and mine inspections reached an all time high of more than 70,000. Evidence suggests that after 1973 deep mine labor productivity decline was less related to the CMHSA. The evidence also suggests that enforcement of the CMHSA (inspections, penalties, etc.) as well as the actions mines take to comply with the CMHSA provisions have depressed productivity. In addition, the CMHSA appears to have had a greater productivity impact upon continuous mining methods than on other methods (conventional, longwall, etc.).

The coal strikes of 1971 and 1974 reduced average labor productivity in deep mining in those years. This is most likely due to the disruptive effect that strikes have on the work process and also from the demand surges that precede and follow strikes to build up and replenish industrial and utility coal stockpiles. Wildcat work stoppages, which act as a barometer of the industry's industrial relations, were also found to be negatively related to productivity. Wildcat strikes played a significant role in reducing 1975 deep mine labor productivity.

The results of this study indicate that there is a very strong relationship between coal prices and deep mine labor productivity. All other things being equal, as coal prices increase, labor productivity falls. One possible reason for this relationship is that coal reserves, mines or mining techniques that have lower productivity and are unprofitable at low prices become profitable as prices rise. Another possible reason is that when prices and profits are high, management and workers in the more productive mines need not attain maximum mine efficiency for their mine to stay in business. The high prices of the 1970s may have allowed some inefficiency to develop. General comments in industry trade literature concerning poorer worker attitudes, lack of a work ethic, and "sloppy management" all fit this explanation. The steady increase in coal prices during the 1970-1974 period explains a small portion of deep mine labor productivity decline during that period. In 1975, prices increased dramatically and the negative impact was very strong.

In surface mines, the negative relationship between coal prices and productivity was also strong. However, the contribution of rising coal prices to surface mine labor productivity decline was found to be significant only in the Appalachian region in 1975; prices had a minimal effect in non-Appalachian states. This may be due to the large size of western surface mines that must sell under long-term contracts to lower risks sufficiently to justify the large investment required to cover capital and rail transportation costs. Western mines can not respond to short-term price fluctuations as quickly as the smaller Appalachian surface mines.

The rise in coal prices also encouraged the entrance of many small surface mine operators after 1973. Scale economies exist in surface mines; larger mines have higher average labor productivity than smaller mines. In both the Appalachian and non-Appalachian regions, the entrance of small surface mine producers after 1973 contributed to labor productivity decline.

In addition to prices and the entrance of small mines, surface mine labor productivity was depressed by the implementation of state reclamation laws in both Appalachian and non-Appalachian states. These laws were implemented throughout the 1960s and 1970s, so their effect was cumulative as more states passed laws. The productivity impact of these laws appeared stronger in the non-Appalachian states.

A major conclusion of the study is that a portion of the high labor productivity of the 1960s was possible because some of the costs of coal mining—worker injuries, black lung disability, and environmental damage—were not being paid for by the coal industry and coal consumers. Once these costs were forced internally on the mine operators by legislation, productivity fell and the cost of production increased.

WHAT ARE THE IMPLICATIONS OF THESE FINDINGS FOR FUTURE COAL MINE LABOR PRODUCTIVITY?

Given the strong trade-offs that exist between labor productivity on the one hand and worker health and safety and environmental protection on the other hand, it is doubtful that labor productivity will return to 1969 levels within present legislative and technological bounds. It is also evident that a reasoned comparison between 1969 coal mine labor productivity and coal mine labor productivity in the 1970s is impossible. The 1969 industry had been fighting for its survival for 20 years, and, like U.S. agriculture in the twentieth century, the coal industry had pared down producers to efficient, concentrated, and mechanized units. It had also reduced the work force to a small number who were required to accept the risks associated with mining coal, and management had joined in concert with the union to prevent work stoppages and health and safety legislation.

Given this situation, the portion of labor productivity lost due to the CMHSA and reclamation laws is permanent and can be regained only by improved technology or changes in the laws. In deep mining, the mining research and development (MRD) activity of the Department of Energy had $52.8 million appropriated in fiscal 1979 for research into mine planning, production mining (e.g., automated continuous miners, combination miner/bolters, continuous haulage), transport systems, and testing facilities for new equipment. The fiscal 1979 MRD surface mining appropriation of $12.6 million is being spent to develop a systematic approach for removing overburden, mining, and reclaiming the land and to develop new equipment specifically for reclamation.

There is evidence that part of the productivity decline caused by the CMHSA occurred through enforcement procedures (inspections, penalties, withdrawal orders, etc.) as opposed to compliance. There is also evidence that some provisions of the CMHSA disrupted productivity with little contribution to safety. Research into the provisions of the act could possibly permit adjustment to reduce some of the productivity impacts with no decline in health and safety benefits.

Other portions of the labor productivity decline are related to the demand for coal—the price-productivity relationship and work stoppages. Abrupt short-term swings in coal demand—caused by such factors as surges in demand prior to or after strikes to build stockpiles or in reaction to changing world energy prices—cause rapid coal price increases, large short-term profits, and declining labor productivity. The competitive nature of the coal industry and vast resources available for exploitation imply that in the long run coal prices should approach a cost of production level plus a reasonable return on investments. This long-term posture would result in increasing efficiency (productivity) and falling real coal prices (compared with 1975). In addition, both surface and deep mine production are shifting toward the more geologically favorable western region. The unknowns that could affect this long-term posture include work stoppages, the impact of the 1977 Surface Mine Control and Reclamation Act, and oil cartel actions that disrupt the world energy markets.

The regional distribution of future coal production and productivity also have implications on future work force requirements. The western region work force will increase from less than 10,000 miners in 1975 to over 75,000 in 1985. Although growth in Appalachia mining is not expected to be as great, workers needed to replace experienced workers who retire, die, or switch industries will be greater than 25,000 per year in the 1980s. The 1977 Mine Safety and Health Act requires safety training for all new workers and workers changing occupations or mines as well as annual refresher training. When combined with the certification requirements of foremen, fire bosses, electricians, and mechanics, these training needs will present a challenge to the firms and training institutions to meet the labor needs of a growing coal industry.

PREFACE

This report represents part of the continuing joint effort of the U.S. Department of Energy and the U.S. Department of Labor to improve the Federal Government's ability to evaluate and forecast the labor requirements of domestic energy development. Identifying productivity change in coal mining is important both in terms of forecasting the number of jobs associated with the continued and enhanced recovery of coal resources and in recognizing the potential barriers to expanded coal production. The analysis presented herein was prepared by the Manpower Research Program at Oak Ridge Associated Universities, and was co-funded by the Office of Education, Business and Labor Affairs, U.S. Department of Energy, and the Office of Research and Development, Employment and Training Administration, U.S. Department of Labor. Michael Tannen, U. S. Department of Energy, and Thomas Joyce, U. S. Department of Labor were responsible for overall coordination of the project.

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The author also thanks the Consolidation Coal Company and Ron Smith for the tour of the Matthews Mine and the Tennessee Valley Authority for the tour of their Massengale Mountain Mine. The author also acknowledges the excellent work of Diane Hefling, Jane McPeters, and Duveen Shirley in the preparation of the manuscript.

PART I: ISSUES AND RESEARCH RESULTS

Chapter 1 describes the problem of declining labor productivity and the adverse effects it has on the coal mining industry. Literature relevant to the topic is discussed. Chapter 2 presents the research findings in narrative form. The implications of these findings on coal industry employment, training, government policy, and future research are discussed in Chapter 3.

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CHAPTER 1 - INTRODUCTION AND LITERATURE REVIEW

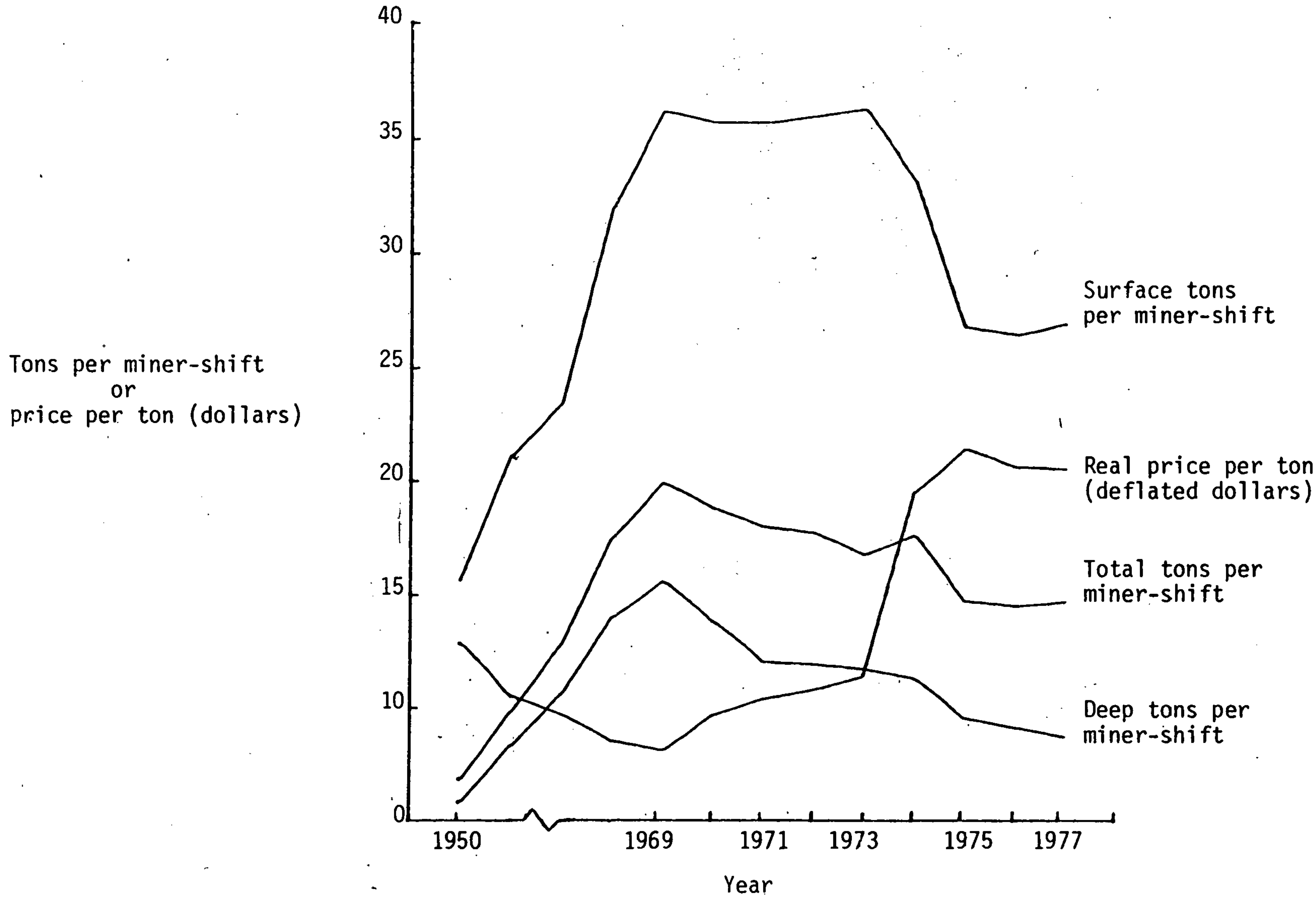
STATEMENT OF THE PROBLEM

During the 1940s, the market for coal was very strong, and annual U.S. output was well over 600 million tons.[1] At that time, however, the coal industry was in danger of losing primary markets such as residential heating and railroads. These markets had been eroded by the availability of cheap, imported fuels and by the substitution of competing energy sources. To maintain a competitive relationship with other basic fuels, the United Mine Workers of America (UMWA) and management restructured their industrial organization to create more efficient and concentrated production units, improved mechanization to increase labor productivity and to lower unit costs, and improved industrial relations to ensure uninterrupted production.[2] The results of these efforts were spectacular: Productivity increased from an average of 6.77 tons per miner-shift in 1950 to 19.90 tons per miner-shift in 1969, an increase of over 190 percent. The average price per ton in 1947 was $4.16; in 1969 the figure was $4.99.[3]

From 1969 through 1977, mine labor productivity declined. Figure 1-1 shows mine labor productivity and selling price per ton for 1950 through 1977. From 1969 through 1977, total productivity declined by one-third and the average price per ton increased fourfold. These trends are particularly distressing given the role coal is expected to play in our energy future: President Carter has called for an increase from 688 million tons in 1977 to 1.2 billion tons in 1985.[4]

The causes of the dramatic productivity decline since 1969 are the source of much speculation and concern in the coal industry. The most popular explanation is the Coal Mine Health and Safety Act of 1969 (CMHSA), and there is evidence that this blame is more than *post hoc, ergo propter hoc* theorizing. However, the post-1969 era has had considerable economic and institutional change—growth in employment after two decades of decline, tripled output prices, labor problems, and growth in the number of active mines, to name a few. While the CMHSA has received the most attention, a variety of other causes could have contributed to the decline.

It is somewhat paradoxical that the coal mining industry, after growth in labor productivity for nearly its entire history, should be beset by rapidly declining productivity while on the verge of expanding production



Source: Department of Interior, Bureau of Mines, *Minerals Yearbook* (Washington, D.C.: Government Printing Office, various years).

Figure 1-1. Coal Mine Labor Productivity and Real Output Price Trends, 1950-1977 to unprecendented levels. The problem of declining productivity is critical to the industry's labor demand, cost of production, and industrial health and safety.

IMPLICATIONS OF DECLINING PRODUCTIVITY

The shift in our energy consumption mix towards coal is an important facet of President Carter's energy plan. The manpower required to produce this coal tonnage (1.2 billion tons in 1985) has been the subject of several studies.[5] The projection methodology employed in these studies is the "fixed coefficient" approach, i.e., there is a unique level of labor input required to produce a given level of output. The relationship between labor input and production output is expressed in terms of the average productivity of labor.

Given a level of output, projected manpower requirements become very sensitive to changes in average labor productivity. For this reason, the average labor productivity has been called the "Achilles' heel" of manpower forecasting.[6] Given the sudden reversal of productivity trends after 1969, uncertainty now surrounds them. The government's Project Independence scenario indicates an increase in total productivity to 24 tons per miner-shift in 1985.[7] The Kramer report projects 1985 levels of 41.4 tons per miner-shift for surface coal and 11.5 tons per miner-shift for underground coal, a total productivity level of 18 tons per miner-shift.[8] If we accept the Kramer productivity estimates and the Project Independence assumptions concerning the surface/underground mix, the 1985 total productivity level is 30 tons per miner-shift. A pessimistic assumption would be an extrapolation of the 1969-1977 negative trend (-3.7 percent annual change) through 1985, resulting in only 10.9 tons per miner-shift.

Table 1-1 examines 1985 manpower implications of the productivity assumptions discussed above. At present, the Energy Information Administration 1985 estimate of 1.033 billion tons appears the most realistic.[9] Given the different assumptions of 1985 productivity, estimates range from 143,000 miners to 395,000 miners needed to produce this tonnage. With a 1977 work force of 214,777,[10] annual work force growth rates to 1985 range from -5.0 percent (due to productivity increasing faster than output) to +7.9 percent a year.[11] It should be noted that the range in manpower requirements in Table 1-1 is greater in the columns (different productivity assumptions) than in the rows (different output assumptions).

Table 1-1. Manpower Requirements for Three Projected Output Levels, 1985[a]

Productivity (Tons/Shift)	1.033 Billion Tons[b]	1.100 Billion Tons[c]	1.230 Billion Tons[d]
30	143,000	152,800	170,800
24	179,000	191,000	213,500
18	239,000	254,600	284,700
13.6	316,000	337,000	376,800
10.9	395,000	552,200	617,500

[a]Assuming 240 shifts per miner per year.
[b]Energy Information Administration report.
[c]Kramer study.
[d]President Carter's goal.

Because a productivity decline increases labor requirements, production bottlenecks, labor misallocations, and shortages are more likely. At a macro (economy-wide) level, these adverse effects can lead to structural unemployment and price inflation. They also make President Carter's 1985 coal output goal (1.2 billion tons) more difficult to achieve. Finally, increased employment impacts from decreasing productivity are extremely important at the community level where the social costs of resource development are high.[12]

Increasing the miner-shift input requirements to achieve a given output goal also increases the exposure of workers to the health and safety problems of the coal industry.[13] Table 1-2 details injuries and injury rates for U.S. deep mining for the period 1960-1976. For both disabling injuries and fatalities, two frequency measures are used: The rate per 100,000 miner-shifts is simply the number of injuries one would expect per every 100,000 miner-shifts of operation; the rate per million tons is a function of both the rate per time period and average labor productivity. The latter rate measures both the probability of a miner getting injured on a given day during the year plus the cumulative total of these days needed to produce a given amount of coal (average labor productivity). Thus, one can have no change in the injury rate per 100,000 miner-shifts, but because of an increase in average productivity, worker exposure and injuries per million tons will decline.

Table 1-2. Deep Mine Injuries and Injury Rates, 1960-1976

	Disabling Injuries			Fatalities		
Year	Total	Per 100,000 Miner-Shift	Per Million Tons	Total	Per 100,000 Miner-Shift	Per Million Tons
1960	8590	32.15	30.15	274	1.03	0.96
1961	8117	33.96	29.76	242	1.01	0.87
1962	8034	34.13	28.56	226	0.96	0.80
1963	7968	33.67	26.36	218	0.92	0.72
1964	7905	33.77	24.56	188	0.80	0.58
1965	8166	34.45	25.45	215	0.91	0.65
1966	7659	33.10	22.62	189	0.82	0.56
1967	7584	32.68	21.72	166	0.72	0.48
1968	7391	33.09	21.48	267	1.19	0.78
1969	7785	35.01	22.43	142	0.64	0.41
1970	8943	36.22	26.40	205	0.83	0.61
1971	8895	38.75	32.24	140	0.61	0.51
1972	9872	38.74	32.68	121	0.47	0.40
1973	8843	34.46	29.54	98	0.38	0.33
1974	6355	25.96	22.92	89	0.36	0.32
1975	8236	26.82	28.13	99	0.32	0.34
1976	8376	25.85	28.40	104	0.32	0.35

Source: U.S. Department of Labor, Mine Safety and Health Administration, mimeographed tables (Health and Safety Analysis Center; Denver, Colorado).

This can be seen by comparing disabling injury rates in 1960 and 1969. If 100,000 workers worked 1 day in 1960, one would expect about 32 disabling injuries. In 1969, these 100,000 workers would experience about 35 disabling injuries per day, three more than in 1960. However, because these 100,000 workers produced 1.06 million tons in 1960 compared with 1.56 million tons in 1969, the number of injuries per million tons fell from about 30 in 1960 to 22 in 1969.

The post-1969 period has seen an increase in disabling injuries per million tons due to falling productivity. Although the disabling rate per 100,000 miner-shifts has fallen from 35 in 1969 to almost 26 in 1976, the rate per million tons has increased from 22 to 28. Even though the probability of a single miner's being injured during his work life has decreased, the total number of disabling injuries that society must bear to meet a given coal output goal has increased. Fatality rates show the same effect: The number of fatalities per 100,000 miner-shifts has been cut in half from 1969 to 1976 (0.64 to 0.32) while the rate per million tons has fallen only 15 percent (0.41 to 0.35).

Declining productivity also has implications related to unit labor cost, which is a function of labor compensation and labor productivity. If wages and productivity increase at the same rate, unit labor cost remains constant. Productivity, then, becomes an important consideration in the cost of coal production.

Table 1-3 focuses on unit labor costs for the period 1950-1975.[14] This table is based upon wage costs only and does not include nonwage costs of labor such as insurance, training costs, and the black lung fund. From 1950 through 1969, productivity increased faster than wage payments, lowering unit labor costs. In the post-1969 period, wage payments continued to increase; however, tons per worker per year declined. This resulted in an increase in unit labor cost from $1.91 in 1969 to $4.45 in 1975. Selling price per ton during this period was increasing faster than labor costs; thus, in 1975 unit labor costs accounted for only 23.8 percent of total selling price.[15]

A study by the Council on Wage and Price Stability pointed out that average selling price per ton rose faster in 1974 and 1975 than did labor costs. The Council concluded, "Unless all other costs have grown more quickly than labor costs (which is doubtful), the average selling price has outpaced total costs."[16] Profit per ton, then, was increasing during this 2-year period.

Wage and nonwage labor costs constitute a substantial portion of the production cost. Bureau of Mines reports estimated in 1974 that labor costs constituted approximately 50 percent of production cost in underground mines

Table 1-3. Unit Labor Costs, 1950-1975

Year	Net Tons per Worker per Year	Average Weekly Wage	Unit Labor Cost	Selling Price per Ton	Percentage Labor Cost
1950	1239	$ 67.46	$2.83	$ 4.84	58.5%
1955	2064	92.13	2.32	4.50	51.6
1960	2453	112.41	2.38	4.69	50.7
1965	3829	140.26	1.90	4.44	42.8
1969	4501	165.79	1.91	4.99	38.3
1970	4302	183.96	2.22	6.26	35.5
1971	3791	194.00	2.66	7.07	37.6
1972	3989	215.83	2.81	7.66	36.7
1973	3745	226.86	3.15	8.53	36.9
1974	3848	236.84	3.20	15.75	20.3
1975	3288	281.97	4.45	18.75	23.8

Source: Bureau of Mines, *Minerals Yearbook* (Washington, D.C.: Government Printing Office), various years.

and from 39 to 49 percent in surface mines, depending upon mine characteristics.[17] If unit labor costs increased 50 percent due to the combined effect of further productivity declines and wage increases from a new union contract, total production cost would increase 25 percent, *ceteris paribus*. These cost increases would be reflected in the long-term selling price of coal.

The selling price of coal is extremely important. A lower relative price of coal allows it to compete better with other energy sources, causing a greater substitution toward coal. Because the output of coal is constrained more by demand than production capacity in the long run, the price elasticity of substitution and relative price of coal become important considerations in meeting President Carter's coal production goal. For these reasons, productivity becomes an important consideration in meeting future projected levels of coal tonnage.

The declining trend in coal industry labor productivity has been a source of concern for both industry and government. To date, most efforts to stabilize and reverse the productivity decline have been concentrated in the areas of miner training and coal mining technology.[18] Partially due to the uncertainty of the causes of the decline, efforts to correct the problem have been general in nature and of limited effectiveness. The obvious first step needed to solve the problem is to determine the causes of productivity decline.

PREVIOUS RESEARCH ON COAL MINE LABOR PRODUCTIVITY

Although the topic of declining productivity has received considerable attention in the literature, there is a paucity of empirical work examining the problem. Those studies that do deal with the problem empirically are limited by time, level of data aggregation, or methodology employed.

A study by Baker and another by Walton and Kauffman provide a review of hypotheses explaining productivity decline but do little empirical research.[19] Both reports are essentially "issue papers" that define the problem and review the literature. Malhotra uses tabular and bivariate analyses to examine sources of variation among Illinois mines.[20] This approach does not allow the researcher to break out the relative contribution of each causal variable and does not examine institutional and labor-related explanations for productivity decline. However, Malhotra's paper offers interesting insights into the relationship between productivity and a variety of mine characteristics.

Neumann and Nelson focus primarily on the impact of the 1969 Coal Mine Health and Safety Act on productivity and safety, although they also examine the influence of production technique (continuous versus noncontinuous) and mine size.[21] Using a rather novel approach of a firm-level model of safety production, they find no statistical evidence that the CMHSA has affected either productivity or safety. This conclusion is based upon regression analysis of national time series data for the years 1950-1976 and, by the authors' own admission, is limited by this level of aggregation.

Louise and Edward Julian of Pennsylvania State University address the productivity problem in two unpublished reports of work in progress.[22] L. Julian's paper examines national time series data utilizing regression analysis to uncover breaks in trends and determinants of accident rates. L. Julian concludes that the CMHSA (1) has reduced accidents and accident rates and (2) has lowered productivity, although there is little direct evidence supporting this second point. E. Julian's paper is based upon a regression analysis of Illinois data for deep mines. Due to autocorrelation and omission of certain variables from the model, his conclusion that the CMHSA has reduced productivity is tenuous. Both of these papers provide an interesting first look at the problem.

A thesis by Charles Fettig, "Impacts on Output per Man-Day, Costs, and Price of the Coal Mine Health and Safety Act of 1969," was completed in August 1978 for the Pennsylvania State University department of mineral economics. Based upon assumptions involving the staffing changes per mining section brought about by the act, Fettig concludes that "productivity is 45 percent lower than would have been the case in the absence of the act."[23] However, there is no direct measure of this decrease; it is based upon the assumption that face crews increased from 20 persons (9 face persons and 11 backup) to 30 persons (10 face persons and 20 backup).[24]

Gordon et al. estimate the impact of the act through a sensitivity analysis using different staffing assumptions. Based upon the characteristics of 326 deep mine sections in Pennsylvania, West Virginia, Virginia, Ohio, and eastern Kentucky, they estimate that work time lost from methane checks, mechanical delays, brattice cloth advances, etc., required by the CMHSA increased delays per shift and reduced output per section from 12 to 23 percent, depending upon mining conditions.[25] Gordon et al. also estimate the impact of the CMHSA upon manpower (increasing section crews from 20 workers to 30) and costs (an additional $700-800 million per year in Appalachia).[26] The purpose of this paper was to measure the impacts of the CMHSA; no attempt was made to quantify other factors that could have affected productivity.

In the Office of Technology Assessment report, six reasons for declining productivity are discussed: (1) mining technology, responsible for productivity growth in the 1960s, reached a plateau in 1969; (2) hundreds of small, inefficient mines entered the market in response to high prices; (3) coal cleaning increased to meet clean air laws; (4) the labor force structure changed; (5) disabling injuries increased and disrupted production; and (6) extensive legislation in the past decade.[27] However, little empirical support for these reasons is given.

In a series of three articles, John Straton assesses the effects of the CMHSA, worker skill, management relations, and mine conditions upon national cost and productivity in deep mines.[28] Straton's analysis is based upon surveys of mine managers who were queried about the influence of various factors upon productivity. The author concludes that the CMHSA increased costs and lowered productivity, although no firm causality is established. The study results, however, leave little doubt that the operators surveyed believe the CMHSA to be the major reason for productivity decline.

Several other studies examine the contributing factors to coal mine productivity variation, although none of these specifically addresses the problem of declining productivity.[29] (In addition, there is a large body of speculative or descriptive literature that examines the problem. See the annotated bibliography in Appendix A.)

Clearly there is a gap in the existing literature examining this problem, and additional research is needed. The work that has been completed suffers from the omission of relevant variables, too limited a time period examined, or data-related problems. The conclusions of several of the studies are contradictory. However, the existing literature is rich in testable hypotheses that are used to develop a conceptual model of coal mine labor productivity.

REPORT TO THE PRESIDENT'S COMMISSION ON COAL

Following the UMWA strike in 1977-1978, President Carter established the President's Commission on Coal to "review the state of the nation's coal industry" in May 1978.[30] As part of this review, the coal commission investigated the problem of declining coal industry productivity. Because research on this topic was under way at Oak Ridge Associated Universities (ORAU), the President's Commission on Coal contracted ORAU to (1) run a 1-day seminar on coal mine productivity, bringing most of the knowledgeable people on the topic together to discuss their research results and views, and (2) develop a report reviewing the most recent research findings on the topic in addition to investigating several areas requested by the coal commission. Both of these tasks are reported in the Oak Ridge Associated Universities report, *Coal Mine Labor Productivity: Review of Issues and Evidence.*[31]

Those attending the 1-day conference included researchers from trade organizations, unions, government, the academic sector, coal companies, and research institutions. The general feeling at the conference was that the CMHSA (for deep mines) and reclamation laws (for surface mines) had been the major causes of decline in the industry.[32] Other problems the attendees judged to be important included the 1974 wage agreement and general work force problems—attitudes, motivation, communication, and union/management relations.

In addition, ORAU examined a number of specific points that were raised during the 1-day conference. One point was that enforcement of the CMHSA, rather than compliance, had caused productivity decline. To test this hypothesis, ORAU examined the experiences of states with restrictive mining laws prior to the CMHSA and compared their post-CMHSA experience to states with less restrictive laws. No difference was found. The experience of mining companies that had progressive safety policies prior to the CMHSA was compared with the experience of other mines after the implementation of the act; again there was no difference. Finally, based on "scores" given by the Mine Safety and Health Administration on the degree of compliance of individual mines, there was no difference in productivity for mines in a given county that were either "compliers" or "noncompliers."[33]

It has also been argued that unionized mines were less productive and lost more productivity during the 1970s than other mines for two reasons: (1) unions pressed for strict enforcement of the CMHSA provisions, and (2) the union/management relationship changed from a cooperative one in the 1960s to an adversary one in the 1970s.[34] Despite empirical problems in comparing union to nonunion mines, Class 4 deep mines (mines with annual output between 50,000 and 100,00 tons) in Pike County, Kentucky, were segregated into UMWA and nonunion mines. There was no statistically significant difference in tons per miner-shift, output, days active, or employment for the period 1973-1976.[35] This result contradicts a survey of mine managers' attitudes in 1977 in which the 44 managers surveyed said they believed productivity was greater in nonunion mines.[36]

Another area examined was that of supervisor inexperience and communication problems between first-line supervisors and miners. Some supporting evidence was found. In Ohio, for instance, the number of supervisors increased over 140 percent from 1969 to 1976. Given the 1967 Ohio coal mine work force of 4000, this amounts to promoting one of every three production workers. Further evidence of manpower shortages was found in the mine responses to the annual Department of Energy Survey of Mines. For mines experiencing production shortfalls in the years 1975-1977, 82 percent reported the first or second most important cause was labor-related.[37]

In addition to the above, the coal commission report reviews the results of the Oak Ridge Associated Universities work that is reported here. The report also contains the conference agenda, list of those attending, and an abstract of the 1-day seminar sponsored by the President's Commission on Coal.

RESEARCH OBJECTIVE

The major objective of this research is to develop empirical evidence of the causes of decline in coal mine labor productivity that will allow policymakers to make useful manpower forecasts and to focus efforts on reversing or ameliorating these downward trends in a cost effective manner. More exactly, this research is concerned with sorting out and weighing the contribution of economic and institutional factors to coal mine labor productivity change.

The results presented here build upon earlier work published by Oak Ridge Associated Universities as progress reports of this project in addition to previously unpublished results.[38]

NOTES

[1]National Coal Association, *Coal Facts 1974-1975* (Washington, D.C.: National Coal Association, 1975), p. 52.

[2]John P. David, "Earnings, Health, Safety, and Welfare of Bituminous Coal Miners since the Encouragement of Mechanization" (unpublished Ph.D. dissertation, West Virginia University, 1972), p. 291.

[3]National Coal Association, *Coal Facts,* p. 52.

[4]Executive Office of the President, Energy Policy and Planning, *The National Energy Plan* (Washington, D.C.: Government Printing Office, 1977), pp. 94-95.

[5]See Kramer Associates, *Determination of Labor Management Requirements in the Bituminous Coal Industry To Reach the Goals of Project Independence* (Springfield, Virginia: NTIS, 1975); Elchanan Cohn et al., *The Bituminous Coal Industry: A Forecast* (University Park; Pennsylvania State University, 1975); Bernard S. Freeman, *Manpower for Coal Mining Supply-Demand-Training* (Washington, D.C.: Government Printing Office, 1977); and Federal Energy Administration, *Project Independence Blueprint: Final Labor Report* (Washington, D.C.: Government Printing Office, 1974).

[6]Mark Blaug and Bashir Ahamad, ed., *The Practice of Manpower Forecasting* (New York: Elsevier Scientific Publishing Co., 1973), p.73.

[7]Federal Energy Administration, *Final Labor Report,* pp. 48-49.

[8]Kramer Associates, *Determination of Labor,* pp. 17-22, 25-29.

[9]Department of Energy, Energy Information Administration, *Annual Report to Congress* (Washington, D.C.: Government Printing Office, 1977).

[10]McGraw-Hill, Inc., *1978 Keystone Coal Industry Manual* (New York: McGraw-Hill, 1978), p. 658.

[11]From 1960 to 1970, coal tonnage increased from 415.5 to 602.9 million tons annually, a compound growth rate of 3.8 percent. However, productivity was increasing 5.8 percent annually, which resulted in an employment decline. See National Coal Association, *Coal Facts,* pp. 52-53.

[12]See Joe G. Baker, *Labor Allocation in Western Energy Development,* Human Resource Institute Monograph No. 5 (Salt Lake City: University of Utah, 1978), pp. 111-12.

[13]It has been argued that productivity and accident rates are related, so this statement may not be as straightforward as it seems. See "Productivity — and the UMWA," *Coal Age,* July 1975, p. 98.

[14]Unit labor costs are calculated using Bureau of Labor Statistics methods as follows:

$$\frac{\text{Wages/Year/Miner}}{\text{Tons/Year/Miner}}$$

[15]Selling price includes the average f.o.b. mine selling price of all operations with annual production of 1000 tons or more. Included in this figure is the average selling price of coal sold on the open market ($15.86 in 1974) and coal not sold on the open market as estimated by the mine ($19.36 in 1974).

[16]Council on Wage and Price Stability, Executive Office of the President, *A Study of Coal Prices* (Washington, D.C.: Government Printing Office, 1976), p. 38.

[17]See Sidney Katell et al., "Basic Estimated Capital Investment and Operating Costs for Coal Strip Mines," *Bureau of Mines Information Circular 8661* (Washington, D.C.: Government Printing Office, 1974), pp. 10, 19, and 29; idem, "Basic Estimated Capital Investment and Operating Costs for Underground Bituminous Coal Mines," *Bureau of Mines Information Circular No. 8682* (Washington, D.C.: Government Printing Office, 1975), pp. 12, 21, and 30.

[18]See, for example, Bureau of Mines, *Mining Technology Research* (Springfield, Virginia: NTIS, 1975); and Joseph Brennan, "Productivity—and the BCOA," *Coal Age,* July 1976, pp. 96-97.

[19]Joe G. Baker, *Coal Mine Labor Productivity: The Problem, Policy Implications, and Literature Review* (Oak Ridge, Tennessee: Oak Ridge Associated Universities, 1978); Daniel R. Walton and Peter W. Kauffman, *Preliminary Analysis of the Probable Causes of Decreased Coal Mining Productivity* (Reston, Virginia: Management Engineers, Inc., 1977).

[20]Ramesh Malhotra, "Factors Responsible for Variation in Productivity in Illinois Coal Mines," *Illinois Mineral Note 60* (Urbana: Illinois State Geological Survey, 1975).

[21]George R. Neumann and Jon P. Nelson, "Regulation and Safety: The Effects of Coal Mine Health and Safety Act of 1969," a revision of a paper prepared for the Department of Labor Conference, "Evaluating the Effects of the Occupational Health and Safety Program" (Annapolis, Maryland, March 18-19, 1975). Paper revised June 1978.

[22]Louise Julian, "Output, Productivity, and Accidents and Fatalities under the Coal Mine Health and Safety Act," mimeographed (University Park: Pennsylvania State University, n.d.); Edward Julian, "Effect of the Coal Mine Health and Safety Act of 1969 on Productivity in Illinois Underground Coal Mines," mimeographed (University Park: Pennsylvania State University, n.d.).

[23]Charles Fettig, "Impacts on Output per Man-Day, Costs, and Price of the Coal Mine Health and Safety Act of 1969," (unpublished M.S. thesis, Pennsylvania State University, 1978), p. ii.

[24]Ibid, p. 36.

[25]Richard Gordon et al., "Simulating the Effects of the Coal Mine Health and Safety Act," mimeographed (University Park: Pennsylvania State University, n.d.), p. 4.

[26]Ibid, pp. 4, and 11.

[27]Congress of the United States, Office of Technology Assessment, *The Direct Use of Coal* (Washington, D.C.: Government Printing Office, 1979), pp. 149-55.

[28]John W. Straton, "Effects of Federal Mine Safety Legislation on Production, Productivity, and Costs," *Mining Congress Journal* 58(7):19-23; idem, "1970-1974—A Period of Adverse Changes in Productivity and Costs at Underground Bituminous Coal Mines," *Mining Congress Journal* 61(10):34-39; idem, "Improving Coal Mine Productivity," *Mining Congress Journal* 63(7):19-23.

[29]Elchanan Cohn et al., *The Bituminous Coal Industry;* Martin B. Zimmerman, "Modeling Depletion in a Mineral Industry: The Case of Coal," *The Bell Journal of Economics* 8(1):41-65; C. L. Christensen and W. H. Andrews, "Physical Environment, Productivity, and Injuries in Underground Coal Mines," *Journal of Economics and Business* 26(3):182-90; and B. S. Maddala, "Production and Technological Change in the U.S. Coal Industry, 1919-54," *Journal of Political Economy* 75(2):352-65.

[30]The White House, Press Release, Executive Order 12062 (President's Commission on the Coal Industry, May 26, 1978).

[31]Joe G. Baker and Robert J. Gaston, *Coal Mine Labor Productivity: Review of Issues and Evidence—A Report to the President's Commission on Coal* (Oak Ridge, Tennessee: Oak Ridge Associated Universities, 1979).

[32]Ibid, p. 17.

[33]Ibid, pp. 5-6.

[34]At UMWA mines, a safety committee composed of miners has the power to inspect the mine, consult operators, and withdraw workers if there exists "imminent danger." In addition, an individual miner can refuse work in "abnormally dangerous" conditions.

[35]Joe G. Baker and Robert J. Gaston, *A Report to the President's Commission on Coal,* pp. 7-9.

[36]See Richard G. Hollis, "Manager's Attitudes: Union vs. Nonunion," *Coal Mining and Processing,* May 1979, pp. 62-66.

[37]Joe G. Baker and Robert J. Gaston, *A Report to the President's Commission on Coal,* pp. 9-10.

[38]Joe G. Baker and Robert J. Gaston, *A Report to the President's Commission on Coal,* and Joe G. Baker, *Determinants of Coal Mine Labor Productivity Change: A Progress Report* (Oak Ridge, Tennessee: Oak Ridge Associated Universities, 1979).

CHAPTER 2 - RESEARCH FINDINGS

This chapter is a summary primarily of Part II of this report. Part II examines deep and surface mine data in detail and estimates the influence of various legal, economic, and geologic factors upon productivity. Based upon the research findings, the following section describes the most likely chain of events and conditions contributing to productivity change in the future. This is followed by a discussion of specific, major research findings.

A HISTORY OF COAL MINE PRODUCTIVITY
1950-1969

To place the productivity experience of the coal industry of the 1970s in proper perspective, one must examine the industry over the prior two decades. The coal reserves in the United States are vast and would last for some 600 years at the current rate of consumption. However, coal is difficult to mine, costly to transport, and dirty to burn. As inexpensive petroleum and other fuels became available during the late 1940s, consumers switched to them from coal, and the industry began a 20-year decline.

During this period of decline, coal prices and profits were low, mine population was decreasing, and many workers were being laid off. Union and management, after years as adversaries, realized that they had to work together to maintain existing markets. Both groups encouraged mechanization (usually workers are highly resistent to mechanization and labor-saving innovations).[1] In addition, the union and management restructured the industry into more efficient and concentrated production units and improved labor relations to ensure uninterrupted production.[2] The official union position was stated by W. A. Boyle in 1969:

> The union . . . recognized the industry was undergoing a serious economic depression and, in fact, its very existence was at stake. . . .It was the consensus of those, both on management's side and on labor's side, that if there were no mechanization, there would be total elimination of coal mining in America.[3]

The industry went through a 20-year period where increased efficiency (higher productivity) was necessary for survival. The active mine population was continually pared back by competitive forces and mechanization to a much smaller number of highly efficient, mechanized producers. Uninterrupted supply sources were assured by an absence of work stoppages, and, from 1950 to 1970, there was not a single authorized strike in the coal fields.[4] Mechanization was adopted at a much more rapid pace than would have been the case without the union's endorsement.

Mechanization, which began in the late 1940s, spread rapidly throughout the industry and was not accompanied by health and safety requirements until 1969. There is evidence that the union worked with industry to prevent safety legislation that would affect coal's already precarious competitive relationship to other fuels.[5] Despite the presence of severe health and safety problems resulting from mechanization (e.g., roof falls from rapid face advance, large pieces of fast-moving machinery, and high dust levels), the coal industry lagged behind other industries in protecting its workers.

On the eve of the 1969 Coal Mine Health and Safety Act, the coal industry was anything but typical. The poor competitive position of coal relative to other fuels had forced the industry to delay health and safety measures, reduce producers to a comparatively small group of highly efficient firms, and mine coal by highly mechanized and productive, if dangerous, methods.

1970-1975

The 1970s saw an abrupt change in the industry environment from the previous two decades. In 1970, the CMHSA placed the industry under restrictive health and safety regulations for the first time in its history. Continuous mining was particularly hard hit by the new regulations. At this same time, previously stable coal prices began to inch upward.

During the first year after enactment of the CMHSA, deep mine productivity was depressed as mines had to change mining methods and even mine design. Even though prices and output were increasing, the CMHSA was largely responsible for the 1969-1970 decline. Still, a 1-year decline after enactment of the industry's first major piece of health and safety legislation was not alarming. Many observers felt that after the industry became experienced with operating under the new institutional rules, productivity would begin to increase.

A return to increasing productivity in 1971 was not to be. In 1971, the first major strike in the industry since the 1940s resulted in higher coal prices and temporary shortages and production surges before and after the strike to replenish stockpiles. The CMHSA also had a depressing effect as the inspection work force grew and enforcement strengthened. Productivity fell below the 1970 level.

The impact of the CMHSA hit a peak in 1972 and 1973. From 1971 to 1972, the total inspection work force grew from 1055 to 1502; after 1972 it remained fairly stable. Inspections under the act reached an all-time high of 70,000 in 1973.[6] The impact of the act in 1972 and 1973 resulted in a slight decrease in productivity from 12.0 tons per miner-shift for deep mines in 1971 to 11.6 tons per miner-shift in 1973. Although this decline was slight, it was alarming because productivity had not started to increase as many had predicted.

Productivity would most likely have grown from 1973 to 1974 except for the impact of the second major work stoppage of the 1970s, the 1974 UMWA strike. The evidence strongly suggests that the CMHSA effect upon productivity had reached a plateau: the inspection work force was fairly stable, and inspections and violations per mine were fairly stable.[7] Only withdrawal orders (i.e., orders withdrawing workers from a mine after a mandatory health or safety violation had not been corrected in the allotted time) increased substantially after 1974.

Coal prices and market demand conditions in this period increased dramatically. Deflated price per ton f.o.b. mine jumped from $11.27 in 1973 to $19.22 in 1974.[8] This surge in demand and price was due largely to a political embargo by the Organization of Petroleum Exporting Countries (OPEC) and the coal strike.[9] Price conditions did not appear to affect productivity to the degree that the intermittent surges in demand caused by the strike did.

In terms of market conditions, prices, and profit, 1975 was a great year for the coal industry. However, the excellent conditions resulted in the entrance of many new mines into the marketplace and a general feeling of prosperity in the industry. The strong relationship between price levels and productivity—whether due to mine development, mining more expensive coal, or to a general change in worker and management attitudes—was responsible for a large portion of the 1974-1975 decline. The number of wildcat work stoppages also increased dramatically during 1975 and contributed to productivity decline.

The market and price conditions also had significant impacts on surface mining. In both Appalachian and non-Appalachian states, the entrance of small surface mines in reaction to changing market conditions drove down industry productivity. In non-Appalachian states, productivity was also significantly reduced by state reclamation laws. Appalachian surface mines, perhaps due to contour stripping and their small size relative to mines in other coal areas, showed a much stronger reaction to price changes and less reaction to reclamation laws.[10]

For deep mining, then, there was no one cause of productivity decline but rather a succession of causes during the 1970s. It is also apparent that comparing productivity in the 1970s with "the good old days" of 1969 is unfair. The 1969 mining industry had been fighting for survival for 20 years, and, like the U.S. agricultural industry in the twentieth century, it had pared producers down to efficient, concentrated, mechanized units; reduced the work force to a small number who were willing to take risks mining coal; allowed management to join with the union to prevent work stoppages and health and safety legislation. Despite the difference in productivity levels, however, it is difficult to argue that the industry was better off in 1969 than in 1975.

PROSPECTS FOR THE FUTURE

What of the future? Given that the effects of health and safety legislation largely dissipated by 1974, future productivity levels in the industry (barring any marked change in technology) will depend upon market conditions and union behavior. The competitive nature of the coal industry and vast resources available for exploitation imply that in the long run coal prices should approach the cost of production plus a reasonable return on capital. This long-term posture would result in increasing efficiency (productivity) and decreasing real coal prices (compared with 1975 figures). With a healthy market and the current health and safety legislative philosophy, it is doubtful that productivity in deep mines will ever return to 1969 levels without major technological developments.

It seems, however, that the deck is stacked against long-term equilibrium for the industry. The union and management, after cooperating in the 1950s and 1960s, have renewed their adversary roles, and each is now concerned with a bigger share of the growing coal "pie." Work stoppages have increased dramatically during the 1970s, and each new coal wage agreement expiration has resulted in a major strike, the last being in 1977-1978. Coal prices and market conditions, largely affected by world energy prices, have been subject to the whims of OPEC oil ministers. The market for coal has thus undergone demand "bumps" in 1973-1974 and 1979 as world oil prices have risen. In addition, surface mining has been, and will be, affected by the 1977 Surface Mine Control and Reclamation Act, which has not yet been implemented fully. This law, with provisions on how surface mines must reclaim the land and protect the environment, will result in a new set of institutional rules (and subsequent adjustments) for mining.

SOURCES OF PRODUCTIVITY VARIATION: RESEARCH FINDINGS

The different explanations that have been advanced to explain productivity decline (as detailed in Chapter 4) fit roughly into four general areas: (1) causes related to the resource base, (2) coal mining technology, (3) changes in the institutional environment, and (4) causes related to the coal mine labor force. In addition, the influence of coal prices and market conditions was expected to be the driving force behind many of these causes, e.g., a higher price for coal would allow the mining of thinner seams, require the hiring of new workers, and allow for more labor intensive mining.

To test these hypotheses, state-level data nationwide and mine-level data for Illinois, Ohio, and Kentucky were examined. The following sections summarize the results of this examination.

Resource Base

The rapid increase in both coal prices and production in the 1970s has changed the number and types of mines in the industry. These price and output increases could have contributed to productivity decline because (1) the easiest coal to mine is mined first, so as industry expands, each new mine is forced to mine geologically less favorable seams (thinner seams, larger overburden ratio, etc.); (2) as price increases, less efficient mines can make a profit and so they enter the industry, and existing mines can profitably work poorer sections of their mines.

Although seam thickness (in deep mines) and overburden ratio (in surface mines) were found to be important in determining productivity for a given mine, there was no evidence that these geologic characteristics were changing enough to affect productivity. Indeed, regional surface mining production has shifted toward more geologically favorable states.

The argument that less efficient mines entered the industry in response to price increases may be true, but the overall influence of these mines on the entire industry appears small. In both Pike County, Kentucky, and in Illinois (two areas examined in detail in Chapter 6), there was no discernable difference between existing and entering mines, both surface and deep. In addition, the productivity trends of all deep mines producing 100,000 tons per year or more and in constant operation from 1967 to 1976 in Kentucky, Ohio, Pennsylvania, and West Virginia were examined. These mines all experienced productivity decreases similar to statewide averages. This fact indicates that the cause of the industry productivity decline was from changes within a given mine and not due to entrance and exit of mines of given characteristics.[11] Although there was no evidence of changes in geologic characteristics, the size distribution of surface and deep mines did have an impact. This will be discussed below.

Coal Mining Technology

There are several different techniques available for deep mining, e.g., longwall, shortwall, continuous, and conventional. Capital intensiveness and labor productivity vary across these extraction techniques, so total labor productivity is influenced by the proportion of total output mined by each method. In surface mining, technique is largely determined by geology and topography (area, contour, and hilltop mining). Most of the change in surface technology has been in equipment (increases in bucket and dragline size). There is also evidence that both surface and deep mines have economies of scale (large mines have higher average labor productivity).

One reason for both the high rates of productivity growth and high injury rates during the 1960s was the rapid diffusion of continuous mining. David has argued that continuous mining is highly productive but also dangerous because of high dust levels and rapid face advance.[12] It has been argued that the CMHSA was directed mainly at making continuous mining safer, thereby reducing its productivity advantage over other techniques.[13]

The evidence gathered during this study supports this view. In both the Ohio mine-level data and state-level results, continuous mining was found to be more productive in the 1960s than other deep mining methods, *ceteris paribus*. However, this productivity advantage disappeared during the 1970s; indeed, continuous mining was estimated to be less productive than other techniques after passage of the CMHSA.[14] The growth in continuous mining from 27.4 percent of deep mine output in 1960 to 65.3 percent in 1975 explains part of both the increase in labor productivity during the 1960s and decrease during the 1970s.[15]

In surface mines, bucket and dragline size were found to be unimportant determinants of productivity. The Pike County results, however, indicate that the ratio of bulldozers to mine output is a significant and negative determinant of productivity (see Table 6-19). This supports the Walton/Kaufmann argument that the role of bulldozers in surface mining is more for reclamation than for mining, thereby diverting labor and capital services toward nonproduction activities.[16]

Mine size (scale) was found to be a very important determinant of productivity. Larger surface and deep mines have higher average labor productivity, *ceteris paribus*. Changes in the size distribution of both surface and deep mines, caused by small mines entering largely in response to high prices, have contributed to the productivity decline in 1974 and 1975. The entrance of small mines is especially important in surface mining because of the small capital requirements relative to deep mines.

Some researchers (see Neumann and Nelson) have attributed small mine closings in the early 1970s to the high costs of compliance with the CMHSA; i.e., mining under the provisions of the act was no longer profitable.[17] The results reported here found no statistical difference between mines leaving prior to the act and those leaving after its passage, so it is difficult to attribute mine closings to the act (see Table 6-5).

Institutional Environment

Perhaps the most popular explanation for declining deep mine productivity is the Coal Mine Health and Safety Act of 1969. It is argued that the act diverted labor and capital services from mining to safety and health tasks, lowering both injuries and productivity.[18] Enforcement of the act has also been cited as a cause of productivity decline; when a mine is being inspected, there is considerable disruption at the work site.

Data from the 1960s indicates that a trade-off between injuries and productivity existed; that is, states with high injury rates also had high productivity, *ceteris paribus* (see Table 5-1). In the 1960s a firm could control injury and productivity rates by choosing a particular safety policy. In the 1970s, the safety policy was legislated.[19] Given the trade-off in the 1960s, a reduction in injuries was also bound to reduce productivity. Therefore, one can view the reduction in number of injuries as having been caused by compliance with the CMHSA.

Likewise, enforcement of the act appears to have affected productivity. States with restrictive mine safety regulations prior to the CMHSA fared no better in terms of productivity loss than other states.[20] Mines owned by companies that were said to be complying to the dust, ventilation, roof control, and other provisions of the act prior to its passage lost as much productivity as other mines.[21] One would expect these mines and states to have had an easier time meeting the provisions of the CMHSA than other mines or states and to have lost less productivity. Finally, the productivity level and change in productivity were found to have no relationship to the level of a mine's compliance.[22]

In a progress report of this project, the impact of the black lung provision of the act was examined; its influence was not found to be significant.[23]

The Bituminous Coal Wage Agreement of 1974 was measured indirectly in this study and was found to have a negative impact, although the magnitude is unknown. It has been estimated that the wage agreement, which changed the staffing patterns in unionized deep mines, reduced productivity by 0.5 ton per miner-shift.[24] In addition to the wage agreement, some have argued that union mines lost more productivity during the 1970s than other mines due to stricter enforcement of the CMHSA. There is no evidence found to support this.[25]

The consensus is that the CMHSA, through both compliance and enforcement, has had major impact upon productivity. The evidence uncovered in this study, however, indicates that the impact peaked in 1973 and may have actually declined slightly after that.

The impact of reclamation laws in Appalachian states is difficult to separate from price and market effects. However, it appears small. In non-Appalachian states, the impact of reclamation laws is significant and explains a large portion of the productivity variation.

Coal Mine Work Force

From 1969 to 1977, the coal mine work force grew from 125,000 workers to 215,000. This growth required the recruiting of many new workers and reduced the average age and experience of coal mine workers—another factor, it has been argued, that has contributed to productivity decline. In addition to experience levels, some observers have argued that the younger workers also have different attitudes from older workers—the younger workers are not as motivated, lack the work ethic, and are militant.[26]

Because these attitude and experience characteristics are associated with younger workers, the influence of age structure (proportion of young and old workers) on productivity was examined. Contrary to expectations, the changing age structure of the coal mine work force in the 1970s was found to have had a slight positive influence; i.e., it contributed to productivity growth.[27]

Increasing absenteeism and turnover have also been cited as possible causes for productivity decline. These influences were not tested due to the lack of adequate data.

During the 1970s, the number of work stoppages increased rapidly. These work stoppages may have affected productivity by disrupting the work process. Work stoppages also affected demand and price for coal by creating demand and production surges prior to contract strikes (to build up stockpiles) and immediately following strike settlement (to replenish stockpiles). These production surges also may have affected productivity.

Empirically, both contract strikes and wildcat strikes were found to be important contributors to productivity decline in the 1970s. Both types of strikes depressed deep mine productivity; the impact of wildcat strikes was especially strong in 1975. The relationship between strikes and surface mine productivity was not nearly so strong. Only the 1974 contract strike in the Appalachian states significantly depressed productivity; this may be due to the large number of unionized surface mines in this region.

In addition to the work force related productivity determinants examined above, evidence of personnel problems was found in the annual Department of Energy Survey of Mines. For mines experiencing production shortfalls from 1975 to 1977, 82 percent reported that the first or second most important cause was labor-related.[28]

Price and Market Conditions

Economic theory predicts that as coal prices rise, productivity will fall. The simple reason for this is that coal reserves, mines, or mining methods that are less efficient and less profitable than those existing now become profitable with higher coal prices. Another reason is more subtle and difficult to measure. If prices are low and the industry is in a depression, efficiency (high productivity) is required merely for firm survival. If the market is strong and profits are high, management and workers need not attain maximum efficiency to survive. While high coal prices of the 1970s may not have caused inefficiency, they have allowed it to exist. Indeed, the general comments concerning worker attitudes, work ethic, and sloppy management would all fit this theory.

Although there are empirical problems with measuring the impact of market conditions, the results of this study make it difficult to argue against the strong relationship between price levels and productivity. In deep mining, this appears to be the major cause of productivity decline after 1974. In surface mining, market conditions strongly affect productivity in Appalachia; the estimated effect is minimal in non-Appalachian states. This latter situation may be due to the large size of mines in the West that must sell under long-term contract to lower the risk of the large investments required for rail transportation and capital costs. The much smaller Appalachian mines can open and close without these scale barriers, making that region more responsive to price. In addition, mine size distribution (scale characteristics) is affected by price in both surface and deep mine operations.

NOTES

[1]Edwin Mansfield, *The Economics of Technological Change* (New York: W. W. Norton, 1968), p. 153.

[2]John Peter David, "Earnings, Health, Safety, and Welfare of Bituminous Coal Miners since the Encouragement of Mechanization" (unpublished Ph.D. dissertation, West Virginia University, 1962), p. 241.

[3]U.S. Senate, Committee on Labor and Public Welfare, *Coal Mine Health and Safety,* Hearing before Subcommittee on Labor (Washington, D.C.: Government Printing Office, 1969), p. 458.

[4]John Peter David, "Earnings, Health, and Safety," p. 70.

[5]Ibid, p. 243.

[6]Joe G. Baker and Robert J. Gaston, *Coal Mine Labor Productivity: Review of Issues and Evidence, A Report to the President's Commission on Coal*, forthcoming (Oak Ridge, Tennessee: Oak Ridge Associated Universities), p.6.

[7]Ibid.

[8]Energy and Environmental Analysis, Inc., *Coal: A Data Book* (Washington, D.C.: The President's Commission on Coal, 1979), p. 103.

[9]Executive Office, President's Council on Wage and Price Stability, *A Study of Coal Prices* (Washington, D.C.: Government Printing Office, 1976), pp. 1-4.

[10]Because he controls the overburden ratio (cubic feet of overburden removed to mine a cubic foot of coal), a contour stripper can increase coal recovery, although this procedure reduces productivity and increases costs as coal prices rise.

[11]Joe G. Baker and Robert J. Gaston, *A Report to the President's Commission on Coal,* p. 11.

[12]John Peter David, "Earnings, Health, Safety," p. 162.

[13]This was suggested by Charles M. Mottley, Department of Energy.

[14]The 1-year cross-section and 2-year pooling of the Pike County, Kentucky, deep mine data (1976-77) estimated that continuous mining was less productive than other techniques. See Chapter 6, Tables 6-17 and 6-18.

[15]U.S. Department of the Interior, Bureau of Mines, *Minerals Yearbook* (Washington, D.C.: Government Printing Office, 1960 and 1976 editions).

[16]See Daniel R. Walton and Peter W. Kauffman, *Preliminary Analysis of the Probable Causes of Decreased Coal Mining Productivity (1969-1976)* (Reston, Virginia: Management Engineers, Inc., 1978), pp. VI-35 and VI-36.

[17]See George R. Neumann and Jon P. Nelson, "Regulation and Safety: The Effects of the Coal Mine Health and Safety Act of 1969," a revision of a paper prepared for the Department of Labor Conference, "Evaluating the Effects of Occupational Health and Safety Programs," Annapolis, Maryland, March 18-19, 1975; and G. L. Christensen and W. H. Andrews, "Physical Environment, Productivity, and Injuries in Underground Coal Mines," *Journal of Economics and Business* 26(1):182-90.

[18]George R. Neumann and Jon P. Nelson, "Regulation and Safety," pp. 9-10.

[19]In Table 5-1, the injury-productivity trade-off is not significant after the 1969 CMHSA. This is perhaps due to a lack of variance in safety policies.

[20]See "Impact of State-Level Deep Mining Regulations" in Chapter 5.

[21]See Joe G. Baker and Robert J. Gaston, *A Report to the President's Commission on Coal,* Appendix A.

[22]Ibid, Appendix B.

[23]Joe G. Baker, *Determinants of Coal Mine Labor Productivity Change: A Progress Report* (Oak Ridge, Tennessee: Oak Ridge Associated Universities, 1979), p. 77.

[24]Joe G. Baker and Robert J. Gaston, *A Report to the President's Commission on Coal,* p. 7.

[25]Ibid, p. 8.

[26]Ted Mills, "Altering the Social Structure in Coal Mining: A Case Study," *Monthly Labor Review* 99(10):3-4; Joseph Brennan, "Productivity—and the BCOA," *Coal Age,* July 1976, pp. 96-97; and Stanley Suboleski, "Boost Your Productivity by Adding Continuous Miners," *Coal Age* March 1975, p. 78.

[27]Joe G. Baker, *Coal Mine Labor Productivity,* p. 75.

[28]Joe G. Baker and Robert J. Gaston, *A Report to the President's Commission on Coal,* Appendix D.

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CHAPTER 3. EMPLOYMENT, TRAINING, POLICY, AND RESEARCH IMPLICATIONS OF STUDY FINDINGS

EMPLOYMENT AND TRAINING IMPLICATIONS

With the recent price boost of world oil to more than $20 per barrel and with public concern for nuclear power safety being expressed, coal is in the strongest competitive position of the industry's history, and production forecasts predict yearly output of well over a billion tons in the 1980s. The manpower implications of expanding coal production are crucial to the industry's ability to meet these output goals.

Average labor productivity is the link between output levels and employment requirements. The results of this study indicate that it is unlikely that deep mine productivity will ever return to 1969 levels without major technological innovations. The strong trade-off between safety policy (injury rates) and productivity that existed during the 1960s implies that the goal of safety requires some sacrifice of production. In addition, a healthy market affects coal productivity two ways: (1) It allows less efficient producers to exist (efficiency is related to quality of the coal reserves, technology, management, worker attitude, etc.), and (2) the industrial relations climate appears to be linked directly to the health of the industry. When the market is poor, there is little time lost to work stoppages; when the market is strong, work stoppages begin to appear (witness 1975). In the post-1973 oil embargo period, U.S. coal output has grown at an annual rate of 3.8 percent. To reach the Energy Information Administration's forecast of 1.034 billion tons in 1985, the industry will have to grow at an annual rate of 5.2 percent from the 1977 base of 689 million tons.[1] To sustain this rate of growth, the industry will require strong demand and sustained high prices, i.e., a healthy market.

When one considers that the effects of the 1977 Surface Mine Control and Reclamation Act have yet to be felt fully, the prospects for a rapid recovery of productivity rates do not look promising. However, projections of real coal prices to 1985 indicate that no substantial increases are expected over 1978 price levels.[2] Given this economic situation, the industry should be able to make a long-term response to these fairly stable market conditions, and one would expect deep mine productivity to creep upward.

Another major influence upon aggregate productivity will occur through the regional distribution of output. The productivity functions estimated in this study indicate that regional coal production characteristics are important determinants of regional productivity; aggregate productivity is thus affected by the proportion of total output from the different coal regions. To a large extent, the adjustment problems of labor supply are also related to the regional output distribution.

Table 3-1 shows the regional percentage distribution of coal output in 1977 and the output expected in 1985. The West is expected to capture a large portion of future coal output with the relative shares of both the Central and Appalachian regions falling.

Table 3-1. Regional Percentage Distribution of Coal Output, 1977 and 1985

	Deep		Surface	
Region[a]	1977	1985	1977	1985
Appalachia	84.0	65.8	51.0	27.9
Central	11.1	9.9	19.7	15.9
West	4.9	24.3	29.3	56.2
Total	100.0	100.0	100.0	100.0

[a]Appalachia: Alabama, Arkansas, Kentucky, Maryland, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia; Central: Illinois, Indiana, Iowa, Kansas, Missouri, Oklahoma, and Texas; West: Arizona, Colorado, Montana, New Mexico, North Dakota, Utah, Washington, and Wyoming.

Sources: Joe G. Baker, "Coal Mine Training Requirements," paper delivered at the National Education, Labor and Business Affairs Conference, Washington, D.C., January 1979. The 1985 projections are based on DOE forecasts of state-level deep and surface mine outputs prepared by CONSAD Corp., 1977.

To examine the influences that redistribution of output and growth in output will have upon productivity, employment, and training, each state's 1975 deep and surface mine productivity levels were used to project 1985 labor requirements. Each state's 1985 DOE projected output for both surface and deep mines was used as an output goal, and 220 shifts per worker per year were assumed.

Table 3-2 shows 1985 labor requirements by region. The region with the greatest impact will be the West. Deep mine employment will grow from 4500 in 1975 to 53,200 in 1985, and surface mine employment will grow from 4900 in 1975 to 24,700 in 1985. The redistribution of output towards the relatively more productive mines in the West will boost deep mine productivity from 9.5 tons per miner-shift in 1975 to 9.8 tons in 1985; surface mine productivity will jump from 26.7 tons per miner-shift to 39.3 tons.

Table 3-2. Labor Requirements and Output by Region, 1975 and 1985

	Region[a]					
	West		Central		Appalachia	
Labor Requirements	1975	1985	1975	1985	1975	1985
Surface	4,860	24,700	9,190	14,300	41,450	41,900
Deep	4,530	53,200	9,150	19,100	121,030	188,300
Output (million tons)						
Surface	77.7	392.9	72.9	111.3	209.4	195.5
Deep	11.6	136.0	32.5	55.3	249.3	368.0

[a]West: Arizona, Colorado, Montana, New Mexico, North Dakota, Utah, Washington, and Wyoming; Central: Illinois, Indiana, Iowa, Kansas, Missouri, Oklahoma, and Texas; Appalachia: Alabama, Arkansas, Kentucky, Maryland, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia.

Source: U.S. Bureau of Mines, *Minerals Yearbook* (Washington, D.C.: Government Printing Office, 1975); Joe G. Baker, "Coal Mine Training Requirements," paper delivered at the National Education, Labor and Business Affairs Conference, Washington, D.C., January 1979; and coal production forecasts developed for DOE by CONSAD Corp., 1977.

Labor requirements, however, represent only the number of job slots that need filling. To estimate training requirements, one needs the number of new jobs created each year plus the number of replacements required to fill openings created by workers retiring, workers leaving the industry for other employment, or death. Historical data based upon social security records indicates that the annual rate of exit from the coal industry has ranged from 10 percent to more than 19 percent between 1960 and 1973. The latest separation rate data (1973) and an annual rate of 12 percent were used here.[3]

Table 3-3 details national training requirements based upon the preceding assumptions concerning output, days worked, productivity, and worker separation. An important point about this table is that the new workers require training as mandated by the 1977 Federal Mine Safety and Health Act (Section 115). Annual training requirements in excess of 60,000 miners per year will most

Table 3-3. Projected U.S. Coal Mine Training Requirements, 1975-1985

	Surface				Deep			
Year	Growth	Replacements	Total Training Requirements	Total Work Force	Growth	Replacements	Total Training Requirements	Total Work Force
1975				55.500				134,680
1976	1290	6650	7,940	56,790	7,400	16,170	23,570	142,050
1977	1450	6800	8,250	58,240	7,950	17,040	24,990	150,000
1978	1740	6980	8,720	59,970	8,900	18,000	26,900	158,900
1979	1940	7200	9,140	51,911	9,720	19,070	28,790	168,600
1980	2140	7400	9,540	64,050	10,870	20,670	31,540	183,900
1981	2440	7680	10,120	66,490	12,200	21,460	33,660	191,700
1982	2880	7940	10,820	69,370	13,800	23,000	36,800	205,500
1983	3300	8300	11,600	72,670	15,760	24,660	40,420	221,260
1984	3790	8710	12,500	76,460	18,190	26,650	44,840	239,450
1985	4340	9160	13,500	80,000	21,150	28,890	50,040	260,600

Source: Figures based on Table 3-2.

likely be the norm in the 1980s. In every year, training requirements for replacements outnumber growth positions, although in some regions, (i.e., the West) growth dominates. Numbers of this magnitude will present a challenge to existing labor market institutions to ensure an adequate supply of trained labor for the industry.

Planning to meet these training requirements is crucial. The regional distribution and magnitude of these requirements are subject to change from government policy, alternative energy prices, and environmental regulation. While planning models exist to examine the impacts of these parameters on regional coal output, no such tool exists for the continuing analysis of the labor implications of different coal output scenarios. Given the rapidly changing energy future of our country, research into the labor implications of coal development as a tool to be used continuously is clearly needed.

POLICY AND RESEARCH IMPLICATIONS

Based upon the results of this study, the following points are made:

1. Productivity decline is transitional. The productivity decline experienced by the coal industry during the 1970s is not a chronic ailment but is transitional—caused by the rather painful adjustments that owners and miners have made from an almost completely unregulated, declining industry to a highly regulated, fast-growing industry. Given present technology, it is doubtful that productivity will ever return to 1969 levels. Because the impact of the Coal Mine Health and Safety Act on productivity was largely expended by 1974, productivity should be able to be improved within present technological bounds to some "productivity ceiling" that is consistent with safe deep mining and environmentally acceptable surface mining.

Several things point towards improved deep mine productivity. Prices for coal (in real terms) are expected to remain near 1978 levels through 1985. The future distribution of coal output is expected to shift towards those more productive and geologically favorable states—the West. If demand grows at the steady rate necessary for the industry to meet DOE projections, market uncertainty will be removed and relatively larger mines, which need stable long-term markets, can be constructed.

Because of the unknown impact of the 1977 Surface Mine Control and Reclamation Act, the future of surface mining is less clear. However, this mining technique will also face the relatively stable prices of coal expected to prevail through 1985; larger producers will be encouraged to enter the industry and to improve productivity levels by scale economies. The regional composition in surface mining will also shift to the western states, but at a much greater rate than deep mining. The sizable productivity advantage of western mines should drive up productivity aggregates.

2. The price/productivity relationship needs to be examined. The strong relationship between price levels and productivity uncovered in this study needs to be examined in more detail. Oak Ridge Associated Universities will begin a project in late 1979 to outline conceptually the possible actions that mines could take in response to an increase in coal prices. The actions that are discussed in Chapter 7 fall into two basic areas:

a. Economic adjustments. When coal prices increase, the total value of reserves controlled by a mine increases. This makes it desirable for the mine to increase the rate of reserve recovery, even though this action might increase costs and lower efficiency (productivity). How, if at all, does this adjustment take place?

b. Motivational adjustments. Many industry observers have blamed part of the productivity decline on the motivational and attitudinal problems of the coal industry work force; blame has also been placed upon sloppy management. The implication is that the declining employment and market conditions of the 1950s and 1960s did not allow firms with poor management or poorly motivated workers to survive; the strong market existing in the 1970s has allowed for their survival.

Evidence to support the charges of changing worker attitudes/motivation and sloppy management is largely anecdotal. What is needed is a comprehensive case study to determine if motivation and management are problems meriting attention. Efforts to increase motivation of the work force are common, and the 1978 Bituminous Coal Wage Agreement has a provision dealing with incentive plans (Article XXII, Section t).[4] A basic problem faced by all incentive plans is that high productivity and safety, after a point, are incompatible.

3. There is a need to examine enforcement of the CMHSA. The productivity impact of the CMHSA occurs through both compliance and enforcement. There is evidence that some provisions of the act and enforcement methods do not contribute to miner health and safety but instead disrupt and reduce productivity.[5] Research into the provisions of the act and enforcement procedures could allow

for reversing some of the negative productivity impact with no corresponding decline in health and safety standards.

4. Health, safety, and reclamation legislation have high opportunity costs. To a large extent, a portion of the tonnage produced per miner-shift prior to 1970 was a noncaptured opportunity cost of production. The results of this research indicate that significant trade-offs exist between protecting workers and the environment on one hand and productivity levels on the other. The high productivity rates of the 1960s were possible partly because some of the costs of mining—worker injuries and black lung disability as well as environmental damage—were simply not being paid by the coal industry and coal consumers. Once these costs were included in the production of coal via legislation, productivity fell and the cost of production increased.

Who pays for the cost—both market and nonmarket—of coal? Because of the increased cost of production, any industry that consumes coal—such as utilities—will experience an increase in its own cost of production. This cost is ultimately passed on to the consumer through either smaller supplies or increased costs. In this way, the previously unincluded costs of coal production that were paid by the miners and coal communities are now being shared among those who benefit from coal use.

A bigger question remains: Who decides what the trade-off will be, i.e., at what productivity level does society deem the injury rate "acceptable"? The experience of the coal industry with legislated health and safety requirements and reclamation requirements demonstrates that safety and a pleasant environment are not free. Actions by legislators concerning industry regulation can have far-reaching implications, as evidenced by the coal industry.

NOTES

[1]Energy Information Administration, *Annual Report to Congress* (Washington, D.C.: Government Printing Office, 1977).

[2]Ibid.

[3]These data are from the Social Security Administration's Longitudinal Employee-Employer Data file.

[4]See, for example, Ted Mills, "Altering the Social Structure of Coal Mining," *Monthly Labor Review* 99(10):3-10; and J. Wes Blakely, "Kentucky Harlan Gets Top Production from Its System and Workers," *Coal Mining and Processing,* October 1975, pp. 46-49.

[5]See Joe G. Baker and Robert J. Gaston, *Coal Mine Labor Productivity: Review of Issues and Evidence, A Report to the President's Commission on Coal* (Oak Ridge, Tennessee: Oak Ridge Associated Universities, 1979), pp. 5-6; and

National Coal Association and Bituminous Coal Operators Association, *Federal Coal Mine Health and Safety Act of 1969: A Constructive Analysis with Recommendations for Improvement* (Washington, D.C.: Bituminous Coal Operators Association, 1977).

PART II. RESEARCH METHOD

The following chapters present a detailed, technical discussion of the conceptual and empirical investigation results of declining coal mine productivity.

Chapter 4 offers a detailed examination of the possible causes of productivity decline that have been mentioned in the literature or would be expected from rational economic behavior. Basically, these explanations fall into four areas: (1) causes related to the resource base, (2) causes related to coal mining technology, (3) causes related to the institutional environment, and (4) changes in the coal mine work force. All of these areas are related to the change in the market for coal and in the regulation of the industry that appeared during the 1970s.

The next two chapters (5 and 6) test these hypotheses empirically using state-level and mine-level data. The use of several data sets allows for the confirmation of results. In addition, some data have strengths that can be exploited for the examination of a particular issue. However, these several data sets make the analysis cumbersome and interpretation lengthy.

Because of complex modeling and conceptual problems, Chapter 7 examines specifically the relationship between coal prices and productivity. Again, the analyses of coal prices and productivity are performed upon several data sets to confirm findings and to determine the universality of the estimated relationships. This chapter also contains a short section on the determination of coal prices.

Chapter 8 applies a labor cost function approach to the analysis of coal industry production. Although some preliminary results of a labor cost function estimation are included, the section stands mainly as a discussion of a method one might employ to examine the relationships among labor, other inputs, and total output.

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CHAPTER 4. CONCEPTUAL MODEL

THEORY OF THE COMPETITIVE FIRM

In theory, the extraction of coal is a production process involving the classical economic inputs of land, labor, and capital. Assuming that a firm has a goal of maximizing profit and is operating in a competitive system, average productivity is determined by the technical constraints of the firm's production function, the relative prices of inputs, and output price (in this case the price of coal).

Given an output price, neoclassical theory predicts a firm will maximize profit by adjusting its output and costs to the point where the incremental cost of the last unit produced equals the incremental revenue received. If capital in the firm is fixed in the short run, the firm will adjust its output and costs by increasing or decreasing its work force. An increase in coal price would cause the neoclassical firm to hire more workers, thereby increasing output. Because the firm's capital stock does not change, an increase in the work force requires each worker to work with less capital (machines), thereby lowering average labor productivity and increasing average cost. If coal prices decrease, the opposite occurs—a work force reduction, causing each worker to have more capital and increasing his average productivity. The competitive firm's reaction to price change in the short run will result in average labor productivity decreasing when prices rise or average labor productivity increasing when prices fall.

In the longer run, the industry as a whole can react to price and demand changes by adding or deleting "marginal" producers. (A mine can remain open or enter the industry as long as it covers its costs of operation.) In a natural resource industry, the cost of operation and relative efficiency of a producer is directly linked to the quality of its reserves (e.g., location, seam thickness, and depth). As demand increases and prices rise, marginal firms can enter the industry and survive, lowering the overall efficiency of the industry (average productivity). If prices are falling, as in the 1960s, inefficient producers are forced out of the industry, and industry-wide average productivity will increase. The response of both an individual firm and the industry as a whole to price changes is such that average productivity and price are inversely related.

For the individual firm in the longer run, output can be increased by increasing the scale of operation. The effect of this adjustment upon the efficiency of the firm depends on the scale characteristics of the production function (increasing or decreasing returns to scale). The effect of an institutional shift is not as easily handled by neoclassical theory. Assuming that a legislated safety requirement increases the amount of labor required to produce a given amount of coal, a *ceteris paribus* enactment of the legislation would result in each firm's reducing output and increasing average labor productivity until profits are again maximized. However, a reduction in output by all firms would reduce total supply, which in turn would drive up the price of coal. As discussed above, an increase in coal prices would cause profit maximizing firms to increase output by adding labor, thereby reducing average productivity. *A priori,* the effect of the institutional change upon average productivity is indeterminant.

SOURCES OF PRODUCTIVITY VARIATION

Conceptually, firm and industry production characteristics are altered in response to institutional changes and market forces. In turn, these altered production characteristics affect the relative productivity of an individual firm and the industry. If the price of coal per ton is increasing rapidly, a firm can now mine sections with "bad top," water problems, thin coal seams with partings, etc., that were economically infeasible to mine at a lower coal price. These newly opened sections require a period of construction and the hiring of new, inexperienced workers. All of these factors contribute to lower mine productivity.

The conceptual and empirical approach taken in this study is to examine the relationships between input characteristics and average productivity in a given institutional environment. After these relationships are established, the changes in input characteristics through time—whether in response to the market or to legislative mandates—and their influence upon productivity can be isolated.

The production characteristics examined in this report can be grouped into four areas:

1. Characteristics related to the resource base, i.e., geological, topographic, and climatic considerations
2. Technological aspects of the production process

3. The institutional environment, e.g., safety legislation and union work rules
4. Characteristics of the coal mine labor force

Resource Base Characteristics and Productivity

Unlike production in nonextractive industries, each mine (i.e., plant) is unique because of its geological characteristics; the production of coal is inexorably linked to the resource base. This makes replication of an optimum "plant" difficult; indeed, the plant itself changes as coal is extracted; its physical characteristics vary over time.

These physical characteristics can be thought of as a qualitative measure of resource input into the production function. For instance, the presence of methane gas and water disrupt production. If gas is detected, production is halted until the gas is bled off to avoid explosions. Water is less dangerous than gas, but it is a nuisance and requires capital and labor for removal. Production is disturbed by interruptions in the coal seam, usually the result of a geological fault. If the mine roof is weak, production is halted until the roof is prepared to avoid cave-ins. Floor buckling is a common problem in very deep mines. After coal is removed, pressure upon the open space causes the floor to buckle, and the floor must be restored for production to continue. In some deep mines, pressure on the coal face is so great that "bumps" on the face will explode, throwing coal through the mine tunnels. Dip (the vertical change of the coal seam per mile) also affects mine productivity (for instance, a large dip makes machine operation and coal movement more difficult).

Thickness of the coal seam affects production: The thicker the coal seam, the more coal is produced per foot of advanced seam face (deep mine) or per cubic yard of overburden removed (surface mine). As seam thickness increases, a deep mine is able to employ larger and more efficient equipment, and general mobility inside the mine increases.

Considerations related to the resource base partly determine production technique. An easily caving roof is required before longwall methods can be used. Overburden characteristics influence the type of deep mine (slope, drift, or shaft) and surface mine (hilltop, area, contour, and auger). A dip of 25 percent or more prohibits mechanized mining.

Topography and climatic considerations affect surface mining. A hilly topography, such as that found in the Appalachian region, increases the difficulty of coal removal and land reclamation. Climate affects surface mine productivity by requiring the construction of collection ponds in rainy regions and slowing production in inclement weather. In extremely arid climates, such as are found in the Northern Great Plains region, revegetation becomes more difficult in reclamation efforts.

Conceptually, resource base factors can affect industry productivity by changing cross-sectional relationships and by the secular depletion of resources. Ricardian rent theory suggests that the first coal mined is the most accessible; therefore, as the industry expands production, mining will advance into more unfavorable seams.[1] Diminishing returns and lower average labor productivity would thus be felt at an industry level (production expansion and new mines opening in less favorable seams) and at the mine level (existing mines expanding production to less favorable seams). In addition, evidence suggests a new mine has considerable start-up costs and takes approximately 2 years to reach maximum productivity.[2]

The General Accounting Office argues that the coal industry has a competitive structure, with the performance characteristics of easy entrance and exit.[3] Given this competitive structure, declining industry conditions in the 1950s and 1960s eliminated the least efficient mines faster than productive mines, reducing the relative output from mines with poorer resource characteristics and thus increasing industry productivity levels. During the 1970s when output prices were increasing, less efficient mines (young mines and mines with poorer resource characteristics) could enter the industry and survive. By increasing the proportion of output from these mines, the overall industry productivity level fell. Legislation can also affect the resource structure of the industry by differential impact on a certain type of mine (e.g., safety legislation affecting gassy mines).

Technology and Productivity

Several different techniques are available for deep mining, e.g., longwall, handcut mining, and continuous mining. Labor productivity and relative capital intensiveness vary across these extraction techniques. Therefore, aggregate labor productivity is influenced by the proportion of total output mined by each method. The 1950s and 1960s saw rapid adoption of continuous mining, which reached a plateau by 1970. Longwall mining, which currently accounts for only 3 percent of total deep production, may be adopted increasingly in the future. As the mix of output mined by these various techniques varies through time, aggregate labor productivity will vary, *ceteris paribus*.

Extraction technique in surface mining is largely determined by geology and topography (area, contour, auger, and hilltop mining). Most of the change in technology has occurred in equipment (increases in bucket and drag-line size) and in mine size. As in deep mining, the impact of technology upon productivity is more of a cross-sectional effect: As the mix of output mined by different techniques varies, aggregate productivity is affected.

There is also evidence that both surface and deep mining production are subject to variable returns to scale.[4] These scale economies (or diseconomies) can affect productivity at the mine level as a mine expands or reduces output or at an industry level as the mix of output from mines of different scales changes.

Institutional Environment

The most popular of all explanations for declining labor productivity in both surface and deep mining is the impact of legislation. In deep mining the principal piece of legislation is the Coal Mine Health and Safety Act of 1969; in surface mining the implementation of state laws, especially concerning reclamation, has been blamed. The possible impact of legislation upon surface and deep mining will be discussed separately.

Prior to the Coal Mine Health and Safety Act, federal legislation concerning coal mine safety focused on disaster prevention (accidents involving the death of five persons or more).[5] These disasters, however, accounted for less than 10 percent of all fatalities; thus, the emphasis shifted from disasters to general safety and health with the passage of the CMHSA in 1969.

The fact that deep mine labor productivity has declined monotonically since the enactment of the CMHSA contributes to the contention that the act is the major cause of productivity disruption. Among the reasons the CMHSA is blamed are the following:

1. The legislation has increased the job requirements of the labor force beyond what is necessary for the extraction of coal, i.e., the CMHSA has altered the trade-off between safety and production. Conceptually, there exists a mine "trade-off frontier" between the production of coal and the production of safety given a fixed amount of capital and labor.[6] Productive resources must be diverted

from resource extraction to the production of safety, thus lowering output per miner-shift and injury rates. Conceptually, the CMHSA has forced firms toward a safer extraction technique, affecting productivity and accident rates.[7] This diversion of the flow of labor services toward safety production has occurred through the CMHSA provisions dealing with areas such as methane gas, dust control, and roof control.

a. Dust control. A major area of impact of the law has been in the increase of labor to control respirable dust (a cause of black lung disease). A mine is required to rock dust (a technique to retard the presence of coal dust) within 50 feet of the face between shifts and to sample the mine air for compliance with federal standards.

b. Roof control. To prevent cave-ins, a roof control plan must be filed with the Mine Enforcement and Safety Administration (after 1977, the Mine Safety and Health Administration) and a roof bolting crew proceeds with a mining crew to provide sufficient roof control, according to the roof control plan.

c. Methane gas. Under the act, face equipment must be equipped with methane gas monitors, and, if dangerous levels are found, production ceases and all personnel are evacuated from the area.

2. Imminent danger withdrawal orders have increased. These orders are given when an inspector believes there exists a condition or practice in a mine that could be expected to cause physical harm. When a withdrawal order is issued, work stops in the mine until the danger is corrected. It is argued that these disruptions are detrimental to productivity.

3. Requirements concerning ventilation have resulted in some mine companies' investing in capital and construction of ventilation facilities, thus increasing both capital and labor inputs for the production of safety.

4. Enforcement of the act has been criticized as being arbitrary, inconsistent, and excessive.[8] It is argued that there is an atmosphere of confrontation between the mining companies and inspectors that results in considerable disruption on the work site when an inspection is performed.[9]

5. The black lung (pneumoconiosis) provision of the act has resulted in early retirement for thousands of miners. These miners have been replaced with younger, less experienced, and, therefore, less productive workers.[10]

The act can directly affect productivity in two ways. First, the act has directly affected productivity within a mine through safety and inspection requirements and indirectly (via labor inputs) through the black lung provision. Secondly, it has been argued that the act has altered the structure of the coal industry by forcing a subset of firms (the less efficient) out of operation.[11] This has changed the mix of output by a given mine characteristic, which has, in turn, affected aggregate industry productivity rates.

Although the primary focus of the CMHSA was on deep mining, it contained provisions affecting both deep and surface mines. The provisions dealt with smoking, first aid, equipment safety, protective clothing, and special inspections when a mine is reopened. In addition, special provisions in the act focused specifically upon surface mine health and safety: methane gas in coal storage, refuse piles, general safety, sediment and slurry impoundments, coal drying, ground control, augering, traffic of loading and hauling vehicles, and filing plans when new seams are mined.

It is generally agreed, however, that reclamation requirements have had the largest impact upon surface productivity.[12] Reclamation requires the diversion of capital and labor services from extraction to reclamation activities with the obvious result of a decrease in tons per miner-shift. Prior to the federal Strip Mine Law of 1977, state reclamation laws were more significant than federal laws: Federal laws applied only to mining occurring on reserves leased from the federal government.[13] The impact of state reclamation laws is not as straightforward as the impact of the CMHSA; it varies among states depending upon the time of enactment, provisions of the laws, and level of enforcement.

In addition to legislation, the National Bituminous Coal Wage agreements of 1968 and 1974 have been cited as causes of declining deep mine productivity. The 1968 agreement instituted "job bidding" as a means of allocating workers to jobs in a given mine. When a job becomes available, it is posted for bid and interested miners apply. After 1 week, the job goes to the most senior miner among those bidding and having the basic ability to perform the work, regardless of the qualifications of the other bidding miners. Union mine operators contend that this provision hinders their personnel policies and, therefore, mine efficiency by preventing promotions and demotions based upon job performance. The effect of job bidding would be more severe in times of rapid employment expansion such as the 1970s.

The 1974 wage agreement created new occupations in unionized deep mines. Article V of this agreement outlines the use of helpers on face equipment.

> A full-time helper shall be assigned to assist each continuous mining machine operator on each continuous mining section, and a full-time helper shall be assigned to assist each roof bolting machine operator on each continuous section and each conventional section . . . .[14]

While there are restrictions on helpers in certain instances, the provision considerably altered the staffing of union underground mines.

Although an extra worker at the face might somewhat increase tonnage output of a section crew, his duties as a helper are not directly related to coal extraction, and one can argue that the relative labor increase is greater than the relative tonnage increase. Further, a helper is trained by a machine operator for 120 days; this training requires the operator to divert part of his labor services from extraction to training, which lowers labor productivity.

Work Force Characteristics

From 1950 to 1969, the coal industry work force fell from 461,000 to 125,000 workers.[15] Declining employment resulted in few vacancies and few new workers entering the industry. As operating firms reduced their work forces, workers with the least seniority were terminated first. Both of these actions resulted in an increase in the mean age and experience level of the work force. This increasing quality of the labor force most likely explains part of the rapid productivity growth of the 1960s.

Between 1969 and 1976, many young and inexperienced miners entered the work force, which increased from 125,000 to 211,000. These miners lowered the mean age and experience level of the work force.[16] Human capital theory suggests that an increase in the number of inexperienced workers decreases labor productivity. The reduction in mean experience was exacerbated by the CMHSA black lung provision.

On the other hand, the general educational level of the new entrants was higher than the level of the existing work force, and we can assume that the health characteristics of these younger workers were superior to those of the older workers.[17] In human capital theory, these are positive attributes that result in an increase in worker productivity. In sum, the predictions based upon human capital theory are ambiguous.

Work stoppages in the coal industry, especially wildcat strikes, have increased dramatically in the 1970s. For the decade 1960-1969, 1.1 percent of total working time was lost due to work stoppages; for the 1970-1976 period, this time increased to 5.1 percent.[18] These work stoppages may have affected productivity through disruption of the work process.

Other work force related causes that have been blamed for contributing to the productivity decline include increased absenteeism and personnel turnover as well as motivational factors and intangibles such as the "work ethic."[19]

CONCEPTUAL MODEL

Conceptually, let us assume that average labor productivity in mine i in time period j (ALP_{ij}) is functionally related to the groupings discussed above in the following manner:

$$ALP_{ij} = ALP\left[G_{ij}, L_{ij}, T_{ij}, C_{ij} | R_j\right]$$

where

$$G_{ij} = \left(g_{1ij}, g_{2ij}, \ldots, g_{nij}\right)$$

is a vector of the geological, topographic, and climatic conditions of mine i in time period j (M_{ij}).

The vector

$$L_{ij} = \left(l_{1ij}, l_{2ij}, \ldots, l_{pij}\right)$$

represents labor force related variables in M_{ij}. The terms l_{1ij} through l_{pij} are factors such as age distribution, experience levels, miner motivation, and health characteristics.

The vector

$$T_{ij} = \left(t_{1ij}, t_{2ij}, \ldots, t_{mij}\right)$$

captures the technological aspects of coal extraction in M_{ij}. This vector contains variables relating to the amount, kind, and vintage of capital employed; scale characteristics; and factor substitution. T_{ij} represents the production function characteristics of M_{ij}.

The vector

$$C_{ij} = \left(c_{1ij}, c_{2ij}, \ldots, c_{sij}\right)$$

captures the effects of capacity expansion—start-up labor costs, capital requirements, construction, etc.

The vector

$$R_j = \left(r_{1j}, r_{2j}, \ldots, r_{vj}\right)$$

contains terms that represent the institutional "rules of the game" existing in year j: The variables r_{1j} through r_{vj} are institutional factors such as state and federal regulations, union work rules, and mine inspection frequency. The institutional framework can be thought of as placing constraints or limits on the other terms of the vectors discussed above. That is, mining legislation concerning safety can be viewed as constraining the substitution characteristics of T_{ij} or the health characteristics of L_{ij}.

For any M_{ij}, tons per miner-shift (ALP_{ij}) is determined by the following:

$$(4\text{-}1) \qquad ALP_{ij} = \frac{TP_{ij}}{N_{ij}}$$

where

TP_{ij} = total product, M_{ij}

N_{ij} = miner-shift input, M_{ij}

The tons per miner-shift (ALP_{Ij}) for an industry containing q mines is simply total industry output divided by total industry miner-shifts input:

$$(4\text{-}2) \qquad ALP_{Ij} = \frac{\sum_{i=1}^{q} TP_{ij}}{\sum_{i=1}^{q} N_{ij}} = \frac{TP_{Ij}}{N_{Ij}}$$

where the subscript I denotes industry-level variables. Multiplying Eq. 4-1 by N_{ij} and substituting in Eq. 4-2 results in

$$(4\text{-}3) \qquad ALP_{Ij} = \sum_{i=1}^{q} \left(W_{ij}\right)\left(ALP_{ij}\right)$$

where $W_{ij} = \frac{N_{ij}}{N_{Ij}}$

The term W_{ij} is a weighting factor that equals M_{ij}'s portion of the total miner-shifts input for the industry. ALP_{Ij} is thus a function of both W_{ij} and ALP_{ij}; that is, industry-wide productivity is affected by the productivity function for each M_{ij} and the structure of the industry as a whole.

The term W_{ij} is affected by the entrance and exit of firms and by variations in N_{ij} for firms in constant operation. In conditions of price depression and output decline, the number of operating mines is reduced. If, as competitive theory suggests, these conditions force out the less efficient producers, then W_{ij} will increase for the efficient mines and ALP_{Ij} can increase with no change in ALP_{ij} for mines in operation. Given the recent increase in the number of active mines and coal tonnage, the W_{ij} term would be affected by the entrance of firms and the expansion of production. These conditions of prosperity would result in increased viability for the less efficient mines, and ALP_{Ij} would be depressed as a result of increases in W_{ij} for less efficient mines and decreases in W_{ij} for the more efficient mines.[20]

In addition to changes in industry structure as a result of market forces, it has been argued that the CMHSA has also altered the structure of the industry because many smaller mining companies found that meeting the legislated health and safety standards increased costs beyond the shut-down point.[21] Again, the resulting exit by a subset of firms would alter W_{ij} for the remaining firms, and ALP_{Ij} would be affected. The same change would occur with a union strike; W_{ij} for nonunion operating mines would increase and the overall ALP_{Ij} would be affected.

NOTES

[1]Zimmerman has estimated the long-term cost curve of the industry based upon secular depletion of resources. See Martin B. Zimmerman, "Modeling Depletion in a Mineral Industry: The Case of Coal," *The Bell Journal of Economics* 8(1):41-65.

[2]Ramesh Malhotra, "Factors Responsible for Variation in Productivity in Illinois Coal Mines," *Illinois Mineral Note 60* (Urbana: Illinois State Geological Survey, 1975), p. 4.

[3]General Accounting Office, *The State of Competition in the Coal Industry* (Springfield, Virginia: NTIS, 1977) p. i-a; and Executive Office of the President Council on Wage and Price Stability, *A Study of Coal Prices* (Washington, D.C.: Government Printing Office, 1976) pp. 40-42. It has

been argued, however, that the recent merger movement has led to quasi-oligopolistic structure: see Sidney Carroll and Daniel Friedman, *Industrial Organization in the U.S. Coal Industry since 1966* (Knoxville: Appalachian Resources Project, University of Tennessee, n.d.), Publication 39, p. 67.

[4]Ramesh Malhotra, "Productivity in Illinois Coal Mines," p. 4.

[5]C. L. Christensen and W. H. Andrews, "Physical Environment, Productivity, and Injuries in Underground Coal Mines," *Journal of Economics and Business* 26(3):184.

[6]Nelson and Neumann examine this relationship in detail and develop a theoretical model that allows a firm to pick an optimum point on this trade-off frontier. See George R. Neumann and Jon P. Nelson, "Regulation and Safety: The Effects of the Coal Mine Health and Safety Act of 1969," a revision of a paper prepared for the Department of Labor Conference "Evaluating the Effects of the Occupational Health and Safety Program," Annapolis, Maryland, March 18-19, 1975. Paper revised June 1978.

[7]The UMWA believes that the high productivity rates of the 1960s were "inflated"—that is, the coal companies took safety risks in an attempt to mine more coal with fewer men. Present lower productivity levels represent a safer mining philosophy. See Anonymous, "Productivity—and the UMWA," *Coal Age*, July 1975, p. 98.

[8]Daniel R. Walton and Peter W. Kauffman, *Preliminary Analysis of the Probable Causes of Decreased Coal Mining Productivity* (Reston, Virginia: Management Engineers, Inc., 1977), p. V-3.

[9]Richard H. Mason, "An Industry Thwarted, but Pushing Ahead," *Coal Mining and Processing*, July 1976, p. 55.

[10]Data from the Social Security Administration's Continuous Work History indicates that in 1963, 11.8 percent of the workers in the coal industry were less than 30 years old; in 1974, 35.0 percent were less than 30 years old.

[11]It has been argued that the safe mining of coal was unprofitable for many smaller mines; thus, the passage of the act forced them to exit the industry. See Ford Foundation, *Exploring Energy Sources*, (Washington, D.C.: Ford Foundation Energy Project, 1974), p. 7.

[12]Walton and Kauffman, *Analysis of the Probable Causes*, p. V1-1; Kramer Associates, *Determination of Labor Management Requirements in the Bituminous Coal Industry To Meet the Goals of Project Independence*, (Springfield, Virignia: NTIS, 1975), p.16; and Aubrey J. Cornette, "Ten-Year Outlook in U.S. Coal Mining" in *1976 Mining Yearbook* (Denver: Colorado Mining Association, 1976), p. 121.

[13]Energy and Environmental Analysis, Inc., *Laws and Regulations Affecting Coal with Summaries of Federal, State, and Local Laws and Regulations Pertaining to Air and Water Pollution Control, Reclamation, Diligence, and Health and Safety* (Springfield, Virginia: NTIS, 1976), p. IV-1. This research publication is an excellent source of information concerning mining legislation at all levels of government.

[14]*National Bituminous Coal Wage Agreement of 1974*, p. 8.

[15]See National Coal Association, *Coal Facts 1974-1975* (Washington, D.C.: National Coal Association, n.d.), p. 52.

[16]See note 10.

[17]A 1975 UMWA survey of new entrants in the coal industry revealed that 27.3 percent had less than a high school diploma compared to 70.6 percent of coal miners in the 1970 Census. See John Short and Associates, "Statistical Survey of Miners," mimeographed (Salt Lake City, Utah: John Short and Associates, 1977), p. 36. Preliminary draft referenced with author's permission.

[18]Bureau of Labor Statistics, U.S. Department of Labor, *Collective Bargaining in the Bituminous Coal Industry,* Report 514 (Washington, D.C.: U.S. Department of Labor, 1977), p. 5.

[19]Ted Mills, "Altering the Social Structure in Coal Mining: A Case Study," *Monthly Labor Review,* 99(10):3-4; Joseph Brennan, "Productivity—and the BCOA," *Coal Age,* July 1976, pp. 96-97; and Stanley Suboleski, "Boost Your Productivity by Adding Continuous Miners," *Coal Age,* March, 1975, p. 78.

[20]These changes in industry output and resulting effects upon average labor productivity are summarized in the industry long-term (variable capital) average product curve of competitive economic theory. Competitive theory argues an inverse relationship between industry output and industry average productivity due to scale characteristics of individual firm production functions (captured in the ALP functions) and the entrance and exit of "marginal" firms (captured in Eq. 4-3). Industry output change is determined by output price and the demand for coal.

[21]Ford Foundation, *Energy Sources,* p. 7.

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CHAPTER 5. EXAMINATION OF STATE-LEVEL DATA

Utilizing the conceptual model discussed in the last chapter, this chapter specifies an empirical counterpart to this conceptual model using state-level data.[1] The unit of observation upon which the following analysis is based is state i in year j (j = 1961, 1962, ..., 1975). Depending upon the year and mine type (deep or surface), 10 to 14 states were included in an annual cross-section. These annual cross-sections were pooled to provide sufficient degrees of freedom for estimation and to include cross-sectional variance in addition to the time series variance of the variables under examination.

When we examine state-level data, the variables are sample means of the mine-level characteristics for the state. These mean values for a given state are based upon a considerable range in mine populations (e.g., in 1975 New Mexico had 2 active deep mines compared with 855 in Kentucky). When used in estimating the influence of various mine characteristics upon productivity, the states with only a few mines would carry as much weight as states with more mines. However, industry-wide productivity is determined by both the productivity of a given state and its relative size (the weighting factor W_{ij}). Because of these factors, two approaches were taken:

1. Generalized least square model estimation. This regression method allows the relative weight of a state to be used in model estimation such that the states with more mines have more influence.[2]
2. Sample restriction. The number of deep-mine states examined was restricted to the states with more deep mines (Alabama, Colorado, Illinois, Kentucky, Ohio, Pennsylvania, Tennessee, Utah, Virginia, and West Virginia). These states represent over 99 percent of the total 1975 U.S. deep coal output and mine population.

Eliminating the other states results in a better model "fit" by reducing the number of atypical cases that are common in microlevel analysis and that are usually absorbed in the error term. On the other hand, the mean values hide many microlevel characteristics. Also, if there are large variances in firm characteristics within a given state, the mean value hides these "end points." Structure of the industry within states, i.e., characteristics of entering and exiting mines, is difficult to determine from state-level averages. The very concept of the coal industry now changes because the basic data for the producing population is provided by states rather than by firms; that is, M_{ij} now becomes state i in year j and

$$(5\text{-}1) \qquad ALP_{Ij} = \sum_{i=1}^{q} (W_{ij})(ALP_{ij})$$

where q = number of coal producing states
ALP_{Ij} = national productivity, year j
ALP_{ij} = state i productivity, year j
W_{ij} = state i weight, year j

As was the case in the mine-level conceptual model, ALP_{Ij} is affected by the values of both ALP_{ij} and W_{ij}. Changes in the values of W_{ij} in this case reflect regional shifts in the production of coal, while ALP_{ij} is related to the production characteristics within a given state.

DEEP MINES

Using Bureau of Mines estimates of tons per miner-shift as the dependent variable, a generalized least square linear regression model was specified for the pooled state data. Coefficients for the following independent variables were estimated:

1. CAP_{ij}, CAP^2_{ij}. These variables refer to the state average daily capacity of deep mines. The effects of scale are estimated in quadratic form with a positive sign expected for the CAP variable and a negative sign expected for the CAP^2 variable.

Changes in the average size of mines nationwide result from the entrance and exit of small mines. That is, large mines do not adjust to changing market conditions as frequently as small mines. Thus, increases or decreases in the daily mean capacity reflect decreases or increases, respectively, in the small mine end of the size distribution.

2. $DAYS_{ij}$. This variable is the mean number of active deep mining days (shifts) in state M_{ij}. A high number of active days implies that few mines in state M_{ij} operate sporadically and that the state industry is near capacity, i.e., on the production frontier. *A priori,* a positive coefficient for this variable is expected.

3. $CONT_{ij}$. This variable is a surrogate for mining technology and equals the portion of deep mine output in a given state produced by continuous mining. Because continuous mining is so capital intensive, it should be more productive than other techniques. However, it has been argued that the 1969 CMHSA affected continuous mining more than other mining techniques, and it actually became less productive.[3] Therefore, the expected coefficient sign is unknown.

4. $STOP_{ij}$. This variable is the percentage of total miner-shifts during a year lost to wildcat work stoppages. In addition to disrupting the work process, the strikes act as a barometer of the industry's industrial relations. *A priori*, a negative coefficient is expected.

5. $SEAM_{ij}$. This is the average seam thickness in inches in state M_{ij} and is included to capture geologic characteristics of coal mines. This variable does not change appreciably through time but exerts its influence in a cross-sectional manner.[4] The expected coefficient sign is positive.

6. $CLEAN_{ij}$. The average productivity figures published by the Bureau of Mines are calculated by dividing total output produced for sale by the total miner-shifts of input. Because some mines clean coal before marketing, net productivity (after cleaning) is less than gross productivity (before cleaning). To control for coal cleaning, $CLEAN_{ij}$ is entered as the portion of coal cleaned (in 10^{-3} units) of all coal produced. The expected sign for the coefficient of this variable is negative.

7. $INJRATE_{ij}$. The injury rate variable is the number of disabling injuries per 1000 miner-shifts of input in M_{ij} and acts as a surrogate for safety policy. A positive relationship between this variable and productivity is expected. Further, the incidence of injury at deep mines after 1970 should decline.

8. $EXPWORK_{ij}$, $CONWORK_{ij}$. These two variables are the percentage increase ($EXPWORK_{ij}$) or percentage decrease ($CONWORK_{ij}$) of a state's mining work force from year j-1 to year j. These variables are included to convey information about the relative condition of the coal mine labor market in M_{ij}.

If employment is increasing, firms are forced to pick workers with less experience and fewer skills than those already employed.[5] In addition, when an industry is expanding, equipment bottlenecks and construction efforts can retard productivity. The expected sign of EXPWORK is negative. CONWORK implies the opposite concerning the M_{ij} coal mine labor market: Labor demand is down, coal production is off, and firms are separating workers. A slack in the labor market could be expected to improve relative productivity because the first workers separated will be those with the least seniority and experience in the mines. This labor situation implies an increase in mean human capital for those workers still employed. If output is declining, competitive theory suggests that the least efficient producers will exit the industry first, leaving the more efficient mines in operation and thereby increase state-level productivity. The expected coefficient sign for CONWORK is negative.

At a theoretical level, both types of adjustment in the state's coal mining work force reflect movements up and down the average product curve of the state's aggregate production function. The "law" of variable proportions implies the same relationships discussed above: An expanding work force reduces average labor productivity; a declining work force increases average labor productivity.

9. DUMS1, DUMS2. These control variables capture the effects of the industry-wide strikes in 1971 (DUMS1) and 1974 (DUMS2). The expected sign for the coefficients of these variables is negative.

10. $INSM_{ij}$. This surrogate variable captures the effects of the Coal Mine Health and Safety Act. To relate the impact of the act to the relative intensiveness of enforcement, this variable takes on the mean number of federal Mine Enforcement and Safety Administration inspections per active deep mine in M_{ij}. This surrogate is far from a perfect measure of the hypothesized effects of the act, and state-level aggregation makes it difficult to determine microlevel impacts. However, INSM can be viewed as a measure of the general atmosphere of enforcement existing in any given state in the post-CMHSA era. The expected coefficient sign is negative.

11. D1975. This control variable takes on a value of 1 in 1975, a year of an exceptionally strong coal market and the only year in the sample in which the 1974 Bituminous Coal Wage Agreement was in effect.[6] The effect of a high price for coal upon productivity is negative; the helper provision of the 1974 BCWA should also depress productivity. *A priori*, the expected coefficient sign is negative.

Regression Results

Table 5-1 contains the generalized least squares regression (5-1, 5-2, and 5-3) for state-level deep mine data from 1961 through 1975.[7] Regression 5-1 covers the entire time period; regressions 5-2 and 5-3 break the model into a pre-1970 and post-1969 period. The influence of the independent variables can be examined in two contrasting periods of the coal industry: the early period (1961-1969) of nonregulation and poor market conditions that was characterized by high productivity, and the later period (1970-1975) of rapidly increasing coal prices, health and safety regulations, and declining productivity.

Table 5-1. Generalized Least Squares Regression Results, State-Level Deep Mining

Variable	Estimated Coefficients[a] Regression 5-1 (1961-75)	Regression 5-2 (1961-69)	Regression 5-3 (1970-75)
Constant	7.404	3.622	16.639
CAP	0.238 (4.65)	0.541(11.53)	0.092 (1.25)
CAP^2	0 (0.53)	-.007 (6.20)	0.001 (1.42)
DAYS	0.014 (1.29)	0.021 (2.84)	-0.011 (0.43)
CONT	0 (0.63)	0.001 (1.59)	-0.002 (1.42)
STOP	-0.048 (3.17)	-0.026 (1.92)	-0.029 (1.66)
SEAM	0.096 (0.94)	0.063 (0.79)	0.398 (2.19)
CLEAN	-0.018 (2.14)	-0.011 (1.38)	-0.056 (4.71)
INJRATE	7.740 (5.73)	10.043(11.48)	2.468 (0.97)
CONWORK	0.008 (0.26)	0.021 (1.00)	-0.018 (0.34)
EXPWORK	-0.001 (0.04)	0.014 (0.36)	-0.002 (0.07)
DUMS1	-2.136 (3.64)	—[b]	-1.053 (1.38)
DUMS2	-0.354 (0.50)	—[b]	-1.338 (1.58)
INSM	-0.065 (9.30)	—[b]	-0.028 (3.19)
D1975	-1.716 (2.20)	—[b]	-2.473 (3.48)
R^2	0.717	0.963	0.782
SEE	1.165	1.087	1.315
N	150	90	60

[a] *t* statistics in parentheses.

[b] Not applicable.

The capacity variables indicate that there were economies of scale in the early period and that they had a quadratic relationship with ALP. In the later period there appears to be no such advantage to mine size. DAYS, another variable that captures scale of operation, is significant in the early period regression but not in the later period model. There are several explanations for this. The average mine size almost doubled from the early period (average daily capacity 663 tons) to the later period (average daily capacity 1370 tons), depressing the influence of small mines. The CMHSA has a differential impact upon mines of different sizes, and the regulations require that larger mines be inspected more often. The productive advantage of larger producers may have been eliminated by the act. In the later period, inspections per mine and capacity are collinear, so it is difficult to separate the effects of the variables.[8]

Another variable that changes significantly between the two periods is INJRATE, the influence of injuries upon productivity. In the early period, productivity and injuries are positively related. In the later period, this relationship does not appear to be nearly so strong. In addition to the capacity, injury rate, and days active variables, the regression describing the entire period indicates that cleaning of coal, the 1971 strike, wildcat work stoppages, inspections per mine, and the 1975 dummy variable are all important in explaining productivity variation.

Sources of Productivity Variation

Industry-level productivity variation has two sources: (1) changes in the independent variables in each state's productivity function, and (2) changes in industry structure (shifts in W_{ij}).

Restating the linear productivity function estimated in the previous section in general form results in

$$(5\text{-}2) \qquad ALP_{ij} = \alpha + \sum_{k=1}^{r} \beta_k X_{kij} + \varepsilon_{ij}$$

where k denotes the independent variables, β_k the appropriate regression coefficients, and ε is the error term. Given that for an industry of q states,

$$(5\text{-}3) \qquad ALP_{Ij} = \sum_{i=1}^{q} (W_{ij})(ALP_{ij})$$

Substituting Eq. 5-2 and assuming that ε has an expected value of zero and constant variance results in

$$(5\text{-}4) \qquad ALP_{Ij} = \alpha + \sum_{k=1}^{r} \sum_{i=1}^{q} \beta_k (W_{ij})(X_{kij})$$

for an industry of q states with r independent variables in the productivity functions for any year j. Equation 5-4 allows one to uncover the sources of productivity variation over time by examining the weighted variables of the productivity function. The weighted values of the independent variables become a function of changes in both x_{kij} and W_{ij}, that is, both industry structure and the functional variables.

Using the weighting process to control for the redistribution of miner-shift input between states, Table 5-2 contains the weighted values of the independent variables estimated by regression 5-1. Overall, the estimated ALP values tend to follow actual productivity in a given year, although the model consistently underestimates ALP in the 1960s. During the period of decline (1970-1975), mine size had a positive impact upon productivity through 1974, although the entrance of small mines in 1975 reduced productivity approximately 0.2 ton per miner-shift.

Table 5-2. Sources of Productivity Variation in Deep Mine States, 1965-1975

Variable[a]	1965	1969	1970	1971	1972	1973	1974	1975
CAP	1.13	2.07	2.30	2.44	2.71	3.04	3.11	2.86
DAYS	3.16	3.15	3.21	2.95	3.20	3.24	2.88	3.20
SEAM	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
CLEAN	-1.35	-1.31	-1.28	-1.30	-1.25	-1.28	-1.17	-1.10
INJRATE	2.66	2.69	2.78	2.98	2.98	2.65	2.01	2.08
CONWORK	0	-0.03	0	0	0	0	0	0
EXPWORK	0	0	0	0	0	0	0	-0.01
DUMS1	0	0	0	-2.14	0	0	0	0
DUMS2	0	0	0	0	0	0	-0.35	0
STOP	-0.25	-0.63	-0.56	-0.69	-0.75	-0.83	-0.90	-1.69
D1975	0	0	0	0	0	0	0	-1.72
INSM	0	0	-0.31	-0.89	-1.85	-4.02	-3.31	-2.77
Constant	7.40	7.40	7.40	7.40	7.40	7.40	7.40	7.40
Estimated ALP	13.23	13.84	14.04	11.25	12.94	10.70	10.17	8.75
Actual ALP	14.0	15.60	13.74	12.04	11.87	11.63	10.90	9.52

[a]The variable CONT is excluded because the estimated coefficient is zero.

The decline in the rate of injuries in the late 1970s reduced productivity by 0.5 to 0.8 ton per miner-shift, given the estimated trade-off between safety and productivity for the entire time period. That is, changing safety policies resulted in a reduction in disabling injuries per 1000 miner-shifts from 0.3846 in 1972 to 0.2691 in 1975 and cost approximately 0.9 ton per miner-shift, *ceteris paribus*.

Of the approximately 4 tons per miner-shift that were lost from 1970 through 1975, wildcat work stoppages account for approximately 1.1 tons. In addition, the 1971 strike is estimated to have had a strong negative impact upon productivity in that year. These data indicate the work stoppages in the 1970s have had significant impacts upon productivity.

The CMHSA surrogate, INSM, explains a significant portion of the productivity decline. The negative effect of this variable is greatest in 1973. The control variable D1975 is also significant and negative, indicating that the atypical market conditions (high prices and coal demand) combined with the union wage agreement depressed productivity in 1975. The variables CONT, EXPWORK, CONWORK, SEAM, CLEAN, DAYS, AND DUMS2 explain little of the productivity variation of the 1970s.

Based upon the regression of state-level characteristics, the following explanation of productivity decline in the 1970s appears reasonable. From 1970 through 1974, work stoppages and the CMHSA appear to be the major cause of productivity decline. In 1975, the influence of the wage agreement and market conditions, in addition to a considerable worsening of the work stoppage situation, appear to take over as the major depressants of productivity.

Changes in the Distribution of Deep Mine Labor Inputs

As shown in Eq. 5-3, productivity variation can orginate from changes in the geographic distribution of production (W_{ij}) or in the state productivity functions (ALP_{ij}). Table 5-3 details W_{ij} for j equals 1969 and 1975. The total ALP figures are the sum of the weights and the weighted total ALP_{ij} for each j. To separate the effects of W_{ij} from ALP_{ij}, ALP_{ij} was held constant and only W_{ij} varied. Substituting in Eq. 5-3 results in

$$(5\text{-}5) \qquad ALP_{I,\,1975} = \sum_{i=1}^{20} (W_{i,1975})(ALP_{i,1969}) = 15.8$$

That is, if each state's productivity did not change after 1969 and the only change was in the geographic distribution of production, $ALP_{I,1975}$ would

Table 5-3. State Distribution of Deep Mine Labor Input, 1969 and 1975

	1969		1975	
State	Weight	ALP	Weight	ALP
Alabama	0.0388	10.8	0.0339	7.2
Arkansas	.0004	6.3	.0000	—[a]
Colorado	.0119	13.7	.0101	10.4
Illinois	.0591	22.9	.0729	14.3
Indiana	.0053	17.7	.0004	16.1
Iowa	.0006	20.9	.0006	22.1
Kentucky	.1628	17.7	.1730	12.4
Maryland	.0013	11.3	.0003	9.6
Missouri	.0000	2.4	.0000	—[a]
Montana	.0000	8.2	.0000	—[a]
New Mexico	.0015	24.9	.0027	9.3
Ohio	.0489	17.3	.0615	8.2
Oklahoma	.0014	3.7	.0000	—[a]
Pennsylvania	.1812	13.9	.1770	8.2
Tennessee	.0127	15.8	.0126	9.9
Utah	.0126	16.6	.0164	13.9
Virginia	.0911	15.0	.0880	8.6
Washington	.0004	6.6	.0001	5.3
West Virginia	.3697	14.8	.3487	8.2
Wyoming	.0005	11.1	.0013	10.8
Total[b]	1.0000	15.7	1.0000	9.5

[a]Not applicable.

[b]Totals may not add to 1 due to rounding.

have been 15.8 tons per miner-shift. $ALP_{i,1969}$ was 15.7 tons per miner-shift indicating that very little of the 1969-1975 productivity change in deep mines occurred as a result of shifts in the geographic distribution of production.

Injury Rate Experience

Table 5-4 contains the unweighted mean values of disabling injuries per 1000 miner-shifts input for the pre- and post-CMHSA period. The means for these two periods are somewhat surprising, with an actual increase in the unweighted injury rate after implementation of the CMHSA. However, the standard deviation for this period is large, indicating a larger dispersion of injury rates during the second period. Given this, the t value indicates that the difference between the two rates of injury is not statistically significant.

Table 5-4. Unweighted Mean Disabling Injury Rate for 1000 Miner-Shifts, Deep Mines

Period	N	Mean Injury Rate	Standard Deviation	t Value	Degrees of Freedom
1960-1969	193	0.3396	0.280	1.66	138
1970-1975	107	0.4324	0.539		

Impact of State-Level Deep Mining Regulations

Prior to the passage of the CMHSA, federal regulations were aimed toward coal mine disasters (accidents involving five or more fatalities). However, individual states had a wide variety of laws regulating coal mines. Theoretically, the states with restrictive deep mine regulations prior to the passage of the CMHSA would be expected to have to make less of an adjustment to the new regulations. This implies that the CMHSA would affect these states' productivity less severely than the productivity of other states. Further, the experience of these states after implementation of the act would give insights to how other states might adjust to the act over the long run.

To test these propositions, five states with pre-CMHSA restrictive regulations were selected: Pennsylvania, Ohio, Illinois, West Virginia, and Kentucky. These states were selected subjectively based upon research completed by Energy and Environmental Analysis, Inc.[9] A new variable, RES, was created; it took on a value of 1 if one of these states was a unit of observation, 0 otherwise. Regression 5-1 in Table 5-1 was recomputed with the addition of the following variable: (RES · INSM). The coefficient for this variable was insignificant (t = 0.359), indicating there was no difference in the productivity experience between these selected states and those with less restrictive regulations.

Summary

The analysis of the state-level deep mine data can be summarized as follows:

1. Resource base characteristics. Average seam thickness and mechanical cleaning were both significant in explaining productivity differences between states. However, these variables explained little of the post-1969 decline.

2. Technology. The average mine size in a state, reflecting mainly changes in the number of small producers, was significant and indicated economies of scale. This variable accounted for a slight increase in productivity through 1974, then a slight drop. The portion of output mined by continuous miners did not explain productivity variation.

3. Labor force factors. Although expansion or contraction of a state's work force did not significantly affect productivity, the sharp rise in work stoppages during the 1970s explained a large portion of the decline. In addition, earlier work examining the effect of changes in the age composition of the work force as it relates to productivity concluded that the net effect was positive, rather than contributing to the decline.[10]

4. Institutional factors. Both of the surrogate institutional variables—D1975 and INSM—explained significant portions of the post-1969 decline. In addition, decreases in the rate of disabling injuries—due, perhaps, to the CMHSA—resulted in depressed productivity in 1974 and 1975. For the entire post-1969 period, however, injury rates did not change significantly. The D1975 control variable also picked up the atypical market conditions of that year (high prices and surges in demand to replenish stockpiles lost during the 1974 strike). How much of the negative impact is due to these market conditions alone is unknown.[11]

SURFACE MINES

In 1974, the Bureau of Mines changed the tabulation format of state surface mining characteristics. Mines that were utilizing both strip and auger techniques were no longer divided; they were put into a new category—

strip/auger. To have a consistent series for analysis, new variables representing total surface mining output, mines, days active, and work force were created from the data covering total production (surface and deep) and deep production. The tons per miner-shift variable was created from surface miner-shifts and total surface output.

Using average tons per miner-shift in all surface mining as the dependent variable, coefficients for the following independent variables were estimated:

1. CAP_{ij}, CAP^2_{ij}. These two variables are the daily output of the average size surface mine in M_{ij}. Because of large variances in the average size mine among states, these two variables are in 100-ton units rather than the 1000-ton units for deep mines. The expected sign of the CAP variable is positive; the expected sign of the CAP^2 variable is negative.

2. $CONWORK_{ij}$, $EXPWORK_{ij}$. These two variables (like those for state-level deep mines) capture the general condition of the labor market for surface miners in state M_{ij}. As suggested in the deep mining analysis, the expected signs for both variables are negative.

3. $DAYS_{ij}$. This variable is the average number of active days of operation by surface mines in M_{ij}. One would expect that the closer mines are to capacity operation, i.e., near the "production frontier," the more productive they are. *A priori*, the expected sign of this variable is positive.

4. $CLEAN_{ij}$. This variable, as in the deep mine analysis, is the portion of total surface output cleaned. *A priori*, the expected sign of the estimated coefficient is negative.

5. $DUMS1_{ij}$, $DUMS2_{ij}$. These two variables control for industry-wide strikes in 1971 (DUMS1) and 1974 (DUMS2). Because many surface mines are not organized by the UMWA, the effect of these strikes is unclear. As was the case during the strike of 1977, surface mine production may have increased to make up for the decline in deep mine output; however, some surface miners were organized by UMWA or sympathized with the strikes and stopped work. *A priori*, the expected sign is unknown.

6. $INSUR_{ij}$. The variable is the number of disabling injuries per 1000 miner-shifts of operation in state M_{ij}. The expected sign is positive.

7. $LT6_{ij}$. This variable is the portion of all power shovels and dragline excavators in M_{ij} that have a capacity of less than 6 cubic yards.

This variable is included to capture technological aspects of surface mining in M_{ij}. It would be expected that the lack of large surface mining equipment would be detrimental to productivity, so the expected sign for this coefficient is negative.

8. $RATIO_{ij}$. This variable is the number of feet of overburden that must be removed to mine a foot of coal. *A priori,* one would expect the estimated coefficient to be negative.[12]

9. $RECLAIM_{ij}$. This is a control variable that takes on a value of 1 a year after the passage of reclamation laws in state M_{ij}. The expected sign for the estimated coefficient is negative.

Table 5-5 lists the titles of the state reclamation laws and the years of enactment. The RECLAIM variable implicitly assumes that the impact of each state law is the same and that this impact is the same over time. Obviously, state laws and enforcement differ, so the impact will vary between states. Further, the impact of a given law in a given state would be expected to vary from year to year as the enforcement staff of the state gears up and gains experience and as the miners themselves learn to operate under the new institutional framework. Modeling these differential impacts is difficult, if not impossible; therefore, the simpler dummy variable approach was taken.

In earlier analysis of these surface data, miner age distribution variables were included. However, these variables were not found to be significant in explaining surface productivity variation and were deleted here.

Regression Results

Table 5-6 contains the regression results for the state-level surface mine data. Preliminary regression results indicated that a separate estimation of an Appalachian model (Alabama, Kentucky, West Virginia, Tennessee, Ohio, Maryland, Pennsylvania, and Virginia) and a non-Appalachian model was appropriate. The estimated coefficients for these two models will be discussed separately.

The capacity variable in the Appalachian model was significant and positive, as expected. The quadratic capacity model was included in earlier regressions, and the results indicated that a simple linear relationship had the best "fit." Average mine capacity in M_{ij} explains almost 30 percent of the productivity variation among the Appalachian states for the period examined.

Table 5-5. State Reclamation Laws

State	Law	Year of Enactment Plus Lag
Arkansas	Open Cut Land Reclamation Act of 1971	1972
Colorado	Open Mining Land Reclamation Act of 1973	1974
Illinois	Surface Mined Land Conservation and Reclamation Act	1972
Indiana	"An Act Regulating Surface Mining of Coal, Clay, and Shale"	1969
Iowa	"Surface Mining," 1967	1968
Kansas	Mined Land Conservation and Reclamation Act	1973
Kentucky	"Strip Mining," revised statutes	1974
Maryland	Maryland Strip Mining Law	1971
Missouri	Mining Land Reclamation Act of 1971	1972
Montana	Montana Strip and Underground Mine Reclamation Act	1976
New Mexico	New Mexico Coal Surface Mining Act	1973
Ohio	Ohio Strip Mine Law	1973
Oklahoma	Mining Lands Reclamation Act	1972
Pennsylvania	Surface Mining Conservation and Reclamation Act	1973
Tennessee	Tennessee Surface Mining Law	1975
Virginia	"Surface Mining of Coal"	1973
Washington	"Surface Mining"	1972
West Virginia	West Virginia Surface Mining and Reclamation Act	1972
Wyoming	Wyoming Environmental Quality Act of 1973	1974

Source: Management Engineers, Inc., *Preliminary Analysis of the Probable Causes of Decreased Coal Mining Productivity (1969-1976)* (Reston, Virginia: Management Engineers, Inc., 1977) pp. VI-2 through VI-10.

Table 5-6. Generalized Least Squares Regression Results, State-Level Surface Mining

Variable	Estimated Coefficients[a] Appalachia	Non-Appalachia
Constant	41.81	33.966
CAP	0.407 (11.29)	0.077 (6.03)
CAP^2	—[b]	-0.00003 (2.21)
CLEAN	-16.396 (5.32)	-0.177 (1.58)
LT6	-0.063 (1.61)	0.037 (0.81)
DUMS1	0.778 (0.44)	-1.278 (0.39)
DUMS2	-3.752 (2.04)	0.069 (0.02)
RECLAIM	-3.852 (2.97)	-7.348 (3.45)
INSUR	2.597 (0.27)	-6.887 (2.08)
DAYS	0.006 (0.39)	0.016 (0.72)
EXPWORK	-0.032 (1.00)	-0.002 (0.84)
CONWORK	0.004 (0.06)	0.129 (1.47)
RATIO	-1.319 (5.97)	-1.064 (8.11)
R^2	0.661	0.645
SEE	1.37	1.48
N	120	215

[a] *t* statistics in parentheses.
[b] Not applicable.

The RECLAIM variable had both a high level of significance and the expected sign. The standard error for this coefficient was 1.30, indicating a relatively large range for the actual coefficient value. Overburden ratio, as expected, was negative and significant.

As was the case with deep mining, mechanical cleaning of coal was detrimental to productivity. Although the 1974 strike was detrimental to productivity in that year, the 1971 strike appeared not to affect productivity significantly. Similar strike results were obtained in the deep mine analysis.

The non-Appalachian surface model differed somewhat from the Appalachian model. Perhaps one of the most troubling results was the estimated negative impact of disabling injuries upon ALP. One could attribute this result to the onsite disruption caused by an accident. The influence appeared to be mainly cross-sectional and explained little of the downward trend in non-Appalachian productivity in the 1970s.

The RECLAIM variable was also significant and negative, although twice as large as the Appalachian value. The estimated coefficient indicated that reclamation laws in the non-Appalachian states cost an average of 7.3 tons per miner-shift. Neither strike variable was significant in the non-Appalachian model. In addition, the quadratic capacity variables were of the expected sign and significant.

Sources of Productivity Variation

Table 5-7 contains the weighted independent variables multiplied by their respective regression coefficients for the Appalachian surface model.

Table 5-7. Sources of Productivity Variation, Surface Mines, Appalachian States

Variable	1965	1968	1970	1971	1972	1973	1974	1975
CAP	14.31	15.25	15.76	15.56	15.59	15.02	13.18	10.47
CLEAN	-5.08	-4.92	-3.94	-2.78	-3.11	-3.11	-2.78	-2.62
LT6	-5.07	-4.97	-4.60	-4.77	-4.93	-5.03	-3.95	-4.37
DUMS1	0	0	0	0.78	0	0	0	0
DUMS2	0	0	0	0	0	0	-3.75	0
RECLAIM	0	0	0	-0.04	-0.59	-2.28	-3.51	-3.44
INSUR	0.45	0.36	0.39	0.47	0.36	0.34	0.23	0.32
DAYS	1.31	1.34	1.28	1.24	1.23	1.21	1.40	1.37
EXPWORK	-0.20	-0.11	-1.10	-0.48	-0.10	-0.24	-1.14	-0.60
CONWORK	-0.02	0	0	0	-0.02	-0.02	0	-0.01
RATIO	-17.02	-18.14	-18.72	-18.8	-19.02	-18.95	-18.59	-18.92
Constant	41.81	41.81	41.81	41.81	41.81	41.81	41.81	41.81
Estimated ALP	30.49	30.62	30.91	32.99	31.22	28.75	22.90	24.01
Actual ALP	30.49	32.46	34.05	33.22	33.16	32.24	23.83	21.72

Although the Appalachian model consistently underestimates productivity in the earlier years, it captures the trend fairly well from 1971 to 1975. Almost all of the decline in the 1970s can be attributed to the decline in the average size of mine and the implementation of state reclamation laws. The 1974 strike also had a significant, 1-year impact upon productivity.

The decline in average mine size can be attributed to the entrance of small producers in reaction to the market conditions of 1973 and 1974 (during the Arab oil embargo). Table 5-8 details the active Appalachian surface mine population and U.S. price per surface ton for the 1970s.

Table 5-8. Changes in Surface Mine Population, 1970-1975, Appalachian States

	Active Mine Population					
State	1970	1971	1972	1973	1974	1975
Alabama	94	99	102	84	117	216
Kentucky	617	878	761	833	986	1505
Maryland	34	45	50	54	61	67
Ohio	262	267	271	207	229	315
Pennsylvania	609	584	677	830	929	703
Tennessee	87	108	103	73	75	104
Virginia	237	315	366	350	332	371
West Virginia	571	426	387	410	307	369
Total	2511	2722	2717	2841	3036	3650
Average mine output/day	387.3	382.4	383.2	369.2	324.0	257.5
Average price/ton, f.o.b. mine	$4.69	$5.19	$5.48	$6.10	$11.10	$13.10

Source: Bureau of Mines, U.S. Department of the Interior, *Minerals Yearbook* (Washington, D.C.: Government Printing Office, various years).

Small surface mines can open and close relatively easily because of the low capital requirements and the option of leasing equipment. As a result, this segment of the industry can respond fairly rapidly to changes in the price of coal, which can be seen from the growth in the number of surface mines from 1970 to 1971 and 1974 to 1975. The requirements of the 1977 Surface Mine Control and Reclamation Act (collection ponds built or examined by certified engineers, core samples, etc.) may curb the ability of small mines to react to changing price and market conditions. The entrance of small producers after 1972 was estimated to have reduced Appalachian surface productivity by 5 tons per miner-shift.

The implementation of reclamation laws in Appalachia reduced productivity by an estimated 3.9 tons per miner-shift. Because the reclamation laws were passed in progression, total Appalachian productivity was affected by a given state's implementing its law (changing its ALP function) weighted by the state's contribution to output (W_{ij}). The effect, then, was cumulative through the 1970s as each state's law became implemented.

Table 5-9 details sources of productivity variation in the non-Appalachian states. The trend in ALP in these states does not show a sharp decline as was experienced in deep mining and in Appalachian surface mines. The estimated negative impact of state reclamation laws through 1973 was almost totally offset by the increase in productivity attributed to mine scale. This influence is due to the large capacity surface mine openings in the far West. However, from 1973 to 1975 the same type of market influence that was evident in the Appalachian model became apparent as decreases in average mine size drove down productivity. Tabel 5-10 details changes in non-Appalachian mine population and U.S. price levels during the 1970s.

Changes in the Distribution of Surface Mine Labor Inputs

Equation 5-1 was used to isolate productivity variation originating solely from geographic shifts in the production of coal, and only the values of W_{ij} were allowed to vary. Table 5-11 details W_{ij} and ALP_{ij} for j equals 1969 and 1975.

By comparing the 1969 weights with the 1975 weights, shifts in the regional production of coal can be examined. The major shifts in Appalachia were a decrease in Ohio's share and a large increase in Kentucky's share. The largest changes in the non-Appalachian production were a decrease in Illinois's production and production increases in Montana, Colorado, and Wyoming.

Table 5-9. Sources of Productivity Variation, Surface Mines, Non-Appalachian States

Variable	1965	1968	1970	1971	1972	1973	1974	1975
Capacity	12.68	17.25	15.34	18.86	20.17	21.56	19.73	17.76
CLEAN	-0.12	-0.13	-0.11	-0.11	-0.10	-0.09	-0.09	-0.09
RATIO	-11.67	-12.69	-14.13	-13.52	-13.65	-13.06	-12.80	-13.39
RECLAIM	0	-0.12	-1.78	-1.83	-5.79	-6.08	-6.71	-6.72
DUMS2	0	0	0	0	0	0	0.07	0
DAYSUR	4.34	4.46	4.83	4.44	4.53	4.35	4.69	4.65
DUMS1	0	0	0	-1.28	0	0	0	0
CONWORK	-0.25	-0.16	-0.16	-0.15	-0.06	-0.17	-0.10	-0.03
EXPWORK	-0.01	-0.02	-0.03	-0.33	-0.03	-0.01	-0.03	-0.05
INSUR	-1.55	-1.41	-1.38	-1.23	-1.18	-1.14	-0.83	-0.82
LT6	1.44	1.51	1.41	1.30	1.36	1.34	1.22	1.35
Constant	33.97	33.97	33.97	33.97	33.97	33.97	33.97	33.97
Estimated ALP	39.13	42.66	37.96	40.12	39.22	40.67	39.12	36.63
Actual ALP*	37.31	39.81	41.26	41.97	42.29	43.76	37.99	36.87

*This may differ from published values due to exclusion of missing values.

Table 5-10. Changes in Surface Mine Population, 1970-1975, Non-Appalachian States

State	Active Mine Population 1970	1971	1972	1973	1974	1975
Arkansas	6	6	7	10	7	8
Colorado	8	9	8	9	8	15
Illinois	31	36	33	32	32	37
Indiana	32	34	36	36	39	60
Iowa	10	11	9	10	6	8
Kansas	5	4	4	4	7	4
Missouri	9	10	11	10	10	13
Montana	4	6	6	8	8	8
New Mexico	3	2	4	5	5	4
North Dakota	20	15	14	12	13	10
Oklahoma	9	8	13	11	14	31
Washington	1	2	2	2	2	3
Wyoming	9	10	13	12	14	15
Total	147	153	160	161	165	216
Average mine output/day	2268.7	2930.4	2966.7	3200.5	2974.7	2726.6
Average price per ton, f.o.b. mine	$4.69	$5.19	$5.48	$6.10	$11.10	$13.10

Source: Bureau of Mines, U.S. Department of Interior, *Minerals Yearbook* (Washington, D.C.: Government Printing Office, various years).

Table 5-11. State Distribution of Surface Mine Labor Input, 1969 and 1975

State (i)	1969 Weight ($W_{i, 1969}$)	1969 $ALP_{i, 1969}$	1975 Weight ($W_{i, 1975}$)	1975 $ALP_{i, 1975}$
Appalachian				
Alabama	0.0657	31.7	0.1047	15.3
Kentucky	.2449	45.4	.3346	24.7
Maryland	.0093	29.1	.0123	21.7
Pennsylvania	.2448	22.7	.2010	20.6
Ohio	.2258	35.7	.1290	26.0
Tennessee	.0302	29.6	.0267	17.7
Virginia	.0322	39.3	.0660	19.7
West Virginia	.1471	31.3	.1259	17.0
Total	1.0000	33.9	1.0000	21.5
Non-Appalachian				
Arkansas	0.0066	13.7	0.0014	8.3
Colorado	.0018	57.5	.0259	45.6
Illinois	.5050	37.6	.3373	24.2
Indiana	.2421	40.6	.2420	29.7
Iowa	.0144	20.3	.0036	18.0
Kansas	.0345	20.8	.0124	13.8
Missouri	.0647	27.8	.0581	21.1
Montana	.0041	132.7	.0412	127.2
New Mexico	.0305	65.2	.0537	51.2
North Dakota	.0334	76.6	.0349	86.9
Oklahoma	.0305	30.7	.0457	14.8
Washington	.0002	11.5	.0347	27.5
Wyoming	.0321	54.3	.1094	67.7
Total	1.0000	38.9	1.0000	38.1

Totals may not add to 1.00 due to rounding.

Using Eq. 5-5 to compute changes in ALP due to geographic shifts in production, the $ALP_{I,1975}$ value for Appalachia was 35.5 tons (compared with an actual 21.5 tons) and the $ALP_{I,1975}$ value for the non-Appalachian states was 44.2 (compared with an actual 38.1 tons). That is, surface mine production shifted toward the more productive states from 1969 through 1975, as competitive economic theory would suggest. The loss in productivity indicated by the examination of regional aggregates actually understates the true productivity loss when the interstate distribution of production is considered.

Summary

Declines in surface mine productivity in the 1970s can be attributed almost entirely to the entrance of small producers and the implementation of state reclamation laws. The 1974 coal strike also depressed Appalachian coal field productivity in that year.

Although the other model variables did little to explain productivity decline, the overburden ratio variable might also have been important as a source of decline if more recent data had been available. Like mine size, one would expect that less favorable overburden ratios would become economically feasible as the price of coal increased.

NOTES

[1]See Appendix B for a description of these data.

[2]The weight that a state received in the model estimation was the reciprocal of the variance of the residuals of an ordinary least squares regression. In general, this was directly related to the amount of the state's coal output.

[3]Joe G. Baker and Robert J. Gaston, *Coal Mine Labor Productivity: Review of Issues and Evidence, A Report to the President's Commission on Coal* (Oak Ridge, Tennessee: Oak Ridge Associated Universities, 1979), p. 13.

[4]The *Minerals Yearbook* publishes seam thickness data in 5-year intervals. Because changes in seam thickness are virtually nonexistent for each state over time, the most recent published seam thickness value was used for analysis in the years for which data was not published.

[5]In earlier work, variables that captured the portion of younger and older workers in the work force were tested. The younger workers (less than 25 years old) were found to affect productivity positively while older workers (more than 50 years) had a negative influence. These variables had a secular nature to their change and explained little of the productivity drop of the 1970s. They were dropped from the analysis here so that one more year of observation (1975) could be added. See Joe G. Baker, *Determinants of Coal Mine Labor Productivity Change: A Progress Report* (Oak Ridge, Tennessee: Oak Ridge Associated Universities, 1979), pp. 51-52.

[6]The price of coal per ton jumped from $8.53 in 1973 to $15.75 in 1974 and to $18.75 in 1975.

[7]See Appendix C for detailed statistics.

[8]The model was rerun using CMHSA inspections per 100,000 tons of output (INTU), and none of the coefficients changed significantly. The new variable was not collinear with mine size, indicating that the high R statistic between INSM and capacity did not influence the estimation. See Appendix C for the model using INTU.

[9]Energy and Environmental Analysis, Inc., *Laws and Regulations Affecting Coal with Summaries of Federal, State, and Local Laws and Regulations Pertaining to Air and Water Pollution Control, Reclamation, Diligence, and Health and Safety* (Springfield, Virginia: NTIS, 1976).

[10]See note 5.

[11]See the discussion of price in Chapter 7.

[12]As was the case with seam thickness data in the deep mine model, overburden ratio data were available in 5-year increments, with the last year available being 1970. Overburden ratios also exhibited much more variance within a given state than seam thickness. For the period 1970-1975, changes in overburden ratio, as used in this study, reflect only cross-sectional shifts. It is not known how much this biases the results.

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CHAPTER 6. EXAMINATION OF MINE-LEVEL DATA

OVERVIEW AND SUMMARY

In order to test further the empirical relationships established in the last chapter, this chapter applies a similar conceptual and analytical framework of productivity analysis to mine-level data. In addition to confirming the macrodata results of the last chapter, these microdata provide further insights into determining mine productivity by allowing for the examination of such characteristics as technology employed, mine size and age, and changes in the structure of the industry.

The data examined here are from three sources: surface and deep mine data from Illinois for the period 1965-1976; deep mine data from Ohio for the period 1965-1977; and surface and deep mine data from the DOE microdata file focusing on Pike County, Kentucky, for 1974-1977. Each of these data sets and analysis results will be discussed separately in this chapter.

The mine-level results generally agree with the state-level findings discussed in the previous chapter. Major causes of productivity decline in deep mines have been the CMHSA, market conditions, strikes, and the wage agreement of 1974. Changes in the structure of the industry by firms entering and exiting apparently did not effectively depress productivity. Mine age was a significant determinant of productivity but contributed little to productivity change over the period examined.

One major insight gleaned from the mine-level analysis was the influence of mining technique upon productivity. While lack of variance and collinearity eliminated investigation of technique with the Illinois data, both the Ohio and DOE microdata analyses lent support to the argument that the CMHSA has generally had a more severe impact upon continuous mining than other techniques.

ILLINOIS COAL INDUSTRY

The coal industry in Illinois has experienced much the same patterns as the national industry in terms of active mines, prices, and productivity. Table 6-1 compares these data for the Illinois industry and the national industry from 1965 through 1975. Although the Illinois industry generally has higher productivity and lower output prices than the national industry, the trend of these variables is much the same over the period examined.

Table 6-1. Descriptive Comparison of the Illinois and U.S. Coal Industries

	Tons/Miner-Shift		Number of Active Mines		Price per Ton, f.o.b. Mine	
	Illinois	U.S.	Illinois	U.S.	Illinois	U.S.
Deep Mines						
1965	21.0	14.0	41	5280	$ 3.80	$ 4.90
1969	22.9	15.6	28	3097	4.40	5.60
1973	18.1	11.7	23	1737	7.50	10.80
1974	15.8	11.3	23	2039	11.10	19.90
1975	14.3	9.5	21	2292	16.30	26.30
1976	13.4	9.1	23	2422	17.80	26.60
Surface Mines						
1965	37.5	32.0	49	1541	3.70	3.60
1969	37.6	35.7	31	1551	4.20	4.00
1973	35.8	36.3	32	2309	5.80	6.10
1974	26.5	33.2	32	3040	10.00	11.10
1975	24.2	26.7	37	3660	12.70	13.10
1976	22.7	26.4	39	3739	13.80	14.00

Source: Bureau of Mines, *Minerals Yearbook,* various years.

The deep mines in Illinois are generally larger than most deep mines, and the coal tends to be in very thick seams (6 feet or more). These two factors contribute to the high productivity of the Illinois industry. The Illinois surface mines are similar to the western surface mines in that topography allows for mainly area mining versus the hilltop and contour mining found in the Appalachian region. The empirical results obtained from the analysis of the Illinois surface mines should be viewed accordingly.

The State of Illinois has been collecting coal industry data annually since 1881.[1] These mine-level data are perhaps the most comprehensive series collected by any state and include information concerning mine ownership, new mines and mines abandoned, annual output, employment, days active, equipment, geology, and injury characteristics. These cross-sectional data descriptions of the industry were pooled for the 11-year period 1965-1976.

Deep Mine Results

Table 6-2 defines the independent variables used to estimate the Illinois deep mine productivity function. CAP_{ij} is expected to be positive and CAP^2_{ij} negative, indicating a "humped" average product curve. INJ_{ij} is expected to be positively related to productivity as discussed in the conceptual model. The CMHSA control and D1975 control are both expected to be negative. The use of a zero-one control for the CMHSA assumes that its impact will be the same over the period examined. In earlier regressions, the number of inspections per mine was used to capture a differential rate of impact over the life of the act; however, the zero-one control gave a better "fit." D1975 is interpreted in the same way as in the state model.

Table 6-2. Illinois Coal Industry Variable Definitions, Deep Mines

Variable	Definition
CAP_{ij}	Daily mine output, 10^3 tons
CAP^2_{ij}	CAP term squared
INJ_{ij}	Number of nonfatal injuries involving 7 or more days of lost time; rate per 1000 miner-shifts, mine M_{ij}
$CMHSA_{ij}$	Control variable; equals 1 for j = 1970-1976
$D1975_{ij}$	Control variable; equals 1 for j = 1975-1976
$IDLE_{ij}$	Control variable; equals 1 if mine M_{ij} was active less than 150 days during year j
$EXPWORK_{ij}$, $CONWORK_{ij}$	Percentage increase (EXPWORK) or decrease (CONWORK) in mine M_{ij} work force from j-1 to j
$SEAM_{ij}$	Average coal seam thickness in inches
$STRIKE1_{ij}$	Control variable, equals 1 if j = 1971
$STRIKE2_{ij}$	Control variable, equals 1 if j = 1974
NEW_{ij}	Control variable, equals 1 if mine M_{ij} is less than 2 years old
OLD_{ij}	Control variable, equals 1 if M_{ij} is 7 or more years old

$IDLE_{ij}$ is expected to be negative; it is measuring less than capacity operation. $EXPWORK_{ij}$ and $CONWORK_{ij}$ are both expected to have negative coefficients. As workers are added or deleted from a mine work force, one would expect the marginal worker (last hired, first fired) to have less seniority and, therefore, less experience than the other workers. Also, production theory would predict that additions or deletions from a mine work force would result in movements up and down the firm average product function, given no change in capital structure. Thus, rapid additions to the work force should depress productivity; deletions should increase productivity.

The coefficient for $SEAM_{ij}$ is expected to be positive. Both strike variable are expected to have negative coefficients. The NEW_{ij} coefficient is expected to be negative. After a mine is opened, it takes approximately 2 years to reach maximum efficiency. OLD_{ij} is also expected to have a negative coefficient; as a mine ages, production advances to less favorable seam areas and the distance from the face to the entrance increases.

Regression Results. Table 6-3 details the regression results (regressions 6-1, 6-2, and 6-3) for the 1966-1976 period. Regression 6-1 is for the entire time period; regressions 6-2 and 6-3 are for the pre-1970 and post-1969 period, respectively. Ordinary least squares regression was used for model estimation.

The quadratic capacity coefficients have the expected signs, indicating there are significant scale economies in underground coal mining. The estimated coefficients indicate that a mine will encounter decreasing returns at approximately 16,500 tons per day; at 215 days of operation this hypothetical mine would have an annual output of 3.5 million tons (the largest U.S. deep mine in 1977 had an annual output of 2.8 million tons). It is likely that geological and technical constraints would prohibit scale exhaustion.

The capacity variables are collinear with days active, production technique (continuous mining), and type of mine (slope, drift, or shaft). That is, larger mines tend to employ continuous mining techniques, are predominantly slope mines, and have a high number of active days. These collinear variables were dropped in favor of the capacity variable; therefore, its estimated coefficient is picking up some noncapacity effects.

The injury rate coefficient, while of the expected sign, was significant at only the 0.40 level. Thus, the level of injuries in Illinois for the

Table 6-3. Regression Results, Illinois Deep Mines, 1966-1976

Variable	Estimated Coefficients: Regression 6-1	Regression 6-2	Regression 6-3	$P(B_{k2} \neq B_{k3})$
Constant	15.41	21.84	9.62	
CAP_{ij}	1.65 (7.37)	1.86 (5.52)	0.916(2.91)	0.96
CAP^2_{ij}	-0.05 (5.13)	-0.06 (3.96)	-0.02 (1.34)	0.93
INJ_{ij}	0.91 (0.84)	2.00 (1.14)	-1.33 (0.89)	0.85
CMHSA	-4.33 (5.96)	—[a]	—[a]	
D1975	-5.11 (5.38)	—[a]	—[a]	
$IDLE_{ij}$	-3.15 (3.10)	-3.96 (2.58)	-2.94 (2.00)	0.37
$EXPWORK_{ij}$	-0.02 (2.41)	-0.023(6.17)	0.006(0.49)	0.75
$CONWORK_{ij}$	-0.02 (0.56)	-0.065(0.69)	0.019(0.40)	0.33
$SEAM_{ij}$	0.007(0.34)	-0.04 (1.14)	0.033(1.31)	0.91
STRIKE1	0.22 (0.19)	—[a]	—[a]	
STRIKE2	-2.57 (2.16)	—[a]	—[a]	
NEW_{ij}	-0.89 (0.81)	-2.33 (1.17)	-2.96 (2.08)	0.21
OLD_{ij}	-2.19 (3.03)	-6.7 (4.42)	-0.874(1.09)	0.99
R^2	0.491	0.444	0.434	
SEE	4.82	5.77	4.05	
N	299	138	161	

NOTE: t statistics are in parentheses. A t value $\geq$1.96 is significant at the 5-percent level; a $t \geq$ 2.58 is also significant at the 1-percent level.

[a]Not applicable.

period examined does not appear to have affected mine productivity significantly. The hypothesis that the CMHSA has moved the safety/production trade-off point towards safety at the expense of productivity is not verified.

The CMHSA coefficient has both the expected sign and a high significance level (0.01, t = 5.96). In addition, there is little correlation (R = 0.009) between the CMHSA variable and the injury rate variable, indicating that there was no large shift in injury rates in the post-CMHSA period.

When a regression was performed with a time trend variable, it completely dominated the regression, and multicollinearity prohibited distinguishing the separate effects of the following variables: CMHSA, D1975, EXPWORK, STRIKE2, and STRIKE1. However, a simple time trend model of Illinois deep mine productivity for this period resulted in an R^2 of 0.024, which explained very little of the productivity change. The regression model estimated here is much more explicit and is a better representation of the productivity behavior of mines.

The D1975 variable has the expected negative sign and is highly significant (t = 5.38). This variable indicates that the results of the wage agreement of 1974 and the extraordinary market conditions in 1975 and 1976 were detrimental to productivity. The $IDLE_{ij}$ coefficient has a high level of significance and the expected sign. This indiates that sporadic production, a behavioral characteristic of small mines, depresses mine productivity. The $IDLE_{ij}$ coefficient was collinear with a control variable for mines closing down during a given year and was used instead.

While both age coefficients have the expected sign, only the OLD_{ij} variable is significant. This tends to support the Ricardian returns hypothesis that older mines experience decreasing productivity as seam quality decreases and distance from the coal face to the surface increases. The NEW_{ij} coefficient does not support the start-up labor requirement hypothesis. However, almost all new mines have less than 150 active days during the first year of operation. Therefore, the $IDLE_{ij}$ will pick up part of the start-up effect.

The surrogate variables $EXPWORK_{ij}$ and $CONWORK_{ij}$, used to capture shifts in experience and age composition of the work force, behaved much as expected. $CONWORK_{ij}$ is not significant while $EXPWORK_{ij}$ has the expected negative coefficient and is significant at the 0.015 level (t = 2.41). This finding supports the hypothesis that rapid work force growth in the 1970s contributed to a productivity decline in mining.

The STRIKE2 variable has the expected sign and is significant at the 0.067 level. STRIKE1 and $SEAM_{ij}$ both have t statistics less than 1.

To test for changes in the structure of the coal productivity functions, the data were stratified into a pre-CMHSA group (regression 6-2) and a post-CMHSA group (regression 6-3). Separate regressions, dropping the variables that were zero for the entire pre-CMHSA period, were run with the results reported in Table 6-3. The coefficients for the quadratic capactiy variables, seam thickness, and old mines were all significantly different (0.10 level) between these two periods. In addition, the Chow test for statistically significant differences between the two equations resulted in $F_{9281} = 13.1$, indicating that two regressions for the period are appropriate.[2]

However, when the regression is fit to only the 1970-1976 data, serious problems are encountered with multicollinearity. STRIKE1 becomes collinear with $IDLE_{ij}$, and NEW_{ij} becomes collinear with $EXPWORK_{ij}$. The OLD_{ij} variable, which was highly significant in the 1965-1976 regression (6-1), loses its significance in the shorter time period. This may be due to the increased survival probability of firms in the growing market of the 1970s. In the 1965-1969 period, 9.4 percent of all active firms suspended operations. This figure dropped to 5.6 percent in the 1970s, indicating that survival probability was increasing. The mean age of firms dropped from 18 years old in 1965 to 13 years old in 1970; old age, then, becomes less of an influencing factor as mine age drops and more new mines enter the industry. In addition, the standard deviation from mean average productivity is larger in the 1965-1969 period than in the 1970s, indicating that there was much more of a variety of firm characteristics in the earlier period. Because of these problems encountered in stratifying the regressions, the following analysis is based upon the results of regression 6-1.

<u>Sources of Productivity Variation.</u> Table 6-4 contains the weighted values of the independent variables multiplied by their respective coefficients. For the most part, the estimated ALP function generates values that correspond well to the actual productivity values. Actual ALP dropped by 6.97 tons per miner-shift from 1969 to 1976; estimated ALP dropped by 7.07 tons during the same period.

During this period of decline, the capacity variable had a positive effect upon productivity through 1973 due to increases in the mean mine size.

Table 6-4. Sources of Productivity Variation, Illinois Deep Mines, 1966-1976

$$B_k \sum_{i=1}^{q} (W_{ij})(\chi_{kij})^*$$

Variable	1966	1969	1970	1971	1972	1973	1974	1975	1976
Capacity	5.37	6.05	6.12	6.36	6.73	7.75	7.64	7.85	7.66
CMHSA	0	0	-4.33	-4.33	-4.33	-4.33	-4.33	-4.33	-4.33
EXPWORK	-0.31	-0.47	-0.30	-0.36	-0.17	-0.21	-0.43	-0.23	-0.09
CONWORK	0.04	0.06	0.08	0.09	0.03	0.09	0.01	0.03	0.01
STRIKE1	0	0	0	0.22	0	0	0	0	0
STRIKE2	0	0	0	0	0	0	-2.56	0	0
NEW	-0.03	-0.04	-0.05	-0.03	-0.02	-0.03	-0.04	0	-0.05
OLD	-1.7	-1.7	-1.3	-1.2	-1.1	-1.3	-1.2	-1.3	-1.4
INJ	0.30	0.22	0.27	0.68	0.25	0.20	0.18	0.19	0.25
SEAM	0.57	0.57	0.57	0.55	0.56	0.56	0.57	0.57	0.57
D1975	0	0	0	0	0	0	0	-5.1	-5.1
IDLE	-0.25	-0.13	-0.17	0	-0.20	-0.16	-0.12	0	-0.03
Estimated ALP	19.39	19.97	16.30	17.39	17.16	17.94	15.13	13.09	12.90
Actual ALP	19.62	19.38	18.17	16.78	15.62	17.74	14.91	13.28	12.41

*Constant term equals 15.41.

Reductions in scale effects caused a decrease in ALP_I by about 0.1 ton per miner-shift from 1973 through 1976. SEAM, NEW, and CONWORK were of little value in explaining movements in ALP_I.

EXPWORK had large, negative impacts in 1971 and 1974, but from 1969 through 1976 it actually exerted a positive influence. Age of mine (OLD) exerted considerable negative impact in all years. The IDLE variable, while very volatile, explained little of the post-1969 decline.

The sources of the decreases were concentrated in the institutional variables, with the CMHSA and D1975 variables dominating the decline. STRIKE2 exerted a "ratchet" effect in the contract negotiation year 1974; the actual ALP_I drop in 1971 and 1974 showed similar behavior.

Changes in Industry Structure. The Illinois mine-level data suggest that changes in industry structure had little effect on productivity. For 11 mines that were in constant operation from 1966 to 1976, weighted ALP dropped from 25.3 tons per miner-shift in 1969 to 12.9 in 1976, indicating that a major source of change was the mine productivity function, not the industry structure.

To test the hypothesis that the CMHSA forced small operators out of the industry, characteristics of exiting mines were examined. As shown in Table 6-1, mines were exiting the Illinois industry prior to the CMHSA; these mines exited for non-CMHSA reasons. If implementation of the act forced firms to exit for atypical reasons, then the characteristics of these firms would differ from those exiting for non-CMHSA reasons. In other words, if firms that exited after the act were no different from those that exited before implementation, it would be difficult to blame post-CMHSA exit upon the act.

Table 6-5 contains means and standard deviations for exiting mine groups from 1965 through 1969 and from 1970 through 1973. The years 1974 to 1976 were excluded due to the rapid expansion of the industry during this time (only two firms exited, and the influence of the market was different from the previous period).

The *t* tests in Table 6-5 indicate that none of the descriptive statistics had a significantly different value for the two groups. The types of firms that exited the industry after implementation of the act were no different in terms of the characteristics examined than those that left before implementation. In particular, the rate of injuries per 1000 miner-shifts was not significantly affected, although the mean was lower after the act's implementation.

Table 6-5. A t Test for Exiting Mine Groups

Variable	Mean	Standard Deviation	t Value	Degrees of Freedom
ALP				
1965-69	11.98	4.09	0.27	16
1970-73	11.43	7.09		
Seam thickness				
1965-69	71.57	20.82	-0.29	18
1970-73	74.23	18.77		
Daily capacity				
1965-69	1.22	1.44	0.60	32
1970-73	.86	1.39		
Injury rate				
1965-69	.347	.389	0.92	32
1970-73	.210	.343		
Employment				
1965-69	89.0	88.9	0.82	32
1970-73	58.0	88.8		

To examine the impact of the CMHSA on injury rates, all mines were stratified into pre- and post-CMHSA groups. Table 6-6 details the mean number of nonfatal injuries involving 7 or more lost days per 1000 miner-shifts of operation. The difference in means is insignificant, indicating there is no statistical difference between the unweighted injury rates for these two periods.[3]

Table 6-6. A t Test for Accident Rates, Illinois Deep Mines

Period	Mean	Standard Deviation	t Value
1965-69	0.2740	0.2905	-0.17
1970-76	0.2794	0.2618	

Summary. The Illinois deep mine analysis largely supports the state-level analysis. The variables D1975 and CMHSA explained a large portion of the productivity decline with both industry-wide strikes also depressing productivity.

The rate of injuries in Illinois was not significantly related to productivity as was the case at the state level. This may be explained by the fact that the definition of injuries was different in these two models; also, microanalysis usually results in a poorer "fit" of the model than obtained with macrodata.

Areas tested with the Illinois data that were not examined with the macrodata included entrance and exit of mines and age of mines. Changes in industry structure explained little of the productivity change. While the age of mines was important in explaining productivity for a given mine, the age structure of the industry changed so little during the period of analysis that little productivity variation was explained.

Surface Mines

Table 6-7 details the independent variable definitions used in the Illinois surface mine analysis. The variables are defined as in deep mine analysis with the exception of $IDLE_{ij}$, $LCRA_{ij}$, and $RATIO_{ij}$.

$LCRA_{ij}$ is a control variable to capture the effects of the Illinois Surface Mine Land Conservation and Reclamation Act of 1971. This act had provisions concerning backfilling and grading, regrading, revegetation, and water impoundment. *A priori,* it would be expected that the reclamation law would divert labor and capital from resource extraction to reclamation, thereby lowering productivity. LCRA takes a value of 1 for 1972 through 1976. A 1-year lag was assumed because the law requires grading to occur within 11 months of June 30 of the year in which mining occurred; other reclamation must occur within 3 years of the same date.[4] *A priori,* the LCRA variable should have a negative sign.

The $IDLE_{ij}$ variable equals 1 when mine M_{ij} has less than 100 active days. Surface mines operate much more sporadically than deep mines and are not subject to the problems of idleness in deep mines resulting from roof falls, flooding, etc. $RATIO_{ij}$, as in the state-level analysis, is the number of feet of overburden that must be removed to mine 1 foot of coal.

Regression Results. Table 6-8 contains the estimated coefficient values from an ordinary least squares regression. Regression 6-4 is for 1966-1976, regression 6-5 for 1966-1971, and regression 6-6 for 1972-1976.

Table 6-7. Illinois Coal Industry Variable Definitions, Surface Mines

Variable Name	Definition
CAP_{ij}	Daily mine output, 10^3 tons
CAP^2_{ij}	CAP term squared
INJ_{ij}	Nonfatal injuries involving 7 or more days lost time, rate per 1000 miner-shifts
$IDLE2_{ij}$	Control variable, equals 1 if M_{ij} had less than 100 active days
$EXPWORK_{ij}$, $CONWORK_{ij}$	Percentage increase (EXPWORK) or decrease (CONWORK) in mine M_{ij} work force from j-1 to j
OLD_{ij}	Control variable, equals 1 if M_{ij} is 7 years or older
NEW_{ij}	Control variable, equals 1 if M_{ij} is less than 2 years old
STRIKE1, STRIKE2	Control variables for 1971 and 1974 strikes
$RATIO_{ij}$	Overburden ratio of M_{ij}
$LCRA_{ij}$	Control variable, equals 1 for 1972-1976

Table 6-8. Regression Results, Illinois Surface Mines, 1966-1976

Variable	Estimated Coefficients		
	Regression 6-4	Regression 6-5	Regression 6-6
CAP_{ij}	2.79(13.4)	3.11(9.83)	2.37 (9.44)
INJ_{ij}	1.63(0.87)	0.81(0.33)	4.34 (1.48)
RATIO	-0.33(2.40)	-0.42(2.17)	-0.26 (1.38)
$IDLE_{ij}$	6.74(2.84)	8.53(2.33)	2.81 (0.98)
LCRA	-9.57(5.48)	0	0
NEW_{ij}	2.75(1.06)	3.26(0.75)	1.33(0.47)
OLD_{ij}	-8.84(4.28)	-12.78(3.69)	-5.60 (2.42)
STRIKE1	-5.34(1.88)	0	-5.13 (2.08)
STRIKE2	-0.65(0.21)	0	-0.32 (0.12)
$EXPWORK_{ij}$	-0.05(1.98)	-0.24(3.46)	0.019(0.75)
$CONWORK_{ij}$	-0.19(2.31)	0.10(0.64)	-0.30 (3.64)
Constant	37.02	41.11	25.92
R^2	0.364	0.381	0.336
SEE	15.34	16.91	12.38
N	408	216	192

NOTE: *t* statistics are in parentheses.

Both of the work force related variables had the expected sign and were significant. The percentage reduction in work force variable, CONWORK, was surprisingly strong in the regression, although most of this effect occurred in the pre-1972 data.

As was the case with deep mines, surface mining in Illinois was subject to considerable returns to scale. Preliminary results indicate that the scale relationship did not change with size but was homogeneous throughout the capacity range examined here; therefore, CAP^2_{ij} was dropped.

Injuries, as was the case in deep mines, had a statistically insignificant coefficient, but the variable had the expected positive sign. $RATIO_{ij}$, the measure of geological and topographic characteristics of the mine, was highly significant and had the expected sign. Overburden ratio varies more throughout the life cycle of surface mines than does seam thickness in deep mines; i.e., geological changes that occur more frequently in surface mines than in deep mines could therefore be expected to influence productivity over the life of the mine.

The OLD_{ij} variable indicates that Ricardian returns in surface mining exert considerable influence upon mine efficiency. Old surface mines are significantly less productive than younger mines, *ceteris paribus*. As was the case with deep mining, the start-up labor hypothesis was not verified in surface mines. The coefficient for NEW_{ij} was insignificant and not of the expected sign. Both strike variables had the expected sign; however, the variable for the 1971 strike was the only one of any significance (0.061 level, $t = 1.88$).

A somewhat surprising result of the regression estimate was the coefficient for the $IDLE_{ij}$ variable. The expected sign was negative (as in deep mining); however, the coefficient was very strong and positive. A possible explanation for this would be the two- and three-worker "mom and pop" strip mines that are prevelant in most eastern surface mining areas. These small mines have a life of several months and operate only where coal is easily accessible, although the economically feasible reserves are small. Thus, for short periods of time these mines are highly productive but contribute an insignificant amount to annual tonnage mined. In addition to these small mines, surface mines are not subject to deterioration from inactivity to the same extent as deep mines.

The Illinois Land Conservation and Reclamation Act variable was highly significant and had a negative sign. This result appears to support the contention that legislated reclamation requirements in Illinois depressed surface mining productivity considerably. In preliminary regressions on the Illinois surface mine data, both CMHSA mean inspections per surface mine and the variable LCRA were entered. However, these varaibles were highly collinear with each other (correlation coefficient = 0.859). Because reclamation requirements are widely held to have had a much greater influence than safety and health requirements in surface mines, the LCRA variable was used.

Sources of Productivity Variation. Using the weighted means of the independent variables in the productivity function, productivity values were estimated for 1966 and 1969 through 1976 in Table 6-9. Actual weighted productivity fell by 12.69 tons per miner-shift during the 1969-1976 period; the estimated productivity from the productivity function fell by 10.62 tons per miner-shift. The capacity term showed considerable range, varying from 10.58 tons per miner-shift in 1976 to 14.27 in 1969.

Most of the productivity decline is explained by changes in the mine size distribution and the LCRA. The 1971 strike had a strong 1-year impact as did the rapid expansion of the work force in 1973. These results largely confirm the state-level surface mine results.

Changes in Industry Structure. To test the hypothesis that small operators were forced out of the industry due to the legislated reclamation requirements, the exiting mines were divided into a 1965-1970 group and a 1971-1973 group. Due to rapid expansion of output in the 1974-1976 period, these years were excluded. Descriptive statistics for the two groups are shown in Table 6-10. In none of the characteristics examined was the mean value significantly different. The reclamation law apparently had no effect upon type of mine to exit.

Summary. The results of the Illinois surface mine analysis largely support the state-level analysis. The majority of productivity decline can be attributed to the entrance of small mines and the Illinois Mined Land Conservation and Reclamation Act (LCRA) of 1972 that required mines to expend labor and capital in reclaiming the land. The 1971 strike also depressed productivity.

Areas tested with the Illinois surface mine data that were not tested with the state-level model include the effect of legislation on industry structure and the influence of mine age. No evidence was found to support the charge that the LCRA changed industry structure by forcing small mines out of business. Old surface mines were significantly less productive than other surface mines, indicating that operators mine the most accessible reserves first.

OHIO DEEP MINES

In addition to confirming the earlier deep mine analysis, the Ohio microdata point to several interesting characteristics. As shown in Table 6-11, the Ohio deep mine industry followed much the same pattern as the U.S.

Table 6-9. Sources of Productivity Variation, Illinois Surface Mines

$$B_k \sum_{i=1}^{q} (W_{ij})(\chi_{kij})^*$$

Variable	1966	1969	1970	1971	1972	1973	1974	1975	1976	Change (1969-1976)
Capacity	12.73	14.27	13.57	14.10	13.49	13.46	12.98	11.02	10.58	
OLD	-6.50	-6.48	-5.88	-5.78	-4.49	-5.31	-4.74	-4.74	-4.43	
LCRA	0	0	0	0	-9.58	-9.58	-9.58	-9.58	-9.58	
IDLE2	0.54	0.30	0.23	0.45	0.23	0.07	0.49	0.26	0.19	
RATIO2	-4.00	-4.30	-4.45	-4.61	-4.65	-4.91	-4.68	-4.39	-4.32	
CONWORK	0.34	0.72	1.27	0.38	1.11	0.70	0.44	0.42	1.19	
EXPWORK	-0.49	-0.56	-0.33	-0.37	-0.50	-1.52	-0.63	-0.74	-0.42	
STRIKE1	0	0	0	-5.34	0	0	0	0	0	
STRIKE2	0	0	0	0	0	0	-0.65	0	0	
NEW	0.15	0.10	0.14	0.18	0.11	0.09	0.12	0.33	0.30	
INJ	0.19	0.21	0.32	0.24	0.26	0.16	0.17	0.21	0.13	
Actual ALP_I	43.06	38.01	37.16	39.16	40.11	32.44	30.57	26.60	25.32	-12.69
Estimated Weighted	40.00	41.29	41.88	36.26	31.56	30.18	30.96	29.82	30.67	-10.62

*Constant term = 37.02

Table 6-10. A t Test for Exiting Surface Mine Groups

Variable	Mean	Standard Deviation	t Value	Degrees of Freedom
ALP				
1965-70	35.48	26.19	-0.58	55
1971-73	31.14	12.49		
Overburden ratio				
1965-70	12.05	7.58	-2.44	46
1971-73	6.42	4.16		
Capacity				
1965-70	1.08	1.71	-0.78	55
1971-73	.69	.96		
Employment				
1965-70	30.36	51.48	-0.49	54
1971-73	23.08	29.00		
Injury rate				
1965-70	.176	1.01	.42	55
1971-73	.312	1.04		

Table 6-11. Descriptive Statistics, Ohio and U.S. Deep Mines, 1965-1976

	Tons/Miner-Shift		Active Mines		Price/Ton, f.o.b. Mine	
Year	Ohio	U.S.	Ohio	U.S.	Ohio	U.S.
1965	13.6	14.0	93	5280	4.30	4.90
1969	17.3	15.6	46	3097	4.70	5.60
1970	15.4	13.8	44	2939	5.40	7.40
1971	11.3	12.0	35	2268	6.80	8.90
1972	12.5	11.9	35	1996	7.40	9.70
1973	11.9	11.7	28	1737	8.50	10.80
1974	10.0	11.3	28	2039	13.70	19.90
1975	8.2	9.5	33	2292	18.80	26.30
1976	8.6	9.1	31	2422	17.80	26.60

Source: Bureau of Mines, *Minerals Yearbook*, various years.

through 1975. The Ohio deep mines are typical of Appalachian mines with much more variance in mine size, technique employed, and seam characteristics than the Illinois mines. In 1976, however, Ohio mines experienced falling prices, falling mine population, and increasing productivity, all contrary to the trends in Illinois and the U.S. Although the data collected by the Ohio Department of Industrial Relations are not as rich as the Illinois data, these characteristics make the state's industry a fertile empirical topic.[5]

Regression Results. Table 6-12 contains the independent variable definitions for the Ohio deep mine analysis. All of the variables, except CONT and DRIFT, are defined as in the Illinois analysis. CONT could not be used in Illinois because it was collinear with days active and mine size; DRIFT was not used because there were so few observations.

Table 6-12. Variable Definitions, Ohio Deep Mines

Variable	Definition
$SEAM_{ij}$	Coal seam thickness, inches
$CONT_{ij}$	Control variable; equals 1 if mine uses continuous mining
$DRIFT_{ij}$	Control variable; equals 1 if mine is drift type
CAP_{ij}	Daily output, tons
CAP^2_{ij}	CAP term squared
CMHSA	Control varaible; equals 1 for 1970-1977
$CONWORK_{ij}$, $EXPWORK_{ij}$	Percentage increase (EXPWORK) or decrease (CONWORK) in mines work force from last year
NEW_{ij}	Control variable; equals 1 if mine is less than 2 years old
DUMS1, DUMS2	Control variables; equal 1 in 1971 (DUMS1) or 1974 (DUMS2), years of industry-wide strikes
$IDLE_{ij}$	Control variable; equals 1 when mine has less than 150 active days
D1975	Control variable; equals 1 for years after 1974

One explanation for the high rates of injuries and productivity growth during the 1960s was the rapid diffusion of continuous mining technology.[6] Continuous mining is highly productive and requires small crews, resulting in high rates of labor productivity. However, it is also more dangerous than other mining techniques due to high dust levels and rapid face advance. The Coal Mine Health and Safety Act, it is argued, was directed mainly at making continuous mining safer, resulting in a reduction of its productivity advantage over other mining techniques.[7]

Empirically, then, prior to 1970 the variable CONT should have a positive and significant coefficient that changes during the 1970s. Drift mines, because the mine entrance is the same altitude as the coal seam, do not require the conveyance systems necessary in slope and shaft mines. *A priori,* the expected coefficient for DRIFT is positive.

Preliminary regressions on the Ohio data indicated that the structural relationships in large deep mines were different than those in small mines. To capture these structural differences, the data were stratified in large mines (output equal to or greater than 435 tons per day) and small mines (output less than 435 tons per day).

Table 6-13 details the regression results for the large mines. Regression 6-7 is for the 1966-1976 period, regression 6-8 is for the 1966-1969 period, and regression 6-9 is for the 1970-1977 period.

The regression results for the Ohio mines have several differences from the other mine data examined. IDLE, the variable measuring mine inactivity, is estimated to have a positive influence upon productivity in regressions 6-7 and 6-9. DRIFT, as expected, has an estimated strong positive relationship with productivity. The output per miner-shift in drift mines is estimated to be from 6.2 tons to 11.5 tons greater than in other deep mines, depending upon time period examined.

The CMHSA control variable is significant and negative, indicating that implementation of the CMHSA cost Ohio deep mines approximately 10 tons per miner-shift. The CMHSA variable in regression 6-7 is absorbed by the lower constant term in regression 6-9. Unlike the previous models, none of the strike variables was significant in Ohio.

The CONWORK coefficient is significant and positive, indicating a negative influence upon productivity (the variable CONWORK is negative). Further, this relationship holds for all three time periods; that is, as Ohio deep mines reduced their mine work forces, productivity fell. Work force expansion did not significantly affect mine-level productivity.

Table 6-13. Regression Results, Large Ohio Deep Mines, 1966-1977

Variable	Regression 6-7		Regression 6-8		Regression 6-9	
	Estimated Coefficients					
Constant	21.37		25.18		8.00	
IDLE	10.01	(3.30)	3.51	(0.70)	14.96	(3.87)
DRIFT	7.56	(5.91)	11.55	(4.63)	6.16	(3.80)
CAP	.0007	(2.95)	.0009	(2.12)	*	
CAP^2	*		*		.00000001	(2.99)
CMHSA	-10.31	(8.22)	—[a]		—[a]	
DUMS2	-1.94	(1.02)	—[a]		*	
CONWORK	11.28	(2.16)	16.09	(1.88)	16.89	(2.62)
EXPWORK	*		-0.32	(1.18)	.23	(1.69)
DUMS1	*		—[a]		*	
NEW	-2.66	(1.36)	*		-9.49	(2.67)
SEAM	*		-0.18	(1.17)	.061	(0.74)
CONT	*		7.22	(3.00)	*	
D1975	*		*		*	
R^2	.394		.409		.254	
SEE	7.94		7.12		7.51	
N	225		55		156	

NOTE: *t* statistics in parentheses.

*Variables insignificant at the 0.5-percent level.

[a]Not applicable.

New mines in Ohio were significantly less productive than other mines, *ceteris paribus*. Also, Ohio deep mines exhibited the scale economies that have been typical of most deep mine regressions.

The behavior of the CONT variable lends some support to the argument that the CMHSA had a disproportionate effect upon continuous mining systems. In the 1960s (regression 6-8), mines employing continuous mining methods were significantly more productive than mines employing other techniques, *ceteris* *paribus* (the regression estimates approximately 7.2 tons per miner-shift as the productive advantage of continuous mining). In the 1970s, however, continuous mining was no more productive than other systems.

The behavior of CONT in the small mine model (Table 6-14) supports this result. Regression 6-10 is for the period 1966-1977, regression 6-11 is for the 1966-1969 period, and regression 6-12 is for the 1970-1977 period. For the period 1966-1969, small mines employing continuous miners could expect to produce approximately 9.8 tons per miner-shift more than if they used other techniques. In the 1970s, this relationship reversed and small mines employing continuous miners could expect approximately 5 tons per miner-shift less than from other techniques.

Table 6-14. Regression Results, Small Ohio Deep Mines, 1966-1977

	Estimated Coefficient					
Variable	Regression 6-10		Regression 6-11		Regression 6-12	
Constant	1.14		2.73		8.22	
SEAM	*		*		-0.11	(1.06)
CONT	2.02	(1.47)	9.79	(5.36)	-5.04	(2.22)
DRIFT	3.63	(3.43)	3.69	(3.51)	*	
CAP	.07	(4.86)	.04	(8.20)	9.10	(3.27)
CAP^2	-0.00006	(1.49)	*		-0.00009	(1.25)
CMHSA	-1.08	(1.05)	—[a]		—[a]	
CONWORK	-6.60	(4.70)	-6.64	(4.55)	-7.90	(2.32)
EXPWORK	*		-0.04	(0.88)	-0.78	(0.79)
NEW	1.08	(0.91)	*		*	
DUMS1	*		—[a]		-3.48	(1.32)
DUMS2	*		—[a]		*	
IDLE	*		-1.48	(1.55)	1.96	(0.97)
R^2	.462		.503		.540	
SEE	6.62		5.96		7.31	
N	267		202		64	

NOTE: *t* statistics are in parentheses.

*Variable insignificant at the 0.5-percent level.

[a]Not applicable.

The variable CONWORK, which had a significant negative impact upon productivity in the large mines, has the expected positive influence in the small Ohio deep mines. The CMHSA variable is not significant in explaining productivity in the small Ohio deep mines. Indeed, with the exception of a 1-year drop in 1973, average productivity for all small Ohio deep mines climbed steadily from 9.52 tons per miner-shift in 1969 to 15.75 in 1976.

Sources of Productivity Variation. Table 6-15 details the weighted independent variables multiplied by their respective coefficients for large mines for 1970 through 1977 (regression 6-9 in Table 6-13). (The small mine analysis is excluded due to the small number of mines active during the 1970s.)

Table 6-15. Sources of Productivity Variation, Large Ohio Deep Mines with Daily Capacity of 435 Tons or More, 1970-1977

Variable	1970	1971	1972	1973	1974	1975	1976	1977
SEAM	3.51	3.51	3.55	3.58	3.54	3.49	3.42	3.40
IDLE	0	.70	.28	.91	.40	0	.10	.48
DRIFT	1.35	1.45	1.55	1.11	1.36	1.55	1.60	1.65
CAP^2	2.95	1.76	1.71	1.81	1.57	1.44	1.58	1.66
DUMS1	0	5.42	0	0	0	0	0	0
EXPWORK	.06	.58	.66	.10	.09	.11	.05	.01
CONWORK	-0.07	-1.39	-0.69	-0.68	-1.06	0	-0.25	-1.82
NEW	0	-0.87	0	0	-0.26	-0.98	0	-0.54
INTERCEPT	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Estimated ALP	15.80	19.16	15.06	14.83	13.64	13.61	14.50	12.84
Actual ALP	22.70	18.22	16.84	16.42	12.88	10.09	11.84	11.79

For 1970 the model grossly underestimates productivity. However, it follows the trend fairly well from 1971 through 1977. The trends in Ohio are not as smooth as the general state-level and Illinois results, and it is difficult to pinpoint major sources of change.

Factors contributing to the decline through 1975 include reductions in the average mine size, the entrance of immature mines, and changes in the size of the work force. During this period the CMHSA also had a depressing effect picked up by the low INTERCEPT term.

In particular, the 1974 and 1975 productivity declines are attributed to mines cutting back work forces and new mines entering the industry. The maturation of these new mines and increase in average mine size contributed to the increase in productivity in 1976.

Summary. In general, the Ohio mine level analysis supported the Illinois analysis with the exception of the strike and CONWORK variables. One interesting result of the Ohio analysis was the behavior of the variable CONT. This variable indicated that continuous mining was considerably more productive than other techniques during the 1960s, but that it lost its productive advantage during the 1970s. This finding can explain both a large portion of the productivity growth in the 1960s (percentage of deep mine output by continuous mining grew from 27.4 percent in 1960 to 50.1 percent in 1970) and productivity decline in the 1970s.

DEPARTMENT OF ENERGY COAL SYSTEM DATA ANALYSIS: EXAMINATION OF PIKE COUNTY, KENTUCKY

This section reviews work completed for the President's Commission on Coal examining Pike County, Kentucky, surface and deep mine productivity.[7] The examination of a small geographic area allows some control for such variables as climate, surface topography, underground geology, worker attitudes, and other cultural influences that cannot be accounted for at the state level. The analysis also employs a data set by individual mine obtained from the Department of Energy. However, missing data have reduced somewhat the utility of the data set.

Pike County is located in the center of the extreme eastern boundary of Kentucky. Pike County is dominated by western slope Appalachian geology and contains a relatively uniform series of bituminous coal beds. This county was selected because of the large number of both surface and deep mines, the large rate of mine turnover, and the size range (from less than 10,000 tons per year to more than 1 million tons per year). In general, the county has more smaller mines than most coal areas. Pike County mines employ a variety of mining techniques and have higher productivity than the nation as a whole for deep mines (15.3 tons per miner-shift in 1977 versus 8.7 nationally). Productivity in surface mines is lower (18.8 tons per miner-shift in 1977 versus 26.9 nationally).

The Department of Energy, through its coal information system, attempts to collect and store coal mine related data on magnetic tape (hereafter called

"Coal System"). An examination of the Coal System documentation revealed extensive and detailed classification for the collected information. Unfortunately, examination of the actual data revealed extremely spotty reporting by individual mines, although more data is available for more recent years. It soon became obvious that only by limiting the analysis to 1976 and 1977 and then by pooling the data from these two years could sufficient observations on individual mines be obtained for regression analyses, hence the limitation to primarily cross-sectional analysis.

Deep Mine Regression Results

Table 6-16 contains the variable definitions used in the Pike County deep and surface mine analysis.

Table 6-17 details the ordinary least squares regression results for cross-sectional analysis of individual mines in 1977 and in a pooled sample of 1976 and 1977. The estimated coefficients are followed by estimates of the level at which the coefficients are significant. The variable for coal seam thickness was dropped from all Pike County regressions when it was discovered there was virtually no variance. IDLE2 and AGE^2 were found by a step-wise procedure to be insignificant. The regression results show generally little difference between the 1977 data and the 1976-1977 data.

Comparison of the results in Table 6-17 with those for Illinois are generally similar and noncontradictory. The similarity in the estimated value of the INTERCEPT (15.9 for Pike County versus 15.4 for Illinois) is particularly noteworthy. The R^2 for Table 6-17 is low but not unusual for microlevel cross-sectional estimates.

Mines using continuous mining methods in Pike County were found to be less productive than other mines, *ceteris paribus*. This supports the Ohio mine-level results and the state-level analysis. The behavior of the other variables examined in the Pike County model (mine size, age) generally support the Ohio and Illinois deep mine results.

Also included in the mine-level models is the price per ton that a mine was receiving for its output. Cross-sectionally and with the 2-year pooling, this variable was significant at the 0.01 level. Economic theory would predict that as coal price increases, a firm will increase the incremental cost of production. This is done by increasing output, which reduces the efficiency of the firm (reduces productivity). The estimated negative coefficient for price supports this theory. This point will be further examined in the next chapter.

Table 6-16. Variable Definitions, Pike County Deep and Surface Mines

Variable	Definition
ALP_{ij}	(Annual production)÷(men x days active)
$ALP2_{ij}$	(Annual production)÷(annual miner-hours)
$PROD_{ij}$	(Annual production)÷(days active)
$PRODAN_{ij}$	Annual production
$IDLE_{ij}$	365 - (days active)
$IDLE2_{ij}$	1 if days active $\leq$ 150 0 if days active $\geq$ 150
$BULLDOZ_{ij}$	(Number of bulldozers)÷(PROD)
$BULLDOZ2_{ij}$	(Number of bulldozers)÷(PRODAN) x 100,000
$OPVALTON_{ij}$	(Dollar value of annual tonnage sold in open market)÷(total annual tonnage)
$RECL_{ij}$	(Acres reclaimed)÷(acres mined)
$RATIO_{ij}$	(Thickness of overburden)÷(seam thickness)
AGE_{ij}	(Year of data)-(year mine started)
$CONT_{ij}$	(Annual tonnage by continuous mining method) ÷ (PRODAN)
CUT_{ij}	(Annual tonnage by conventional or cutting machines)÷(PRODAN)
$LONGWALL_{ij}$	(Annual tonnage by longwall method)÷(PRODAN)
$OPENTON_{ij}$	Annual tonnage sold on open market
$NOTTON_{ij}$	Annual tonnage sold under contract

Table 6-17. Regression Results for Deep Coal Mines, Pike County, Kentucky

Variable	1977		Pooled 1976-77	
INTERCEPT	15.894	—[a]	17.008	—[a]
PROD	0.033	(0.0001)	0.031	(0.0001)
$PROD^2$	-0.001	(.0001)	-0.001	(.0001)
AGE	-0.403	(.0056)	-0.421	(.0006)
OPVALTON	-0.284	(.0158)	-0.297	(.0010)
CONT	-0.052	(.0669)	-0.044	(.0643)
CUT	0.045	(.0414)	—[b]	—[b]
R^2	0.298		0.294	
N	107		143	

NOTE: Significance levels in parentheses.

[a]Not applicable.

[b]Insignificant coefficient (less than 0.5).
Dependent variable equals ALP.

Source: Robert J. Gaston, *Coal Mine Labor Productivity: Mine-Level Data from Pike County, Kentucky, and Other Selected Counties* (Oak Ridge: Oak Ridge Associated Universities, forthcoming).

In addition to Pike County mines, the same general model was applied to mines in the following areas:

Jefferson County, Alabama
Williamson County, Illinois
Harlan County, Kentucky
Ohio County, Kentucky
Belmont County, Ohio
Indiana County, Pennsylvania
Somerset County, Pennsylvania
Buchanan County, Virginia
McDowell County, West Virginia
Monongalia County, West Virginia

The results of these regressions gave empirical support to the Pike County results; in particular, the price variable was consistently negative and significant.[9]

Table 6-18 applies the regression model to all of the counties listed above. These regressions are also stratified by mine size.

Table 6-18. Regression Results, Selected Counties, 1976-1977

	Estimated Coefficients			
Variable	All Mines	Less Than 100,000 Tons per Year	101,000-500,000 Tons per Year	More than 500,000 Tons per Year
INTERCEPT	20.019	7.73	7.49	3.18
PROD	.003 (.015)	.090 (.001)	.011 (.001)	.002(.0001)
$PROD^2$	-0.0001(.025)	-0.0001 (.001)	-0.0001 (.001)	
AGE	-0.121 (.001)	-0.233 (.001)		
AGE^2				
IDLE	-0.019 (.001)			
OPVALTON	-0.198 (.001)	-0.260 (.001)	-0.151 (.0004)	
CONT		-0.033 (.008)		
R^2	.124	.434	.385	.581
N	444	341	71	30

NOTE: Significance levels in parentheses. Insignificant variables are dropped.

Source: Robert J. Gaston, *Coal Mine Labor Productivity: Mine-Level Data from Pike County, Kentucky, and Other Selected Counties* (Oak Ridge: Oak Ridge Associated Universities, forthcoming).

These regressions do not contradict the Illinois, Ohio, or Pike County results. With the exception of very large mines, the price variable is significant for all regressions. The continuous variable (CONT) is significant and negative for the small mines (less than 100,000 tons per year) only; however, 76 percent of the mines examined were small.

Surface Mine Regression Results

The regression results of the Pike County surface mine data are presented in Table 6-19. As with the deep mine data, an ordinary least squares regression was performed on a 1977 cross-sectional and 1976-77 pooled data.

Even though the geology of Illinois surface mining allows for area mining while contour mining is used in Pike County, the results of the Pike County regression are generally consistent with Illinois. The variable BULLDOZ2 (number of bulldozers per 100,000 tons of coal) is negative and significant. This is consistent with the argument that the role of bulldozers in surface mining is more for reclamation than for mining.[10] Another surprising result of the surface mining regression is the estimated positive influence of price on productivity. The small annual production of the average Pike County surface mine (less than 50,000 tons per year) may be the cause of this positive coefficient.

Table 6-19. Regression Results, Surface Coal Mines, Pike County, Kentucky

Variable	Estimated Coefficients 1977		Pooled 1976-1977	
INTERCEPT	3.250	—[a]	3.411	—[a]
PROD	0.013	(0.0156)	0.015	(0.0003)
BULLDOZ2	-11.00	(0.0004)	-10.71	(0.0001)
AGE	-4.380	(0.0559)	-4.711	(0.0136)
AGE^2	1.574	(0.0053)	1.631	(0.0008)
OPVALTON	0.883	(0.0049)	0.863	(0.0005)
R^2	0.945		0.95	
N	14		16	

NOTE: Significance levels in parentheses.

[a]Not applicable.

Source: Robert J. Gaston, *Coal Mine Labor Productivity: Mine Level Data from Pike County, Kentucky, and Other Selected Counties* (Oak Ridge: Oak Ridge Associated Universities, forthcoming).

When regressions were run on the surface mines in the other selected counties, the results generally supported the Pike County results with the exception of the price variable.[11] In these other regressions the price variable was usually insignificant; however, when significant, a negative coefficient was estimated.

Structural Adjustment of the Coal Industry: Entry and Exit of Pike County Mines, 1974-1977

Changes in productivity for an aggregation of mines can occur by changing the structural characteristics of that aggregation through the entry and exit of mines. For example, if new mines opening in response to higher coal prices are substantially smaller than existing mines, then the observed productivity for all mines may fall even though individual mines have had no change in productivity.

The Illinois and state-level analyses suggest that the influence of entering and exiting mines upon productivity is related to mine type, i.e., surface or deep. For deep mines, the productivity effect of changing industry structure was minor. However, the entrance of small producers explained a large portion of the surface productivity decline. The Pike County data allow a further test of this point.

Table 6-20 details mine characteristics for all mines, entering and exiting, in Pike County in 1977. The most striking observation to be made is the extremely high rate of turnover of mines in the county. More mines (both surface and deep) were abandoned during the year than were in constant operation. Tables 6-21 and 6-22 show that this high turnover is characteristic and occurs each year from 1974 through 1977. The Illinois industry, by contrast, is composed of much larger mines and the structure is more stable.

The results of Table 6-20 indicate that labor productivity was not lower than the average for all mines for entering and exiting mines. On the contrary, labor productivity was higher. As shown in Table 6-21, entering deep mines from 1974 through 1977 had higher productivity than the county average in 1977 in both the year they entered and the second year of operation. Exiting mines, however, had substantially lower productivity the year preceding exit. Neither of these results provides any evidence to support structural change of the industry as a cause of declining labor productivity. However, they generally support the Illinois results.

As shown in Table 6-22, the surface mine industry entry and exit characteristics are quite different from deep mine characteristics. From 1974 through 1977 (Tables 6-20 and 6-22), the productivity of entering (subsequent year) and exiting surface mines was generally lower and higher, respectively, than the county-wide surface mine average. Thus, mines with higher productivity were being replaced by mines with lower productivity. The net effect was that surface mine turnover may have contributed to falling

Table 6-20. Mean Characteristics for Pike County Mines, 1977

	Deep Mines			Surface Mines		
	County Average	Entry	Exit[a]	County Average	Entry	Exit[a]
Number of mines	177	76	212	94	65	106
Average labor productivity (ton/miner-shift)	15.3	18.3	20.0	18.8[b]	18.7	31.9
Average annual production (thousands of tons)	311	250.6	240.6	98.6	163.3	244.3
Annual days idle	228	249	236	279	280	252
Price/ton	$18.70	$15.46	$20.50	$19.40	$20.97	$14.70
Stripping ratio	—	—	—	6.74	7.4	8.9
Percent continuous mining	22.7%	27%	10%	—	—	—
Seam thickness	48.3	48.2	44.9	—	—	—

[a]1976.

[b]1976-1977 period.

Source: Robert J. Gaston, *Coal Mine Labor Productivity: Mine-Level Data from Pike County, Kentucky, and Other Selected Counties* (Oak Ridge: Oak Ridge Associated Universities, forthcoming).

Table 6-21. Pike County Deep Mines Entering and Exiting the Industry

	Mean Values					
	1974		1975		1976	
	Enter	Exit	Enter	Exit	Enter	Exit
Number of mines	141	109	125	123	144	212
Average labor productivity (tons/miner-shift)	19.5	20.9	18.8	16.2	18.3	20.0
ALP (subsequent year or preceding year)[a]	18.3	2.39	16.6	1.85	20.9	3.83
Total production (thousands of tons)	180.1	170.6	180.1	172.6	201.5	240.6
Total production (subsequent year or preceding year)[a]	257.9	189.9	210.2	227.3	314.1	278.1
Annual days idle	253	252.4	256	266.7	258	236.6
Price/ton	$20.04	$18.90	$19.42	$21.90	$15.70	$20.50
Seam thickness (inches)	47.7	46.6	46.2	49.5	44.5	44.9
Mining technique (number of mines)						
Continuous	12	5	9	9	4	15
Hand cut/conventional	57	52	68	56	91	125
Longwall	0	0	0	0	0	0

[a]Entering mine average in subsequent year and exiting mine average in preceding year.

Source: Robert J. Gaston, *Coal Mine Labor Productivity: Mine-Level Data from Pike County, Kentucky, and Other Selected Counties* (Oak Ridge: Oak Ridge Associated Universities, forthcoming).

Table 6-22. Pike County Surface Mines Entering and Exiting the Industry

	Mean Values					
	1974		1975		1976	
	Enter	Exit	Enter	Exit	Enter	Exit
Number of mines	97	106	81	71	81	106
Average labor productivity (ALP)	36.6	41.9	35.2	35.8	31.9	31.7
ALP (subsequent year or preceding year)[a]	3.69	31.8	4.24	29.5	3.07	17.5
Total production (000 tons)	327.0	309.8	364.9	415.1	244.3	246.1
Total production (subsequent year or preceding year)[a]	282.5	256.5	301.5	185.8	215.4	240.4
Annual days idle	257.4	255	262.4	249	252.3	249
Price/ton	$22.50	$24.56	$18.60	$17.42	$14.70	$15.21
Stripping ratio	6.46	9.01	13.2	8.9	8.9	11.1
Bulldozer/mine	3.1	2.2	2.1	1.8	1.9	2.0
Reclamation ratio	.78	.86	1.59	.86	.82	.85

[a]Entering mine average in subsequent year and exiting mine average in preceding year.

Source: Robert J. Gaston, *Coal Mine Labor Productivity: Mine-Level Data from Pike County, Kentucky, and Other Selected Counties* (Oak Ridge: Oak Ridge Associated Universities, forthcoming).

productivity in Pike County. Tables 6-20 and 6-22 also reveal no consistent evidence that entering surface mines were smaller or less active, received a lower price, or had a higher overburden ratio than exiting mines for the 1974-1977 period. In general, then, declining labor productivity in Pike County surface mines was reinforced by turnover; however, for other mine characteristics there was no clear influence of turnover affecting county-wide averages.

A similar type of turnover analysis was done on the selected counties discussed earlier.[12] The results of these county examinations generally supported the Pike County deep mine results. However, the entry and exit of surface mines in the other counties did not support the Pike County results. Again, the small size of Pike County surface mines may be one reason for these unusual results.

Summary

The mine-level examination of Pike County and other selected counties generally supports the state-level and other mine-level results discussed in this report. In addition, the mine-level data from the Coal System allowed the examination of the influence of price per ton on individual mine productivity. In general, price had a significant negative effect, both with the pooled and cross-sectional data.

The influence of mine turnover on productivity and other mine characteristics was also examined with the DOE Coal System data. In general, these results gave little support to the hypothesis that less efficient mines entering in a period of high prices depressed productivity.

NOTES

[1]See Illinois State Department of Mines and Minerals, *Annual Coal, Oil, and Gas Report* (Springfield: State of Illinois, various years).

[2]Gregory C. Chow, "Tests for Equality between Sets of Coefficients in Two Linear Regressions," *Econometrica* 28:591-605.

[3]Because these mean values are based on a census and not on a sample, the *t* statistics are somewhat misleading. The means represented in the table are not estimated means but true population means.

[4]Energy and Environmental Analysis, Inc., *Laws and Regulations Affecting Coal with Summaries of Federal, State, and Local Laws and Regulations Pertaining to Air and Water Pollution Control, Reclamation, Diligence, and Health and Safety* (Springfield, Virginia: NTIS, 1976), pp. V-23, V-25.

[5]These are annual data. See Ohio Department of Industrial Relations, *Division of Mines Report* (Columbus: State of Ohio, various years).

[6]Joe G. Baker and Robert J. Gaston, *Coal Mine Labor Productivity: Review of Issues and Evidence, A Report to the President's Commission on Coal* (Oak Ridge: Oak Ridge Associated Universities, 1979), p. 13.

[7]This was suggested by Charles Mottley, operations research scientist, Fossil Fuel Extraction Office, DOE. Mr. Mottley also believed that equipment design, reliability, and maintenance problems of continuous mining machines "caught up" with continuous mining installations and increased nonproductive downtime. Personal communication.

[8]This section summarizes results contained in the forthcoming ORAU publication, *Coal Mine Labor Productivity: Mine-Level Data from Pike County, Kentucky, and Other Selected Counties*, Robert J. Gaston.

[9]Robert J. Gaston, *Data from Pike County*.

[10]See Daniel Walton and Peter Kauffman, *Preliminary Analysis of the Probable Causes of Decreased Coal Mining Productivity (1969-1976)* (Reston, Virginia: Management Engineers, Inc., 1977), pp. VI-34 through VI-36.

[11]Robert J. Gaston, *Data from Pike County*.

[12]Ibid.

CHAPTER 7. ESTIMATING THE EFFECT OF COAL PRICES AND MARKET CONDITIONS UPON PRODUCTIVITY

During the 1970s, the coal industry has experienced an abrupt shift in both its economic and institutional environment. These changes have resulted in many possible explanations for declining productivity; the previous chapters have examined the relative impact of several of the purported causes.

As discussed in Chapter 4, economic theory of the firm predicts that a firm that is maximizing profit will react to higher prices by increasing output, even though relative efficiency (productivity) will fall. The research method used in the previous chapters examined the effects that actions a firm would take in reaction to high prices—e.g., expanding output, increasing the mine work force and days active, mining thinner seams, or dealing with greater overburden conditions—had directly upon productivity. With the exception of changes in firm size distribution, large amounts of productivity variation were not really explained by any of these factors.

The possible reactions to price that firms make, either consciously or unconsciously, may be more subtle. These reactions could include the following:

1. Ricardian returns. Although this reaction was examined using seam thickness data, many more resource characteristics could influence productivity. For example, a mine could work sections with "poor top," requiring more frequent production stops to bolt the roof. A mine could continue to mine an area where a seam parting is large. These types of reactions—mining in conditions that are unprofitable until coal prices increase—could account for some of the productivity decline.
2. Mine development and construction. As the price of coal increases and the market becomes stronger, mines may try to capture a larger share of the future market by constructing and developing new sections. This short-term reaction to higher prices would lead to a depression of productivity.
3. *x*-efficiency.[1] The main element of the *x*-efficiency concept is that similar individuals will supply different amounts of work effort under different firm and environmental circumstances. The basic decision unit of this theory is the individual who supplies work

effort based upon his perception of what he is expected to do and what he prefers to do in terms of job performance. Thus, the determination of production costs (and productivity) is a result of interconnected effort decisions by a firm's employees and not by the price, production, technique, and quantity decisions of the neoclassical firm. One implication of this theory is that firms do not minimize costs (achieve maximum productivity), and this may hold under competitive conditions.

The *x*-efficiency concept can perhaps be seen best in the light of the 1960s coal market. From 1960 through 1969, the real price per ton declined. Mine population dropped from 7865 to 5118; employment declined from 169,400 to 124,532. The times, so to speak, were tough. With the prevailing rate of exit of mines and decline in employment, mine managers, foremen, and miners knew the mine had to be efficient to show a profit—so they could keep their jobs.

In the 1970s, however, the opposite situation occurred. Coal prices reached record levels and the industry showed record profits. Firm population increased and employment almost doubled. This "fat" in the market throughout most of the 1970s resulted in a different attitude by all workers involved. Despite productivity decreases, mines stayed in business and made a substantial profit; indeed, many were expanding their capacity and employment.

In order to examine more closely the effect of price and market conditions upon productivity, the average real price of deep or surface coal was included in the productivity functions discussed in Chapters 5 and 6.[2] Inclusion of this price variable, however, creates several problems, including simultaneity and modeling.

Because the price of coal is determined by the interaction of supply and demand, a simultaneity problem appears. That is, anything that can affect the supply of coal will have some impact upon price. An industry-wide decrease in efficiency, due to health and safety legislation for instance, would affect aggregate supply and, therefore, price. The change in coal price is a function of productivity change, so including price in the productivity function would mean misspecification (it assumes productivity is a function of price, rather than vice versa). However, if coal prices increase due to the political decisions of a world oil cartel for example, mines would react to this higher price by developing new sections, mining poorer sections, or even changing attitudes. These actions would be the direct result of price and market changes and could lead to a productivity decline.

The result of all this is the proverbial problem of which came first, the chicken or the egg. A decrease in productivity can lead to higher prices, and higher prices can lead to a decrease in productivity. Including price as an independent variable in the productivity function assumes that causality goes from price to productivity only, however.

To avoid this problem, the models in the following section include price lag as the independent variable. That is, productivity in year j is assumed to be related to the other variables and price in year j-1. Obviously, this year's productivity cannot influence last year's price, so one direction of causality is removed. This does not free the model of problems entirely, however, because the models examined use pooled observations. A price lag affects only time series variance; the cross-sectional variance can still result from productivity affecting prices.

The conceptual method employed in the previous sections established a relationship between variables that *a priori* could affect productivity. As coal prices increase, one would expect many of these variables to change (e.g., days active, EXPWORK, CAP, CAP^2, SEAM, IDLE, and NEW), making them a function of price. In this way the influence of coal prices upon productivity could be captured.

By including price in the productivity function, the assumption is made that firm reaction to prices goes much beyond changes in the other variables specified in the model and may be more subtle than such actions as increasing the days worked (e.g., x-efficiency). However, by including price directly in the function, we now have causality from price to some of the other independent variables as well as from price to productivity. It is not known how this might bias the results.

To avoid this problem, the regressions reported here are for two time periods. By dividing the model into time periods, we are assuming that the structure of the model is different for the 1960s (low prices) and 1970s (high prices). The relationship between the independent variables (estimated coefficients) and productivity is allowed to change as prices change between the two periods.

EMPIRICAL RESULTS

Tables 7-1 through 7-4 report the regression results of estimating the state-level models with a price lag variable. Table 7-1 details the general least squares regression estimates for the state deep mine model. The D1975 variable was dropped because it was collinear with LPRICE.

In comparing regression 7-2 with regression 5-3 (Table 5-1), the most apparent change is the better "fit" that the price lag model gives. Although most of the coefficients change somewhat, the only two that are substantially different are INJRATE and CLEAN. The coefficient values and t statistics for LPRICE in both the 1960s (regression 7-1) and the 1970s (regression 7-2) indicate that it is the most significant variable in explaining both productivity decline in the 1970s and productivity growth in the 1960s.

Table 7-2 contains the weighted independent variables multiplied by their respective coefficients from regression 7-2 for the 1970-1975 period. The most striking result from Table 7-2 is the accuracy with which the productivity function estimates average labor productivity from the performance of the independent variables.

With the exception of the 1-year impacts estimated for the 1971 and 1974 strikes, sources of productivity decline are concentrated in the work stoppage variable, the CMHSA inspections variable, the continuous mining variable, and LPRICE. The behavior of LPRICE in 1975 indicates that the majority of the influence of D1975 in regression 5-3 is from market effects. Market conditions account for a decrease of approximately 0.5 ton per miner-shift per year through 1975, when rapid price increases and demand conditions resulted in a decrease of approximately 2 tons per miner-shift. Work stoppages also contributed heavily to productivity decreases in that year.

The influence of the CMHSA and continuous mining are more gradual in nature. However, the negative coefficient for CONT may be a result of the CMHSA. If this is the case, then much of the drop from 1969 to 1970 could be explained by this variable.[3]

Table 7-3 contains generalized least square regression results for the state-level surface mine models including LPRICE. In both the Appalachian (regression 7-3) and non-Appalachian (regression 7-4) models, price enters the regressions as a highly significant variable and has the expected sign. For the Appalachian model, price and the reclamation variable (RECLAIM) were collinear; therefore, RECLAIM was dropped from the model estimated in regression

Table 7-1. General Least Squares Regression Results, State-Level Deep Mines with Price Lag, 1961-1975

Variable	Estimated Coefficients: Regression 7-1 (≤1969)	Estimated Coefficients: Regression 7-2 (>1969)
Constant	7.22	19.66
CAP	.354 (8.91)	.070 (1.14)
CAP^2	-0.004 (5.61)	.001 (1.46)
DAY	.023 (3.87)	-0.013 (0.65)
SEAM	.341 (3.77)	.367 (2.38)
CLEAN	.032 (4.25)	-0.025 (2.79)
INJRATE	3.98 (3.88)	-0.067 (0.03)
DUMS1	—[a]	-1.25 (2.10)
DUMS2	—[a]	-1.29 (1.56)
INSM	—[a]	-0.023 (3.03)
STOPS	-0.011 (0.80)	-0.037 (2.62)
EXPWORK	.040 (1.49)	-0.015 (0.71)
CONWORK	-0.002 (0.11)	.003 (0.07)
CONT	-0.001 (1.60)	-0.003 (2.81)
LPRICE	-0.096 (7.53)	-0.036 (6.54)
R^2	.985	.830
SEE	1.03	1.24
N	90	60

NOTE: *t* statistics are in parentheses.

[a]Not applicable.

Table 7-2. Sources of Productivity Variation, State-Level Deep Mines, 1970-1975

Variable	1970	1971	1972	1973	1974	1975
Capacity	0.87	0.92	1.05	1.23	1.30	1.21
DAYS	-2.98	-2.74	-2.97	-3.01	-2.67	-2.98
SEAM	1.92	1.92	1.92	1.92	1.92	1.92
CLEAN	-1.77	-1.80	-1.74	-1.77	-1.62	-1.53
INJRATE	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02
DUMS1	0	-1.25	0	0	0	0
DUMS2	0	0	0	0	-1.29	0
INSM	-0.11	-0.32	-0.65	-1.42	-1.15	-0.98
EXPWORK	-0.14	-0.03	-0.06	-0.01	-0.12	-0.21
CONWORK	0	0	0	0	0	0
CONT	-1.53	-1.68	-1.78	-1.83	-1.90	-1.96
LPRICE	-1.88	-2.33	-2.92	-2.85	-2.96	-5.01
STOPS	-0.44	-0.52	-0.58	-0.64	-0.69	-1.30
Estimated ALP	13.6	11.8	11.9	11.3	10.5	8.8
Actual ALP	13.7	12.0	11.9	11.6	10.9	9.5

Constant term = 19.66.

Table 7-3. Generalized Least Squares Regression Results, State-Level Surface Mines with Price Lag, 1970-1975

Variable	Regression 7-3 (Appalachian)		Regression 7-4 (Non-Appalachian)	
	Estimated Coefficients			
Constant	35.83		57.70	
CAP	.199	(5.33)	.079	(4.76)
CAP^2	—[a]		-0.00003	(2.04)
RATIO	—[a]		-1.58	(5.44)
CLEAN	-14.03	(2.60)	—[a]	
LT6	—[a]		.031	(0.53)
DUMS1	-0.40	(0.25)	-3.86	(0.88)
DUMS2	-6.88	(4.70)	—[a]	
RECLAIM	—[b]		-16.02	(4.47)
LPRICE	-0.125	(6.92)	-0.045	(4.13)
INJRATE	-8.73	(0.60)	-8.74	(2.38)
DAYS	-0.016	(1.12)	—[a]	
EXPWORK	0.023	(0.83)	-0.004	(1.70)
CONWORK	—[a]		—[a]	
R^2	.809		.740	
SEE	1.53		1.46	
N	48		89	

NOTE: *t* statistics are in parentheses.

[a]Variable insignificant at the 0.5 level.

[b]Variable dropped because it was collinear with LPRICE.

7-3. Part of the negative impact of LPRICE in regression 7-3 (Appalachian) is thus related to state-level reclamation laws. Both RECLAIM and LPRICE were significant in the non-Appalachian model.

Table 7-4 contains the weighted independent variables multiplied by their respective coefficients for the Appalachian model (regression 7-3, Table 7-3).

Table 7-4. Sources of Productivity Variation, Appalachian Surface Mines, 1970-1975

Variable	1970	1971	1972	1973	1974	1975
Capacity	7.72	7.63	7.64	7.37	6.46	5.14
CLEAN	-3.37	-2.38	-2.67	-2.67	-2.38	-2.24
DUMS2	0	0	0	0	-6.88	0
LPRICE	-4.65	-5.60	-6.49	-6.27	-6.77	-13.49
DUMS1	0	-0.40	0	0	0	0
INJRATE	-1.34	-1.59	-1.19	-1.10	-0.82	-1.06
DAYS	-3.14	-3.30	-3.29	-3.21	-3.74	-3.66
EXPWORK	.92	.40	.08	.20	.95	.50
INTERCEPT	35.83	35.83	35.83	35.83	35.83	35.83
Estimated ALP	31.97	30.59	29.91	30.15	22.65	21.02
Actual ALP	34.05	33.22	33.16	32.24	23.83	21.72

Again, the productivity function accurately estimated productivity from the independent variables. Except for the 1-year impacts of the 1971 and 1974 coal strikes, the LPRICE and capacity variables explain the majority of productivity decline. Appalachian surface mines had no significant drop in productivity until 1974. In 1974 and 1975, market conditions, reclamation laws, and strikes combined to depress productivity by almost 10 tons per miner-shift.

The weighted independent variables multiplied by their respective regression coefficients for the non-Appalachian model (regression 7-4) are contained in Table 7-5. Both actual and predicted productivity are volatile in this table; the non-Appalachian model does not estimate productivity as well as the Appalachian surface model and the deep mine model.

Table 7-5. Sources of Productivity Variation, Non-Appalachian Surface Mines, 1970-1975

Variable	1970	1971	1972	1973	1974	1975
Constant	15.39	18.79	20.25	21.62	19.74	17.72
RATIO	-21.09	-20.17	-20.37	-19.49	-19.10	-19.99
RECLAIM	-3.88	-3.99	-12.63	-13.27	-14.63	-14.66
LPRICE	-1.70	-1.71	-1.96	-1.86	-1.84	-2.38
DUMS1	0	-3.86	0	0	0	0
EXPWORK	-0.05	-0.59	-0.07	-0.03	-0.05	-0.09
INJRATE	-1.74	-1.56	-1.50	-1.46	-1.06	-1.04
LT6	1.19	1.09	1.15	1.13	1.03	1.13
INTERCEPT	57.70	57.70	57.70	57.70	57.70	57.70
Estimated ALP	45.82	45.70	42.57	44.34	44.79	38.39
Actual ALP	31.26	41.97	42.29	43.76	37.99	36.87

Price does not play an important role in the non-Appalachian region. Both mine size and reclamation laws appear to be major causes of the rather slight relative drop in productivity in this region. One possible explanation for the small role coal prices play is the rather large size of mines in the non-Appalachian region. In 1975, the average daily output of Appalachian surface mines was 258 tons compared with 2727 in non-Appalachian surface mines (Tables 5-8 and 5-10 show this). These larger mines may not be able to react quickly to changing market conditions; most are probably selling under long-term contract and are insulated somewhat from the market.

PRICE AND THE MINE-LEVEL MODELS

The Ohio and Illinois data did not contain mine-level price information. However, these models were recomputed using the state average price as the price variable. Use of this average eliminates cross-sectional variance that could be the result of different coal grades, marketing methods, and transportation.

Tables 7-6, 7-7, and 7-8 contain the results of these regressions. In two of the models (the Illinois deep mines for 1966-1969 and small Ohio deep mines) LPRICE is insignificant. In all of the other regressions the

Table 7-6. Regression Results, Illinois Deep Mines with Price Lag, 1966-1976

Variable	Estimated Coefficients: Regression 7-5 (≤1969)	Regression 7-6 (>1969)
Constant	26.72	17.56
CAP	.199 (5.26)	.156 (7.45)
CAP^2	-0.0006 (3.78)	-0.0005 (4.57)
CMHSA	—[a]	-0.119 (2.01)
NEW	-2.33 (1.05)	-2.362 (2.04)
INJRATE	1.47 (0.81)	-1.748 (1.44)
IDLE	-4.504 (2.67)	-2.086 (1.75)
STRIKE1	—[a]	—[a]
STRIKE2	—[a]	-0.880 (0.96)
EXPWORK	-2.49 (2.26)	-0.009 (0.95)
CONWORK	-0.074 (0.52)	.010 (0.25)
OLD	-8.091 (4.63)	-0.062 (0.10)
LPRICE	-0.02 (1.09)	-0.062 (7.67)
SEAM	-0.073 (1.82)	—[a]
R^2	.707	.623
SEE	5.80	3.30
N	112	151

NOTE: *t* statistics are in parentheses.

[a] *t* level too low for computation.

Table 7-7. Regression Results, Illinois Surface Mines with Price Lag, 1970-1976

Variable	Estimated Coefficients: Regression 7-7 (with LCRA)	Estimated Coefficients: Regression 7-8 (without LCRA)
Constant	41.81	41.93
CAP	.237 (9.91)	.237 (9.91)
OLD	-5.19 (2.38)	-5.20 (2.39)
LCRA	.384 (0.16)	—[a]
SPR	-0.160 (3.79)	-1.58 (4.33)
IDLE	1.301 (0.55)	1.317 (0.55)
CONWORK	-0.288 (3.65)	-0.287 (3.62)
RATIO	-0.321 (1.85)	0.321 (1.85)
EXPWORK	-0.033 (1.36)	0.033 (1.36)
NEW	3.643 (1.34)	3.360 (1.33)
INJRATE	8.874 (3.32)	8.860 (3.32)
STRIKE1	—[b]	-1.81 (0.65)
STRIKE2	-3.819 (1.37)	-3.719 (1.43)
N	214	214
SEE	12.60	12.61
R^2	.390	.390

NOTE: *t* statistics are in parentheses.

[a]Not applicable.

[b]*t* level too low for computation.

Table 7-8. Regression Results, Ohio Deep Mines with Price Lag

Variable	Estimated Coefficients: Regression 7-9 (Small Mines)		Regression 7-10 (Large Mines)	
Constant	8.219		20.659	
IDLE	1.96	(0.97)	12.901	(3.55)
DRIFT	—[a]		6.242	(4.61)
CAP	.099	(3.27)	.0007	(2.62)
DUMS1	-3.484	(1.32)	—[a]	
DUMS2	—[a]		-3.352	(1.97)
EXPWORK	-0.777	(0.79)	.196	(1.55)
CONWORK	-7.901	(2.32)	10.993	(1.83)
LPRICE	—[a]		-0.0126	(5.69)
NEW	—[a]		-6.746	(2.10)
CAP^2	-0.00009	(1.25)	—[b]	
SEAM	-0.114	(1.06)	—[a]	
CONT	-5.035	(2.23)	—[a]	
N	73		165	
SEE	7.31		6.97	
R^2	.545		.357	

NOTE: *t* statistics in parentheses.

[a] *t* level too low for computation.

[b] Not applicable.

price variable has the expected negative coefficient and is highly significant. As was the case with the Appalachian surface mine price model, the Illinois surface mine model indicates that part of the effect captured by the RECLAIM variable is due to price changes.

While these mine-level results support the state-level findings, the DOE microdata results reported in Chapter 6 also tend to confirm the strong relationship between price and productivity. Using the small area study approach to control for excluded variables in the regression, individual mine prices in these models are highly significant and of the expected sign both cross-sectionally and with the pooling of these data.

These microresults support the argument that causality moves from price to productivity. Most of the mines in these areas are small producers selling on the spot market, implying that they cannot markedly affect aggregate supply and are largely price takers. Price to these small operators is exogenously determined, and, given a price level, they adjust their mine operation characteristics accordingly.

CONCLUSIONS

Upon the inclusion of price variables in the productivity functions, one is impressed by the consistently high levels of significance and explanatory power that price has. Almost any way the variable is examined, i.e., cross-sectionally, pooled, time series or with micro- or macrodata, the variable consistently explains large portions of productivity variance.

While these results are consistent with predictions of the theory of the firm, the empirical problems of isolating price and market effects are large. Many of the purported causes of productivity decline could be a result of high prices and "fat" in the 1970s coal market. Industry observers have alluded to work force attitudes and intangibles that largely support the *x*-efficiency theory. Management complaints that workers are "militant," "not motivated," and "lack the work ethic" all tend to support this *x*-efficiency theory.[4] Management approach and ability have also been blamed.[5] All of these complaints were largely nonexistent during the 1960s when the industry was fighting for survival.

A NOTE ON COAL PRICES[6]

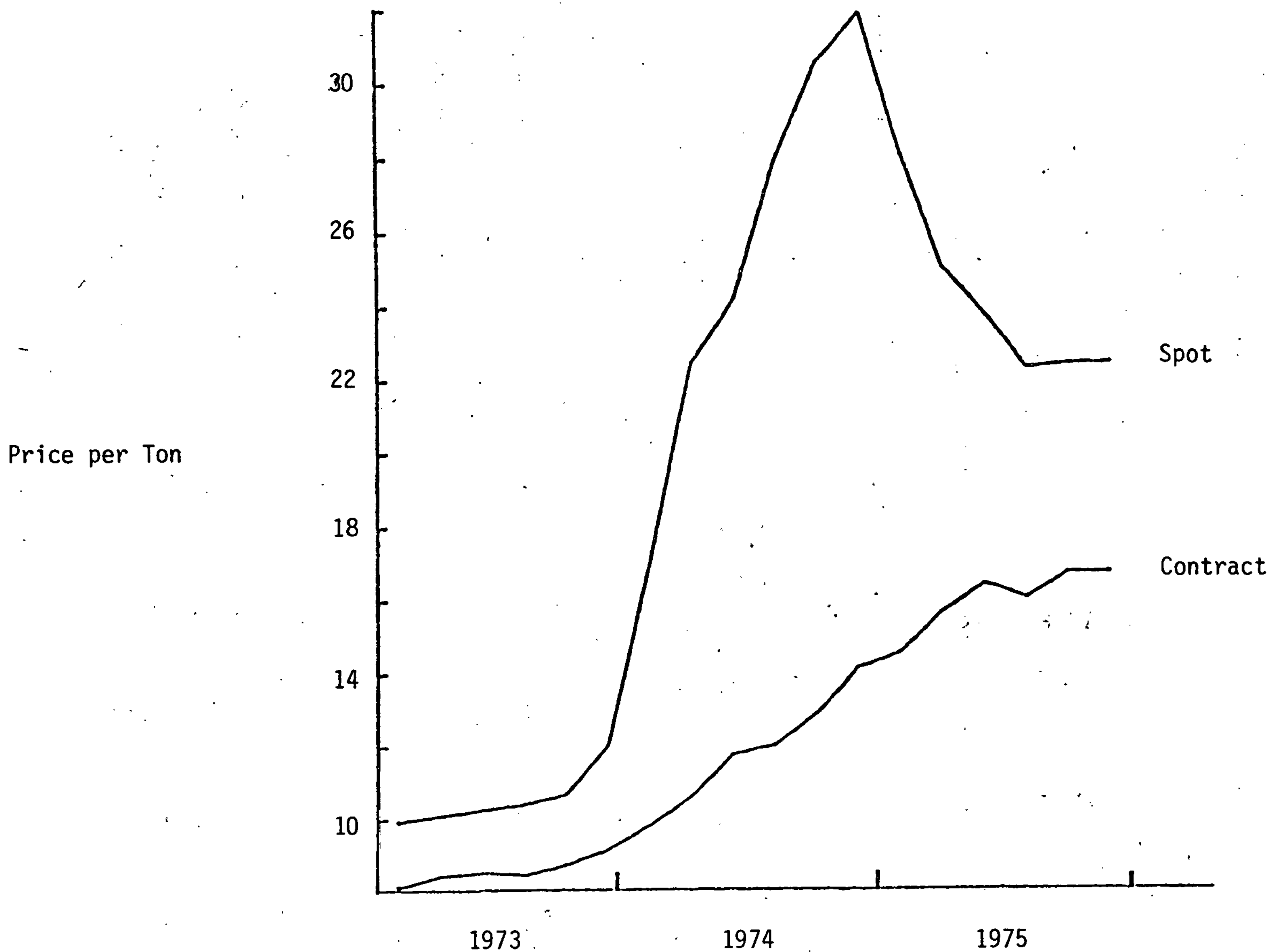
Excluding captive production (approximately 18 percent of the total 1977 tonnage), coal consumers can purchase coal on the spot market, negotiate or renegotiate a long-term contract, or negotiate the purchase of coal to be supplied within a given year. Coal prices are affected by both market forces and the multiple grades of coal that can be purchased.

Long-term contract prices for coal show the least variance. Because consumers can contract for future delivery, present market conditions do not influence long-term contract prices as much as they do in the spot market. However, prevailing market conditions do affect long-term contracts. Coal producers are willing to trade a portion of the price available on the spot market for the security of a long-term consumer commitment.

Conceptually, there would exist some "indifference price" for long-term contracts in which the coal producers would be indifferent toward a long-term contract with security and lower profit or high profit/high risk spot market sales. If the contract price is lower than this indifference price, producers will sell on the spot market. As shown in Figure 7-1, long-term contract prices show a sluggish response to the volatile spot market.

The spot market for coal must absorb most short-term fluctuations in demand, and the large swings in the spot market prices reflect this role. Due to the lead time necessary to open a large new mine, most short-term output response is limited to small surface mine openings, mine reopenings, and existing mines expanding output on the intensive margin (e.g., using backup equipment to mine a previously unmined section).

In the short run, coal output is constrained by supply, and this constraint is reflected in spot market prices. Because of the immense amount of our national coal reserves (with the exception of metallurgical grade coal), long-term output is constrained by demand. Given this situation, one would expect the long-term prices to approach the cost of production plus a reasonable return on capital, as was the situation during the 1960s. The 1970s have seen abrupt shifts in the demand for coal due to the world oil cartel price increases and relatively smaller reserves of petroleum available for demand, government policy, and union strike activity. These shifts in demand (both total and regional demand) have prevented the coal industry from achieving the long-term cost of production pricing characteristics of a competitive industry.



Source: Federal Power Commission, Form 423 reports.

Figure 7-1. Utility Steam Coal Prices

NOTES

[1]Harvey Leibenstein, "Aspects of the *x*-Efficiency Theory of the Firm," *The Bell Journal of Economics* 6(2):580-605.

[2]The inclusion of price in the productivity functions was orginally suggested by Frank Ladd, University of Utah, and follows the method employed by Harold Wool and John Ostbo of The Conference Board. Wool and Ostbo found price to be a significant variable explaining coal industry productivity variation using national and regional time series data.

[3]The behavior of the CONT variable in the state-level regressions 7-1 and 7-2 and in particular the Ohio mine-level results in regressions 6-8, 6-9, 6-11, and 6-12 all support this argument. See also Joe G. Baker and Robert J. Gaston, *Coal Mine Labor Productivity: Review of Issues and Evidence, A Report to the President's Commission on Coal* (Oak Ridge, Tennessee: Oak Ridge Associated Universities, 1979), p. 13.

[4]Ted Mills, "Altering the Social Structure in Coal Mining: A Case Study," *Monthly Labor Review* 99(10):3-4; Joseph Brennan, "Productivity—and the BCOA," *Coal Age*, July 1976, pp. 96-97; Stanley Suboleski, "Boost Your Productivity by Adding Continuous Miners," *Coal Age*, March 1975, p. 78; and Joe G. Baker and Robert J. Gaston, *Report to the President's Commission*, pp. 9-10, 17-18, and E8-E9.

[5]See Joseph P. Brennan, "Labor Relations and the Coal Industry," *Mining Congress Journal* 62(7):19-20; and Anonymous, "Productivity—and the UMWA," *Coal Age*, July 1975, p. 98.

[6]This section is provided only to familiarize the reader with pricing practices in the coal industry and is not intended to be an exhaustive treatment. For a more detailed discussion of the pricing and marketing conventions of the coal industry, the reader is referred to ICF, Inc., *Coal and Electric Utilities Model Documentation*, 3rd edition (Washington, D.C.: ICF, Inc., March 1979), Appendix B; Executive Office of the President Council on Wage and Price Stability, *A Study of Coal Prices* (Washington, D.C.: Government Printing Office, March 1976); and Charles River Associates, *Coal Price Formation* (Palo Alto, California: Electric Power Research Institute, 1977).

CHAPTER 8. ESTIMATING A COAL INDUSTRY COST FUNCTION

Since 1969, coal industry output has increased less rapidly than employment, resulting in a marked decline in the average productivity of labor. In an attempt to better understand this phenomenon, average labor productivity has been shown to be related to several quantifiable factors representing a number of economic, legal, and institutional changes ranging from increased coal price and production to health and safety regulations and union activities. While much has been learned, data limitations leave some questions unanswered.

What remains to be clarified is the nature of the basic relationship between labor, other inputs, and total output. Knowing more about the way in which inputs can be combined and substituted for one another would contribute to an understanding of recent trends in output, productivity, and costs. Declining labor productivity might be explained by changes in the production function over recent years. If no significant changes are observed, the best explanation for productivity changes might be in terms of input substitution and the mix of inputs.

The purpose of this chapter is to discuss a methodological approach that might prove fruitful in an analysis of coal industry production. The method involves inferring the characteristics of the production function from an estimate of the related cost function. After making some fairly restrictive assumptions, the technique is used to analyze the incomplete data that is readily available. Although far from conclusive, the results suggest there may have been significant changes in cost and production relationships in recent years and that more extensive research on this problem is needed.

TRANSLOG COST FUNCTION

The following analysis relies very heavily on the results shown by Shephard and refined by others[1]: If producers can be assumed to minimize costs at any level of output, then the cost function contains sufficient information to describe completely the production relationship. Thus, the values of production parameters can be obtained from an estimate of the cost function $C = C(Y, P_1, P_2, \ldots, P_n)$ where Y is a measure of output or value added and $P_1, P_2, \ldots, P_n$ are input prices. No specific form of the cost function is necessary for this result, but because it imposes no prior restrictions on substitution possibilities and allows scale economies to vary with output, the translog form is frequently used in empirical studies.[2]

In the three-input case where there is no interaction between output and factor prices, the translog cost function takes the form

$$(8\text{-}1)\qquad \ln C = \alpha_0 + \alpha_y \ln y + \tfrac{1}{2}\gamma_{yy}(\ln y)^2 + \alpha_1 \ln P_1 + \alpha_2 \ln P_2 + \alpha_3 \ln P_3 + \tfrac{1}{2}\gamma_{11}(\ln P_1)^2 + \tfrac{1}{2}\gamma_{22}(\ln P_2)^2 + \tfrac{1}{2}\gamma_{33}(\ln P_3)^2 + \gamma_{12} \ln P_1 \ln P_2 + \gamma_{13} \ln P_1 \ln P_2 + \gamma_{23} \ln P_2 \ln P_3$$

The parameters of the model can be estimated directly using Eq. 8-1 or by simultaneous estimation of the input cost share equations:

$$(8\text{-}2)\qquad \begin{aligned} S_1 &= \alpha_1 + \gamma_{1y}\ln y + \gamma_{11}\ln P_1 + \gamma_{12}\ln P_2 + \gamma_{13}\ln P_3 \\ S_2 &= \alpha_2 + \gamma_{2y}\ln y + \gamma_{21}\ln P_1 + \gamma_{22}\ln P_2 + \gamma_{23}\ln P_3 \\ S_3 &= \alpha_3 + \gamma_{3y}\ln y + \gamma_{31}\ln P_1 + \gamma_{32}\ln P_2 + \gamma_{33}\ln P_3 \end{aligned}$$

where S_i (i = 1,2,3) is the proportion of total cost represented by expenditures on factor i. For this function and the corresponding production function to be well-behaved, it is necessary that the cost function be (1) homogeneous of degree one in prices and (2) monotonically increasing in input prices. This can be guaranteed by the conditions

$$\alpha_1 + \alpha_2 + \alpha_3 = 1$$

$$\sum_i \gamma_{ij} = \sum_j \gamma_{ij} = 0$$

$$\gamma_{ij} = \gamma_{ji}$$

The derivations of the share equations (Eq. 8-2) and the above restrictions have been shown elsewhere.[3]

DATA AND MODEL SPECIFICATION

Fairly complete cost data is available for coal mining from the *Census of Mineral Industries* for 1963, 1967, and 1972.[4] Values are given for 13 separate geographical regions in 1963 and 1976 and for 12 regions in 1972 (survey results for 1977 were unavailable for this report). Pooling these cross-sections provides a sufficient number of observations for estimation of the model.[5]

Two measures of costs are provided for each of the survey years. The first is total cost of production and includes not only annual payroll but also supplies and other principal costs. Capital expenditures and payments for land and mineral rights are not available for 1963 and are not included in the measure of total costs. The second measure is labor costs alone and includes total payroll but excludes supplemental labor costs that were not provided for 1963. These figures are available separately for all production and nonproduction workers. From disaggregated figures, cost shares for production and nonproduction workers are easily computed.

Input prices for labor are also readily available. The hourly wage for production, development, and exploration workers is obtained by dividing the annual payroll by the number of hours worked during the year. For nonproduction workers, only the average number of employees is available. Hourly wages are computed from nonproduction payroll figures by assuming an average of 2000 hours worked per year. Unfortunately, proper estimation of a three-input cost function such as Eq. 8-1 or the corresponding share equations (Eq. 8-2) requires information on the price of capital. In other time series or cross-industry studies, a price for capital is estimated by reference to rental price of comparable equipment. This is done taking into account differential tax treatment and variation in capital markets.[6] No such series is available to show regional variations by industry. Consequently, the price of capital is assumed constant across regions for the analysis that follows. Any temporal variations are accounted for by using control variables. The result is to confuse interpretation of the control variables, thereby making it impossible to isolate increasing capital and material costs from other factors affecting the cost function over time.

Using *Census of Mineral Industries* data, two models are estimated. The first model is a cost function of the following form:

$$\begin{aligned} \ln C = {} & \alpha_0 + \alpha_y \ln y + \tfrac{1}{2}\gamma_{yy}(\ln y)^2 \\ & + \alpha_1 \ln P_1 + \alpha_2 \ln P_2 + \tfrac{1}{2}\gamma_{11}(\ln P_1)^2 \\ & + \tfrac{1}{2}\gamma_{22}(\ln P_2)^2 + \gamma_{12}(\ln P_1)(\ln P_2) \\ & + \delta_1 t_{1963} + \delta_2 t_{1972} \end{aligned}$$

where y is value added, P_1 and P_2 are the price of production and nonproduction workers, respectively, and t_{1963} and t_{1972} are control variables for 1963 and 1972, respectively.

Two measures of cost are used to obtain values for the dependent variable. As discussed above, c alternately represents total cost and labor costs of production. The estimated coefficient for the control variables shows any shifts in the cost function (and, therefore, the production function) after accounting for changes in the wages paid to workers.

In the second model, two of the three share equations are estimated. The third is dependent on the first two, and its coefficients can be computed from the restrictions that $\sum_j \gamma_{ij} = \sum_i \gamma_{ij} = 0$ and $\sum_i \alpha_i = 1$. Furthermore, the restriction that $\sum_i \gamma_{ij} = 0$ makes it possible to rewrite the system of share equations as follows:

$$S_1 = \alpha_1 + \gamma_{1y} \ln y + \gamma_{11} \ln P_1 + \gamma_{12} \ln P_2 + (-\gamma_{11} - \gamma_{12}) \ln P_3$$

$$S_2 = \alpha_2 + \gamma_{2y} \ln y + \gamma_{21} \ln P_1 + \gamma_{22} \ln P_2 + (-\gamma_{21} - \gamma_{22}) \ln P_3$$

or

$$S_1 = \alpha_1 + \gamma_{1y} \ln y + \gamma_{11} (\ln P_1 - \ln P_3) + \gamma_{12} (\ln P_2 - \ln P_3)$$

$$S_2 = \alpha_2 + \gamma_{2y} \ln y + \gamma_{21} (\ln P_1 - \ln P_3) + \gamma_{22} (\ln P_2 - \ln P_3)$$

so that γ_{11}, γ_{12}, γ_{21}, and γ_{22} measure the impact on cost shares of changes in relative prices (P_1/P_3) and (P_2/P_3) measured in natural logs.[7]

While the rental price of capital, P_3, can be expected to change over time, it is not unreasonable to assume that within a given industry the rental price of capital will be relatively invariant across regions. Thus, including the control variables t_{1963} and t_{1972}, the parameters of the above model can be estimated from

$$S_1 = \alpha_1 + \gamma_{1y} \ln y + \gamma_{11} \ln P_1 + \gamma_{12} \ln P_2 + \delta_{11} t_{1963} + \delta_{12} t_{1972}$$

$$S_2 = \alpha_2 + \gamma_{2y} \ln y + \gamma_{21} \ln P_1 + \gamma_{22} \ln P_2 + \delta_{21} t_{1963} + \delta_{22} t_{1972}$$

subject to the restrictions discussed earlier. The homogeneity and monotonicity constraints also provide estimates for the remaining parameters: α_3, γ_{13}, γ_{23}, γ_{31}, γ_{32}, and γ_{33}.

The values of δ_{11}, δ_{12}, δ_{21}, and δ_{22} indicate, after controlling for differences in the price of production and nonproduction workers, P_1 and P_2, respectively, how cost shares of the two categories of workers have changed over time.

EMPIRICAL RESULTS

A cost function is estimated in four different forms using the pooled cross-sectional data just discussed. So that the estimated regressions conform to the homogeneity and monotonicity constraints discussed earlier, restricted least squares estimates are obtained whenever appropriate. The regressions are reported in Table 8-1 using symbols defined in Eq. 8-1. In regressions 8-1 and 8-3 the cross product terms are excluded ($\gamma_{ij} = 0 \ \forall_{ij}$) so the equations correspond to Cobb-Douglas functions. In regression 8-2, it is assumed that $\alpha_3 = \gamma_{33} = \gamma_{13} = \gamma_{23} = 0$ because the dependent variable is labor costs and is not directly affected by the price of capital, P_3. In regression 8-4, all of the parameters are included with α_3, γ_{33}, γ_{13}, and γ_{23} estimated from the restrictions.

The most interesting empirical finding is that regardless of specification, the cost function has shifted significantly over time. The labor cost function has shifted down over the entire period of analysis. This can be seen from the values of the regression coefficients on the control variables representing the different time periods. The positive coefficients for t_{1963} indicate that, after controlling for differences in wages and the value of output, labor costs were higher in 1963 than during the omitted period, 1967. Thus, the function decreased between 1963 and 1967. The negative coefficients for t_{1972} suggest that the labor cost function continued to shift down between 1967 and 1972. These results are consistent with the increase in the average product of labor observed over most of the period of analysis. As data becomes available for later years, it will be interesting to see whether this trend is reversed during the period of declining productivity.

When total costs are analyzed, a somewhat different picture emerges. Again, concentrating on the estimated coefficients for t_{1963} and t_{1972}, the total cost function is observed to rise between 1963 and 1972 after accounting for differences in value added and wages. To the extent that they are not accounted for in higher value added, material and capital cost increases no doubt explain part of this change. What remains a mystery is the extent to which other factors analyzed in this study (most notably health and safety regulations) contribute to the change in the cost functions. These results do provide some support, however, for the argument that recent years have seen a change in the basic cost and production relationships in the coal mining industry.

Table 8-1. Restricted Least Squares Estimates of Cost Function Parameters

Coefficients (t-values)	Dependent Variable (Natural Logs): Labor Costs		Total Costs	
	Regression 8-1	Regression 8-2	Regression 8-3	Regression 8-4
α_0	-1.78 (-8.97)	-1.94 (-8.57)	0.55 (2.24)	1.00 (1.49)
α_y	0.78 (7.65)	0.81 (7.88)	1.04 (13.8)	1.02 (12.4)
γ_{yy}	0.06 (2.34)	0.05 (2.06)	0.01 (0.5)	0.01 (0.61)
α_1	0.966 (6.79)	1.002 (7.05)	-0.74 (-3.58)	-1.58 (-1.29)
α_2	0.034 (0.24)	-0.002 (-0.02)	0.098 (0.99)	0.37 (0.87)
α_3	—[a]	—[a]	—[a]	1.21[b]
γ_{11}	—[a]	1.298 (1.43)	—[a]	0.03 (0.02)
γ_{22}	—[a]	1.298 (1.43)	—[a]	-0.73 (-0.98)
γ_{33}	—[a]	—[a]	—[a]	0.40[b]
γ_{12}	—[a]	-1.298 (1.43)	—[a]	0.55 (0.72)
γ_{13}	—[a]	—[a]	—[a]	-0.58[b]
γ_{23}	—[a]	—[a]	—[a]	0.18[b]
δ_1(1963)	0.29 (3.87)	0.34 (4.17)	-0.20 (-2.94)	-0.25 (-2.94)
δ_2(1972)	-0.45 (5.75)	-0.41 (-4.98)	0.30 (3.11)	0.29 (1.98)

[a] Variable not included.

[b] Estimated from restriction that $\sum_i \alpha_i = 1.00$ and $\sum_i \gamma_{ij} = \sum_j \gamma_{ij} = 0$.

The simultaneous estimates of the input share equations tend to confirm the changing nature of the cost function. Using symbols defined in this chapter and letting i = 1, 2, and 3 for production workers, nonproduction workers, and other inputs, respectively, total cost share equations are estimated. The parameters of the capital share equation are estimated from values obtained for the labor share equations using the homogeneity and monotonicity constraints. The results are given in the following equations:

$$S_1 = 0.21 \underset{(-3.67)}{- 0.02} \ln y \underset{(1.35)}{+ 0.09} \ln P_1 \underset{(2.32)}{+ 0.07} \ln P_2 - 0.16 \ln P_3 \underset{(5.58)}{+ 0.12}\, t_{1963} \underset{(-2.02)}{- 0.06}\, t_{1972}$$

$$S_2 = 0.11 \underset{(0.19)}{+ 0.001} \ln y \underset{(2.32)}{+ 0.07} \ln P_1 \underset{(-2.24)}{- 0.08} \ln P_2 + 0.01 \ln P_3 \underset{(0.75)}{-0.02}\, t_{1963} \underset{(0.60)}{-0.015}\, t_{1972}$$

$$S_3 = -0.33 + 0.02 \ln y - 0.16 \ln P_1 + 0.01 \ln P_2 + 0.15 \ln P_3 \quad -0.10\, t_{1963} + 0.08\, t_{1972}$$

It is readily seen that after controlling for value added and price of labor effects, there is a significant decrease in production workers' share of total costs. Most of this decline occurs, however, between 1962 and 1967. The decrease between 1967 and 1972 is about one-half as great. The change in production workers' share of costs is balanced by an increase in the share of costs corresponding to capital and other inputs. After controlling for differences in wages, only the share equation for nonproduction workers shows no significant relationship to time.

These results are consistent with the shift observed earlier in the cost functions, particularly if production is becoming more capital intensive. Such an interpretation is consistent with other findings in this study and with recent investments required by health, safety, and environmental legislation. The increasing importance of surface mining over this period also contributes to an industry-wide shift toward more capital intensive production.

CONCLUSIONS

It was not the purpose of this section to make a definitive statement concerning the nature of the cost or production relationship in the coal mining industry. What has been established is a methodological approach that, with more complete data, has the potential of generating very useful results. The greatest obstacle to more meaningful use of this method is acquiring acceptable figures on regional variation in the price of capital and other inputs used in the industry. When these become available, data from more recent surveys will also improve this analysis.

Of greatest importance at this point is that preliminary figures provide support for the idea of a significant change in the production relationship in recent years. Labor represents a declining portion of the total production cost and, it seems, is being combined with other inputs in a changing manner. Additional confirmation of these results should be an important part of any further research agenda in this area.

NOTES

[1]R. W. Shephard, *Cost and Production Functions* (Princeton: Princeton University Press, 1953); H. Uzawa, "Production Functions with Constant Elasticities of Substitution," *Review of Economic Studies* XXIX:291-99; and W. E. Diewert, "An Application of the Shephard Duality Theorem: A Generalized Leontief Production Function," *Journal of Political Economy* LXXIX:481-505.

[2]See, for example, Hans P. Binswanger, "The Measurement of Technical Change Biases with Many Factors of Production," *The American Economic Review* 64(6):964-78; Ernst R. Berndt and David O. Wood, "Technology, Prices, and the Derived Demand for Energy," *The Review of Economics and Statistics* 57(8):259-68; Laurits R. Christensen and William H. Greene, "Economies of Scale in U.S. Electric Power Generation," *Journal of Political Economy* 84(4):655-76; and James M. Griffin and Paul R. Gregory, "An Intercounty Translog Model of Energy Substitution Responses," *The American Economic Review* 66(5):845-57.

[3]For derivations using a similar model, see Christensen and Greene, "Economies of Scale," pp. 659-61.

[4]U.S. Bureau of the Census, *Census of Mineral Industries*, Industry Series: Bituminous Coal and Lignite Mining (Washington, D.C.: Government Printing Office) various years.

[5]Lack of independence among the error terms poses well known problems with pooled cross-section data. Using similar data, however, this method was used successfully by Hans Binswanger, "A Cost Function Approach to the Measurement of Elasticities of Factor Demand and Elasticities of Substitution," *American Journal of Agriculture* 56:377-85; and "The Measurement of Technical Change Biases with Many Factors of Production," *The American Economic Review* 64(6):964-76.

[6]For complete explanation of this procedure, see Michael F. Mohr, "The Long-Term Structure of Production, Factor Demand, and Factor Productivity in U.S. Manufacturing Industries," Bureau of Labor Statistics Working Paper, 1977.

[7]To avoid using restricted least squares estimation, Nerlove uses a similar method in "Returns to Scale in Electricity Supply," *Measurement in Economics: Studies in Mathematical Economics and Econometrics in Memory of Yehuda Grunfeld*, Carl F. Christ, ed. (Stanford, California: Stanford University Press, 1963).

APPENDIX A - ANNOTATED BIBLIOGRAPHY

Anonymous. "Equipment Sales, Production, and Productivity by Mining Method in 1971." *Coal Age,* February 1972, 75-77.

Article examines equipment sales and data on labor productivity by technique for the years 1969, 1970, and 1971. Includes tables.

Anonymous. "Productivity—and the BCOA." *Coal Age,* July 1975, 96-97.

Interview with J. Brennan, president of the Bituminous Coal Operators Association. Discussion of productivity, problems with young work force, safety concerns, and ways to increase productivity.

Anonymous. "Productivity—and the UMWA." *Coal Age,* July 1975, 98.

Summary of answers by various union officials to questions concerning productivity trends, safety, and solutions to declines in productivity.

Anonymous. "Stemming the Slide in Productivity Is a Job for Both Machinery Manufacturer and Mine Operator." *Coal Age,* July 1976, 63-73.

Article addresses the 1969 Coal Mine Health and Safety Act, declining productivity, and methods to stabilize and reverse decreasing productivity. Review of new technology and equipment.

Anonymous. "Surface Mining Productivity Tied to Performance in Associated Areas." *Coal Age,* July 1976, 163-69.

Article addresses ways to halt decline in surface mine labor productivity. Examines equipment innovations such as bucket size and shovel technology.

Anonymous. "Underground Mining of Coal." *Mining Congress Journal* 59(2):128-36.

Review of new machinery, mines, and trends in productivity in underground mines. Examines mine research programs.

Anonymous. "1973 Shipments of Mining Equipment, Production, and Productivity from Various Methods of Mining." *Coal Age,* February 1974, 84-86.

Article examines equipment sales and data on productivity by technique for 1971, 1972, and 1973. Includes tables.

Baker, Joe G., *Coal Mine Labor Productivity: The Problem, Policy Implications, and Literature Review.* Oak Ridge, Tennessee: Oak Ridge Associated Universities, 1978.

This study describes the historical decline in labor productivity, the implications of this decline on mine safety, production cost, and labor demand, and reviews hypotheses explaining the decline. Includes data appendix, annotated bibliography, and tables.

-------. *Determinants of Coal Mine Labor Productivity Change: A Progress Report*. Oak Ridge, Tennessee: Oak Ridge Associated Universities, 1978.

Study examines the problem of declining coal mine labor productivity, reviews the literature, develops a conceptual model of productivity determination, and tests this model using nationwide state-level data and Illinois mine-level data. This research is an interim progress report on the research reported in this final report.

Baker, Joe G., and Gaston, Robert J. *Coal Mine Labor Productivity: Review of Issues and Evidence. A Report to the President's Commission on Coal.* Oak Ridge, Tennessee: Oak Ridge Associated Universities, forthcoming.

Prepared for the President's Commission on Coal, the study examines the research evidence relating to the causes of productivity decline in coal mining. The report also discusses the proceedings of a coal labor productivity seminar sponsored by the coal commission. The seminar included researchers from government, unions, coal companies, and the academic sector. The purpose of this seminar was to critically review existing research and discuss any evidence that bore on the topic of coal mining labor productivity.

Brennan, J. P. "Labor Relations and the Coal Industry." *Mining Congress Journal*, 62(7):18-21.

President Brennan discusses areas where management and labor must cooperate to achieve energy goals of coal. Discussion of productivity.

Christenson, C. L. *Economic Redevelopment in the Bituminous Coal Industry.* Cambridge, Massachusetts: Harvard University Press, 1962.

Contains analysis of productivity in underground mines, including Christenson's theory of discriminating selection, that is, a relationship between seam thickness, daily output scale, and type of company. Study is dated.

Christenson, C. L., and Andrews, W. H. "Physical Environment, Productivity, and Injuries in Underground Coal Mines." *Journal of Economics and Business*, 26(3):182-90.

Authors examine the relationship between physical environment (seam thickness), productivity, and injuries in coal mining in 1965. The results of this study show that productivity increases as seam thickness increases, then falls off at the 9-foot level. Christenson and Andrews attribute part of this to the theory of discriminating selection (larger mines are associated with integrated coal companies that can acquire the most easily worked reserves) and the use of "bulkier," but more efficient, equipment in the larger working area of thick-seam mines. The authors find a similar relationship between safety (lack of fatalities) and seam thickness, i.e., increasing safety as seam thickness increases to approximately the 9-foot level, then falling off. The authors also examine a 1971 case study county in West Virginia to compare with the pre-1969 era. They find the basic relationship of 1965 still holds true. However, there is a drastic reduction in the number of mines, and, while the average seam thickness remains constant, productivity declines in large mines and rises in small mines. Overall, the county coal industry becomes safer. In conclusion, the authors believe small mines working thin seams will face severe challenges to their existence.

Cohn, Elchanan, et al. *The Bituminous Coal Industry: A Forecast.* University Park: Institute for Research on Human Resources, The Pennsylvania State University, 1975.

This study is perhaps the most thorough and vigorous examination of the determinants of productivity in coal mining. The purpose of the research is to generate labor supply and demand estimates for 1988 and 2000. To generate these forecasts, the study employs a structural equation approach to estimating future labor productivity. The form of these equations is the following:

$$AP_j = a + \sum_{i=1}^{n} B_i x_i + E$$

$$\text{when } j = 1,\ n = 6$$
$$\text{when } j = 2,\ n = 4$$

When j equals 1, AP_1 equals average labor productivity underground and x_1 equals average hours per week; x_2 equals percentage of output from mines producing at least 0.5 million tons per year; x_3 equals time trend; x_4 equals percentage of coal cut by hand; x_5 equals percentage cut by continuous machines; x_6 equals percentage cut by longwall machines; and E equals error term. When j equals 2, AP_2 equals average labor productivity surface mines; x_1, x_2, x_3, and E were as above; and x_4 equals percentage of buckets and dippers having a capacity of 12 or more cubic yards. Using time series data from the 1948-1970 period, the coefficients of the two equations were estimated. Variables x_1 and x_3 in equation AP_1 were dropped due to collinearity; variable x_6 had an insignificant t statistic, as did x_2 in equation AP_2. Despite this, both equations had an R^2 of 0.98, indicating that virtually all of the changes in labor productivity for this period were explained by the structural equations. However, the period examined was one of virtually constant increase in productivity. A simple time trend model of the form (total productivity) = a + b (year) results in R^2 = 0.983 for 1950-1970 data.

Comptroller General of the United States. *U.S. Coal Development—Promises and Uncertainties.* Washington, D.C.: General Accounting Office, 1977.

Detailed report assessing prospects of expanding coal output to 1.2 billion tons in 1985. Includes section on labor productivity, extensive tables, statistics, and bibliography.

Congressional Research Service. *Factors Affecting the Use of Coal in Present and Future Energy Markets.* Washington, D.C.: Government Printing Office, 1973.

Study examines issues related to coal utilization, e.g., interfuel competition, mining regulations, and reserve characteristics. Short discussion of CMHSA and declining productivity.

Cornette, Aubrey J. "Ten Year Outlook in U.S. Coal Mining." *1976 Mining Yearbook,* 118-21. Denver: Colorado Mining Association, 1976.

Article assesses feasibility of doubling coal output by 1985. Discussion of declining productivity and the CMHSA.

Executive Office of the President, Council on Wage and Price Stability. *A Study of Coal Prices*. Washington, D.C.: Government Printing Office, 1977.

Report analyzes the causes of the tripling of coal prices in 1973 and 1974 and the future outlook for coal prices. The study discusses the reasons for declining mining productivity and the impact of unit labor costs on coal prices.

Fettig, Charles, "Impacts of Output per Man-Day, Costs, and Price of the Coal Mine Health and Safety Act of 1969". Unpublished thesis. Univeristy Park: Pennsylvania State University, 1978.

Based upon assumptions concerning changes in the staffing of underground mines, this study attempts to isolate and quantify the effects of the CMHSA. Results indicate that productivity is 45 percent lower than if there had been no act; accounting costs increased by 37 percent and selling price increased by 32 percent because of the act.

Friedman, Bernard S. *Manpower for Coal Mining Supply - Demand - Training*. Washington, D.C.: Government Printing Office, 1977.

Report assesses current and potential demand for coal mining manpower at the management, professional, and operative levels. Brief discussion of productivity.

Gaston, Robert J. *Coal Mine Labor Productivity: Mine Level Data from Pike County, Kentucky, and Other Selected Counties*. Oak Ridge, Tennessee: Oak Ridge Associated Universities, forthcoming.

This study reports the results of an analysis of Pike County, Kentucky, deep and surface mines. Using the Department of Energy coal system data, the relationship between mine productivity and various economic, geologic, and technological mine characteristics are discussed. This report also examines mine level data from other states.

Gordon, Richard L.; Manula, Charles B.; Fettig, Charles; and Gresham, James B. "Simulating the Effects of the Coal Mine Health and Safety Act." Mimeographed. University Park: Pennsylvania State University, no date.

This paper reports the results of a sensitivity analysis that uses a mine simulation model with different assumptions concerning the changes in manning brought about by the Coal Mine Health and Safety Act. Also included in this analysis is the effect of the act upon delays caused by methane checks, brattice cloth advances, and mechanical delays. The overall impacts on productivity and costs of production are discussed.

Gresham, J. B. "Impacts upon Production and Worker Productivity of the 1969 Coal Mine Health and Safety Act." Unpublished thesis. University Park: Pennsylvania State University, 1978.

Using a simulation model, this study employs a sensitivity analysis to examine the increase in work delays caused by provisions of the Coal Mine Health and Safety Act. These delays include brattice cloth advance, increased methane checks, and mechanical delays.

Julian, Edward. "Effect of the Coal Mine Health and Safety Act of 1969 on Productivity in Illinois Underground Coal Mines." Mimeographed. University Park: Pennsylvania State University, no date.

Using aggregate time series data for the Illinois deep coal mine industry from 1950 to 1975, this study uses regression analysis to examine the impact of the CMHSA on productivity. Due to autocorrelation and omission of certain variables, the author's conclusion that the CMHSA reduced productivity is tenuous. This is an interim report.

Julian, Louise. "Output, Productivity, and Accidents and Fatalities under the Coal Mine Health and Safety Act." Mimeographed. University Park: Pennsylvania State University, no date.

Using national-level time series data for 1950 to 1975, this interim report examines miner-hours worked, injuries, and productivity. The author concludes that the act reduced accidents, accident rates, and labor productivity.

Kramer Associates, Inc. *Determination of Labor Management Requirements in the Bituminous Coal Industry To Meet the Goals of Project Independence.* Springfield, Virginia: National Technical Information Service, 1975.

Study examines the manpower requirements of expanding coal production to 1.1 billion tons in 1985. Includes a chapter on productivity and discussion of changes in surface and underground labor productivity and projections. Little empirical analysis.

Maddala, G. S. "Productivity and Technological Change in the Bituminous Coal Industry, 1919-54." *Journal of Political Economy,* 75(2):352-65.

Study fits Cobb-Douglass production function to the bituminous coal industry. Author concludes that increase in productivity is due almost entirely to increase in horsepower per worker, with residual due to work force quality changes.

Malhotra, Ramesh. "Factors Responsible for Variation in Productivity of Illinois Coal Mines." *Illinois Mineral Note 60.* Urbana: Illinois State Geological Survey, 1975.

This study utilizes data from 29 underground mines and 32 strip mines in Illinois from 1970 to 1973 to determine factors influencing productivity variation among mines. The author utilizes tabular analysis and charts to draw conclusions; thus, the interrelatedness of the various factors cannot be determined. The results of the study indicate that in underground mines productivity is related to (1) seam thickness, (2) roof and floor conditions, (3) size of operation, (4) age of operation, (5) coal washing, and (6) effective equipment use. In surface mining, the relevant variables were (1) overburden to coal seam ratio, (2) nature of overburden (consolidated or unconsolidated), (3) mining method, (4) mine age, (5) mine capacity, (6) quality of final product, and (7) effective equipment use.

Mason, Richard H. "An Industry Thwarted, But Pushing Ahead." *Coal Mining and Processing,* July 1976, 52-56.

Author discusses decline in labor productivity and its causes—age and experience of the work force, CMHSA, labor disputes, and shortages of materials.

Meador, H. W. "One Company's Experience with Productivity." *First Symposium on Coal Management Techniques, Volume II,* 33-34. Washington, D.C.: National Coal Association, 1975.

Author discusses decline in labor productivity at the Westmoreland Coal Company. Examines the CMHSA; labor unrest; and a younger, inexperienced work force and their contributions to labor productivity.

Mills, Ted. "Altering the Social Structure in Coal Mining." *Monthly Labor Review* 99(10):3-10.

Review of an experiment to restructure the management and decisionmaking process at the Rushton Mine (Pennsylvania). Brief discussion of productivity decline and its relationship to a higher educated work force.

Nelson, Jon P., and Neumann, George R. *Labor Productivity and the Coal Mine Health and Safety Act of 1969.* Springfield, Virginia: National Technical Information Service, 1975.

Paper developes a firm-level production function for safety. Empirical estimates of this function are generated using aggregate time series data from 1950 to 1970. Paper concludes that ability to draw inferences from data is very limited given level of aggregation. Also, the increase in inexperienced operators, opening of new mines, and changes in work practices are all considered to have adversely affected injury experience from 1971 to 1972.

Office of Technology Assessment. *The Direct Use of Coal.* Washington, D.C.: Government Printing Office, 1979.

This report assesses the social, economic, physical, and biological benefits and risks of a major increase in U.S. coal production. The report includes a small discussion on the possible causes of productivity decline and proposes some actions to improve productivity.

Sommers, Paul. *Productivity in Underground Coal Mining: Preliminary Overview of Institutional Factors Influencing Productivity Levels.* Seattle, Washington: Battelle Memorial Institute, 1978.

This study examines the possible relationships between coal mine ownership patterns (captive, utility, independent coal company, etc.), leasing patterns, mine financing, and coal industry research and development on coal industry incentives. Author concludes that these factors could have reduced industry incentive and therefore productivity and suggests that research in this area would be worthwhile.

Stradley, Scot. "Human Resource Implications of the Production Process in Underground Bituminous Extraction, Especially for Utah." Unpublished dissertation. Salt Lake City: University of Utah, 1977.

Author examines the determinants of average labor productivity in underground coal mines using a cross-sectional approach with individual mines as the unit of observation. Despite some data limitations, Stradley concludes that highest average product is produced by longwall mines, second highest by room and pillar. There is a direct relationship between technique and average product. Following Christenson, Stradley finds a strong relationship between seam thickness and productivity. Stradley finds some inconclusive evidence supporting the theory of discriminating selection, that is, a relationship between seam thickness and company type.

Straton, J. W. "Effects of Federal Mine Safety Legislation on Production, Productivity, and Costs." *Mining Congress Journal* 58(7):19-23.

Using survey data from 64 mines, the author assesses effects of the CMHSA on productivity and costs. Based upon study results, author finds that (1) small mines are affected the most by declines in productivity, (2) conventional mining is affected more than continuous, (3) thin-seam coal mine productivity is greatly affected, and (4) captive mines are affected less than independent mines. Author also finds that mines report an average of $1.47 per ton extra cost as a result of the CMHSA. The majority of mines indicate that the ventilation requirements of the act are the most restrictive. This research attributes all productivity declines to the CMHSA and does not attempt to examine other possible causes.

-------. "Improving Coal Mine Productivity." *Mining Congress Journal* 63(7):20-24.

Article examines various factors affecting labor productivity: state and national laws, labor-management relations, worker skill, natural mine conditions, and equipment changes. To isolate the effect of the CMHSA, the author conducted a survey of 163 underground mines in 1975. The mines surveyed reported that average total production time per shift had dropped from 332 minutes to 245 minutes due to the CMHSA. The author assesses the impact of declining productivity on future manpower requirements.

-------. "1970-1974—A Period of Adverse Changes in Productivity and Costs in Underground Bituminous Coal Mines." *Mining Congress Journal* 61(10):34-39.

This research is an update of the author's 1972 survey, utilizing 1974 survey results from 124 underground mines. Author finds that the mines suffering the greatest productivity loss are (1) nongassy, (2) independently owned, (3) thin-seam, (4) 100,000 to 500,000 tons per year, and (5) eastern U.S. In addition, the survey indicates that the CMHSA adds from $3.50 to $4 per ton in independent mines and $2 to $2.50 per ton in captive mines.

Suboleski, Stanley. "Boost Your Productivity by Adding Continuous Miners." *Coal Age,* March 1975, 78-80.

Article discusses scheme to use two continuous miners per crew. Brief discussion of productivity decline, which author attributes to "work ethic."

U.S. Department of Labor. *Project Independence Blueprint: Final Labor Report.* Washington, D.C.: Government Printing Office, 1974.

Discussion of coal manpower requirements to meet the Project Independence scenarios. Includes short discussion of productivity decline and its causes.

Walton, Daniel R., and Kauffman, Peter W. *Preliminary Analysis of the Probable Causes of Decreased Coal Mining Productivity.* Reston, Virginia: Management Engineers, Inc., 1977.

This study reviews possible explanations for productivity decline in both surface and deep mining. Includes tables, graphs, and annotated bibliography.

Wearly, W. L. "The Crises of Declining Productivity: Its National Impact, Causes, and Solution." *First Symposium on Coal Management Techniques, Volume I,* 5-17. Washington, D.C.: National Coal Association, 1975.

Article examines different aspects of declining productivity—costs, interfuel competition, and labor requirements. Author attributes productivity decline to the CMHSA and MESA enforcement.

Zimmerman, Martin B. "Modeling Depletion in a Mineral Industry: The Case of Coal." *The Bell Journal of Economics*, 8(1):41-65.

Author estimates the long-term marginal cost of producing coal and the effect that gradual depletion has on production cost. As the resource is depleted, the producing firms are forced to mine less fertile seams, affecting both productivity and production cost. This relationship is estimated in a nonlinear regression of the form "productivity is a function of seam thickness and scale of operations." Increased labor costs are then combined with equipment and operating costs resulting from depletion to estimate total marginal cost.

APPENDIX B - DESCRIPTION OF DATA SETS

STATE-LEVEL DATA SETS

The following are descriptions of the data sets used in the state-level models in Chapters 5 and 7.

U.S. Bureau of Mines, *Minerals Yearbook*

These annual publications contain data concerning production, preparation, shipments, prices and markets, employment, machinery, and other data at county, state, district, and national levels. ORAU has the publications from 1950 through 1975 and magnetic tape of the 1960 to 1975 characteristics.

Mine Enforcement and Safety Administration, CMHSA Inspection Data

These data are from the Mine Enforcement and Safety Administration, *Annual Report* (Washington, D.C.: Government Printing Office, various years). These annual reports contain information concerning CMHSA inspections by type and state, violations, penalties, and withdrawal orders. These data are annual for the 1970-1976 period.

Health and Safety Analysis Center Data

These data are state-level aggregations of injury and fatality incidents by type of injury and mine for the period 1960-1976. These data were obtained from the Department of Labor, Health and Safety Analysis Center.

Social Security Administration Continuous Work History Sample

These data are a 1-percent sample of all workers whose primary source of income was from employment in bituminous coal and lignite mining. These data are compiled by state for the 1963-1974 period and contain age distribution, turnover characteristics, and experience levels of the state work force.

Work Stoppage File, Bureau of Labor Statistics

These data contain information concerning type of work stoppage, workers involved, and days lost by industry by state for the 1953-1977 period.

MINE-LEVEL DATA SETS

The following are descriptions of the data sets used in the mine-level models in Chapters 6 and 7.

State Government Sources

These data contain mine-level characteristics such as employment, days active, mine type, injury experience, seam characteristics, and production technique. These data are from the following sources:

1. Illinois State Department of Mines and Minerals, *Annual Coal, Oil and Gas Report* (Springfield: State of Illinois, 1965-1976).
2. State of Ohio Department of Industrial Relations, *Division of Mines Report* (Columbus: State of Ohio, 1965-1976).

Energy Information Administration Coal System Data

These data (on tape) are based upon the annual survey *Bituminous Coal and Lignite Production and Mine Operation* and are available for the period 1974-1977. The data are compiled from mandatory responses of all mines of 1000 or more annual tonnage and contain detailed characteristics of miner-hours, production, location, seam characteristics, coal preparation, coal characteristics, mine equipment, and market information. In addition, there is partial coverage of mines from 1972 through 1974, and aggregated characteristics at the county level are available from 1960 to 1977.

Cost Function Data (Chapter 8)

U.S. Bureau of the Census, *Census of Mineral Industries,* Industry Series: Bituminous Coal and Lignite Mining (Washington, D.C.: Government Printing Office, 1962, 1967, and 1972).

These publications contain regional data on production and nonproduction workers and payroll costs, miner-hours, value added, cost of energy and supplies, capital expenditures, and related data for bituminous coal and lignite mining.

APPENDIX C - STATISTICAL APPENDIX TO STATE-LEVEL MODELS

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Table C-1. Correlation Coefficients, State-Level Deep Mine Data, 1961-1975

	CAP	DAY	CAP^2	SEAM	CLEAN	INJRATE	DUMS1	DUMS2	INSM	STOPS	D1975	DPLAG
DAY	0.500											
CAP^2	0.938	0.375										
SEAM	0.336	0.203	0.258									
CLEAN	0.269	0.465	0.133	0.131								
INJRATE	0.053	0.092	0.020	0.248	-0.084							
DUMS1	0.059	0.004	0.026	-0.003	0.057	0.183						
DUMS2	0.143	-0.026	0.129	-0.003	-0.109	-0.158	-0.071					
INSM	0.646	0.335	0.650	0.119	0.071	-0.031	0.006	0.349				
STOPS	0.335	0.140	0.295	-0.148	0.059	0.005	0.007	0.090	0.366			
D1975	0.132	0.118	0.124	-0.003	-0.129	-0.177	-0.071	-0.071	0.296	0.407		
DPLAG	-0.023	0.153	-0.083	-0.072	0.202	-0.279	-0.018	0.103	0.288	0.297	0.626	
CONWORK	0.262	0.331	0.190	-0.008	0.219	0.068	0.076	0.155	0.239	0.229	0.121	0.135
EXPWORK	0.140	-0.003	0.113	0.047	-0.210	-0.076	-0.068	0.170	0.220	0.209	0.477	0.174
CONT	0.358	0.504	0.262	0.544	0.154	0.208	0.066	0.158	0.373	0.159	0.182	0.095
PRDU	0.488	0.350	0.424	0.355	0.143	0.334	-0.031	-0.108	-0.093	-0.133	-0.240	-0.548
INTU	0.109	0.267	0.060	-0.055	-0.177	0.020	0.065	0.396	0.594	0.230	0.366	0.470

	CONWORK	EXPWORK	CONT	PRDU
EXPWORK	0.330			
CONT	0.251	0.150		
PRDU	0.066	-0.057	0.156	
INTU	0.205	0.302	0.306	-0.281

Table C-2. Correlation Coefficients, State-Level Deep Mine Data, 1961-1969

	PRD	CAP	CAP^2	DAY	SEAM	CLEAN	INJRATE	CONWORK	EXPWORK	STOPS	CONT
CAP	0.810										
CAP^2	0.732	0.958									
DAY	0.604	0.546	0.458								
SEAM	0.352	0.384	0.292	0.165							
CLEAN	0.313	0.350	0.222	0.597	0.129						
INJRATE	0.466	0.196	0.230	0.094	0.119	-0.163					
CONWORK	0.235	0.218	0.175	0.318	-0.053	0.305	0.006				
EXPWORK	-0.004	-0.066	-0.050	-0.112	-0.026	-0.170	0.130	0.365			
STOPS	0.139	0.275	0.277	0.164	-0.180	0.261	-0.044	0.118	-0.081		
CONT	0.372	0.294	0.177	0.456	0.557	0.281	0.092	0.164	0.008	-0.162	
DPLAG	-0.475	-0.270	-0.317	-0.008	0.142	0.465	-0.557	-0.101	-0.151	0.102	-0.003

Table C-3. Correlation Coefficients, State-Level Deep Mine Data, 1970-1975

	PRDU	CAP	CAP²	DAY	SEAM	CLEAN	INJRATE	CONWORK	EXPWORK	DUMS1	DUMS2	INSM
CAP	0.428											
CAP²	0.494	0.958										
DAY	0.116	0.407	0.351									
SEAM	0.376	0.357	0.310	0.341								
CLEAN	-0.178	0.275	0.142	0.379	0.133							
INJRATE	0.245	-0.098	-0.104	-0.004	0.413	0.017						
CONWORK	-0.107	0.193	0.147	0.063	0.093	0.139	0.081					
EXPWORK	0.031	0.067	0.045	-0.240	0.108	-0.266	-0.247	0.262				
DUMS1	0.060	-0.050	-0.058	-0.241	0.000	0.124	0.213	-0.051	-0.231			
DUMS2	-0.086	0.063	0.063	-0.308	0.000	-0.155	-0.291	0.119	0.062	-0.200		
INSM	0.045	0.746	0.708	0.314	0.247	0.198	-0.173	0.149	0.008	-0.243	0.206	
STOPS	-0.239	0.269	0.232	-0.060	-0.164	-0.004	-0.033	0.220	0.139	-0.119	-0.018	0.253
CONT	0.011	0.298	0.250	0.408	0.621	0.039	0.282	0.168	0.045	-0.078	0.082	0.355
DPLAG	-0.687	-0.137	-0.182	0.014	-0.222	0.149	-0.296	0.101	0.062	-0.205	-0.046	0.062
D1975	-0.337	0.048	0.056	0.003	0.000	-0.187	-0.319	0.045	0.441	-0.200	-0.200	0.136
INTU	-0.375	-0.240	-0.209	-0.029	-0.115	-0.342	-0.157	-0.101	0.038	-0.313	0.239	0.274

	STOPS	CONT	DPLAG
CONT	0.184		
DPLAG	0.208	-0.098	
D1975	0.370	0.125	0.640
INTU	-0.034	0.113	0.281

Table C-4. Descriptive Statistics, State-Level Deep Mines, 1961-1975 (N = 150)

Variable	Mean	Standard Deviation
CAP	9.48	11.80
DAY	215.72	21.46
CAP^2	228.42	608.31
SEAM	5.87	1.98
CLEAN	62.70	24.36
INJRATE	0.30	0.11
DUMS1	0.06	0.25
DUMS2	0.06	0.25
INSM	15.90	33.31
STOPS	8.80	11.85
D1975	0.06	0.25
DPLAG	63.82	26.10
CONWORK	-4.30	6.45
EXPWORK	4.67	9.50
CONT	456.74	270.42
PRDU	13.13	3.35

Table C-5. Descriptive Statistics, State-Level Deep Mines, 1961-1969 (N = 90)

Variable	Mean	Standard Deviation
PRD	13.66	3.51
CAP	6.63	8.37
CAP^2	113.45	297.27
DAY	209.47	22.04
SEAM	5.89	1.99
CLEAN	63.71	24.32
INJRATE	0.29	0.10
CONWORK	-5.91	6.80
EXPWORK	1.84	4.44
STOPS	5.70	5.98
CONT	381.80	252.82
DPLAG	54.86	13.92

Table C-6. Descriptive Statistics, State-Level Deep Mines, 1970-1975 (N = 60)

Variable	Mean	Standard Deviation
PRD	12.34	2.95
CAP	13.74	14.67
CAP^2	400.87	866.48
DAY	225.08	16.78
SEAM	5.85	1.99
CLEAN	61.17	24.54
INJRATE	0.31	0.12
CONWORK	-1.89	5.04
EXPWORK	8.90	12.96
DUMS1	0.16	0.37
DUMS2	0.16	0.37
INSM	39.76	42.87
STOPS	13.46	16.25
CONT	569.16	258.54
DPLAG	77.27	33.49
D1975	0.16	0.37

Table C-7. Generalized Least Squares Regression Results, State-Level Deep Mining Models of Table 5-1 with Inspections per 100,000 Tons (INTU) Replacing INSM

Variable	1961-1975	1970-1975
CONSTANT	4.270	17.468
CAP	0.220(3.90)	-0.011(0.18)
CAP^2	-.001(1.59)	0.002(1.87)
DAYS	0.035(2.80)	-0.006(0.28)
SEAM	0.145(1.25)	0.430(2.61)
CLEAN	-.031(3.33)	-0.067(6.27)
INJRATE	7.963(5.29)	2.090(0.93)
CONWORK	0.016(0.46)	-0.046(1.05)
EXPWORK	0.002(0.08)	0.005(0.24)
DUMS1	-1.442(2.17)	-1.116(1.73)
DUMS2	-0.319(0.39)	-1.152(1.53)
INTU	-0.158(6.57)	-0.095(3.93)
STOP	-0.050(3.07)	-0.024(1.55)
CONT	-0.001(0.73)	-0.002(1.57)
D1975	-1.666(1.84)	-2.377(3.64)
R^2	0.645	0.791
SEE	1.179	1.281
N	159	60

Table C-8. Sources of Productivity Variation, Deep Mines Using INTU

	1965	1969	1970	1971	1972	1973	1974	1975
CAP	0.96	1.66	1.81	1.93	2.11	2.28	2.26	2.07
DAYS	7.75	7.97	8.12	7.45	8.08	8.20	7.29	8.10
SEAM	0.75	0.75	0.75	0.76	0.76	0.76	0.76	0.76
CLEAN	-2.28	-2.23	-2.17	-2.20	-2.12	-2.16	-1.89	-1.87
INJRATE	2.74	2.77	2.86	3.07	3.06	2.73	2.07	2.14
CONWORK	-0.01	-0.06	-0.01	-0.01	-0.01	-0.02	0	-0.01
EXPWORK	0.01	0	0.02	0	0.01	0	0.02	0.03
DUMS1	0	0	0	-1.44	0	0	0	0
DUMS2	0	0	0	0	0	0	-0.32	0
STOP	-0.26	-0.66	-0.59	-0.71	-0.79	-0.87	-0.94	-1.77
D1975	0	0	0	0	0	0	0	-1.66
INTU	0	0	-0.38	-1.19	-2.19	-3.76	-3.11	-2.77
Constant	4.27	4.27	4.27	4.27	4.27	4.27	4.27	4.27
Estimated ALP	13.93	14.47	14.68	11.93	13.17	11.43	10.41	9.29
Actual ALP	14.00	15.60	13.73	12.04	11.87	11.63	10.90	9.52

Table C-9. Correlation Coefficients, State-Level Appalachian Surface Mine Data, 1961-1975

	PRD	CAP	RATIO	CLEAN	LT6	DUMS2	RECLAIM	SPLAG	DUMS1	INJRATE	DAY	EXPWORK
CAP	0.620											
RATIO	-0.193	0.235										
CLEAN	0.217	0.595	0.098									
LT6	-0.114	-0.451	-0.593	-0.278								
DUMS2	-0.220	-0.022	0.120	-0.081	-0.172							
RECLAIM	-0.271	-0.131	0.026	-0.254	-0.075	0.404						
SPLAG	-0.435	-0.113	0.174	-0.127	-0.125	0.099	0.583					
DUMS1	0.077	0.030	0.120	-0.119	-0.221	-0.071	-0.035	-0.037				
INJRATE	0.328	0.356	-0.182	0.405	-0.152	-0.200	-0.254	-0.064	0.150			
DAY	-0.185	0.099	0.533	0.114	-0.289	0.255	0.085	0.057	-0.012	-0.279		
EXPWORK	-0.121	-0.079	0.060	-0.118	-0.205	0.292	0.193	0.315	0.103	0.037	-0.009	
CONWORK	0.059	0.120	0.102	-0.046	-0.214	0.137	0.091	0.087	0.119	0.053	0.116	0.395

Table C-10. Correlation Coefficients, State-Level Non-Appalachian Surface Mine Data, 1961-1975

	PRD	CAP	CAP^2	CLEAN	RATIO	RECLAIM	DAY	DUMS2	SPLAG	DUMS1	CONWORK	EXPWORK
CAP	0.591											
CAP^2	0.425	0.909										
CLEAN	-0.096	-0.047	-0.026									
RATIO	-0.534	-0.321	-0.232	0.070								
RECLAIM	-0.158	0.084	0.021	0.135	0.228							
DAY	0.253	0.258	0.108	0.051	0.150	0.232						
DUMS2	0.056	0.141	0.069	-0.022	-0.002	0.323	0.091					
SPLAG	0.127	0.474	0.459	-0.025	-0.184	-0.025	0.090	0.148				
DUMS1	0.057	0.093	0.084	-0.016	-0.002	-0.045	0.137	-0.075	0.014			
CONWORK	0.216	0.214	0.124	0.031	-0.026	0.036	0.038	0.005	0.048	0.093		
EXPWORK	-0.001	0.045	0.010	0.002	-0.086	-0.034	-0.084	-0.019	-0.001	0.236	0.042	
INJRATE	-0.015	0.005	0.020	-0.006	-0.192	-0.074	-0.011	-0.046	0.091	-0.016	-0.083	-0.015
LT6	-0.269	-0.486	-0.361	0.007	0.052	-0.162	-0.088	-0.203	-0.374	-0.145	-0.323	-0.063

	INJRATE
LT6	0.038

Table C-11. Correlation Coefficients, State-Level Appalachian Surface Mine Data, 1961-1969

	PRD	CAP	RATIO	CLEAN	LT6	SPLAG	INJRATE	DAY	EXPWORK
CAP	0.712								
RATIO	-0.275	0.116							
CLEAN	0.278	0.719	0.166						
LT6	-0.289	-0.765	-0.593	-0.654					
SPLAG	-0.452	-0.008	0.366	0.385	-0.212				
INJRATE	0.380	0.385	-0.312	0.377	-0.119	-0.142			
DAY	-0.081	0.091	0.443	0.137	-0.390	-0.091	-0.332		
EXPWORK	0.017	-0.025	-0.164	-0.084	0.119	0.030	0.154	-0.176	
CONWORK	0.169	0.190	-0.017	0.013	-0.150	-0.200	0.100	0.015	0.400

Table C-12. Correlation Coefficients, State-Level Non-Appalachian Surface Mine Data, 1961-1969

	PRD	CAP	CAP^2	CLEAN	RATIO	RECLAIM	DAY	SPLAG	CONWORK	EXPWORK	INJRATE
CAP	0.537										
CAP^2	0.412	0.933									
CLEAN	0.001	0.106	0.036								
RATIO	-0.489	-0.153	-0.146	0.158							
RECLAIM	-0.047	-0.017	-0.013	-0.010	0.059						
DAY	0.314	0.475	0.308	0.198	0.105	0.112					
SPLAG	-0.691	-0.384	-0.302	0.045	0.240	-0.084	-0.163				
CONWORK	0.211	0.233	0.181	0.038	0.025	-0.034	0.014	-0.266			
EXPWORK	0.088	-0.027	-0.022	-0.054	-0.128	-0.023	-0.098	0.129	0.079		
INJRATE	0.136	0.053	-0.021	0.111	-0.229	-0.038	0.244	0.072	0.059	-0.049	
LT6	-0.226	-0.461	-0.466	-0.066	-0.139	0.072	0.103	0.294	-0.265	-0.114	0.077

Table C-13. Correlation Coefficients, State-Level Appalachian Surface Mine Data, 1970-1975

	PRD	CAP	RATIO	CLEAN	LT6	DUMS2	RECLAIM	SPLAG	DUMS1	INJRATE	DAY	EXPWORK
CAP	0.457											
RATIO	0.017	0.467										
CLEAN	-0.020	0.401	0.388									
LT6	-0.096	-0.283	-0.497	-0.336								
DUMS2	-0.333	-0.051	0.000	0.031	-0.053							
RECLAIM	-0.431	-0.299	-0.365	-0.240	0.250	0.281						
SPLAG	-0.609	-0.244	-0.100	-0.157	0.135	-0.064	0.452					
DUMS1	0.210	0.046	0.000	-0.055	-0.122	-0.200	-0.281	-0.233				
INJRATE	0.203	0.313	0.101	0.442	-0.337	-0.294	-0.395	0.022	0.335			
DAY	-0.305	0.111	0.622	0.230	-0.174	0.323	0.012	0.012	-0.088	-0.184		
EXPWORK	-0.187	-0.172	-0.052	0.090	-0.134	0.228	-0.041	0.200	-0.033	0.038	0.002	
CONWORK	-0.180	-0.106	0.154	0.023	-0.203	0.190	-0.086	0.085	0.141	0.018	0.299	0.440

Table C-14. Correlation Coefficients, State-Level Non-Appalachian Surface Mine Data, 1970-1975

	PRD	CAP	CAP^2	CLEAN	RATIO	RECLAIM	DUMS2	DAY	SPLAG	DUMS1	CONWORK	EXPWORK
CAP	0.612											
CAP^2	0.458	0.926										
CLEAN	-0.146	-0.093	-0.051									
RATIO	-0.616	-0.509	-0.358	0.094								
RECLAIM	-0.425	-0.197	-0.183	0.126	0.427							
DUMS2	-0.024	-0.003	-0.040	-0.047	0.000	0.202						
DAY	0.074	0.019	-0.036	0.033	0.253	0.093	-0.037					
SPLAG	0.136	0.439	0.410	-0.048	-0.323	-0.227	0.060	-0.006				
DUMS1	-0.020	-0.057	-0.018	-0.040	0.000	-0.270	-0.202	0.066	-0.084			
CONWORK	0.203	0.228	0.141	0.042	-0.157	-0.135	-0.138	-0.149	0.046	0.098		
EXPWORK	-0.036	0.014	-0.015	-0.002	-0.111	-0.092	-0.048	-0.199	-0.028	0.226	0.046	
INJRATE	-0.098	-0.045	-0.003	-0.017	-0.200	-0.149	-0.084	-0.218	0.089	-0.048	-0.332	-0.020
LT6	-0.161	-0.401	-0.347	0.081	0.310	0.159	-0.084	0.056	-0.447	0.017	-0.339	-0.026

	INJRATE
LT6	0.107

Table C-15. Descriptive Statistics, State-Level Appalachian Surface Mines, 1961-1975 (N = 120)

Variable	Mean	Standard Deviation
PRD	29.35	7.86
CAP	30.89	16.58
RATIO	13.05	2.84
CLEAN	0.19	0.17
LT6	81.58	15.38
DUMS2	0.06	0.25
RECLAIM	0.17	0.38
SPLAG	47.71	24.34
DUMS1	0.06	0.25
INJRATE	0.13	0.05
DAY	209.32	32.11
EXPWORK	11.96	15.58
CONWORK	-3.60	7.05

Table C-16. Descriptive Statistics, State-Level Non-Appalachian Surface Mines, 1961-1971

Variable	N	Mean	Standard Deviation
PRD	236	39.54	29.07
CAP	236	175.79	243.36
CAP^2	236	89,881.01	278,661.95
CLEAN	236	0.67	6.29
RATIO	215	9.74	7.50
RECLAIM	236	0.19	0.39
DAY	236	236.11	67.28
DUMS2	236	0.07	0.25
SPLAG	224	86.08	167.69
DUMS1	236	0.06	0.25
CONWORK	236	-5.18	11.80
EXPWORK	236	65.44	673.87
INJRATE	236	0.23	0.49
LT6	236	50.77	30.49

Table C-17. Descriptive Statistics, State-Level Appalachian Surface Mines, 1961-1969 (N = 72)

Variable	Mean	Standard Deviation
PRD	30.09	8.20
CAP	30.65	17.58
RATIO	12.20	2.60
CLEAN	0.24	0.19
LT6	86.71	10.21
RECLAIM	0	0
SPLAG	38.53	6.69
INJRATE	0.13	0.05
DAY	205.71	29.62
EXPWORK	7.02	10.38
CONWORK	-4.81	8.23

Table C-18. Descriptive Statistics, State-Level Non-Appalachian Surface Mines, 1961-1969

Variable	N	Mean	Standard Deviation
PROD	138	34.04	22.80
CAP	138	86.67	89.19
CAP^2	138	15,410.54	31,507.35
CLEAN	138	0.31	0.66
RATIO	125	9.79	7.52
RECLAIM	138	0.02	0.14
DAY	138	217.43	70.31
SPLAG	131	45.89	19.91
CONWORK	138	-6.93	13.89
EXPWORK	138	20.66	131.09
INJRATE	138	0.20	0.28
LT6	138	63.20	27.27

Table C-19. Descriptive Statistics, State-Level Appalachian Surface Mines, 1970-1975 (N = 48)

Variable	Mean	Standard Deviation
PRD	28.24	7.25
CAP	31.24	15.13
RATIO	14.33	2.72
CLEAN	0.13	0.12
LT6	73.88	18.44
DUMS2	0.16	0.37
RECLAIM	0.43	0.50
SPLAG	61.47	33.32
DUMS1	0.16	0.37
INJRATE	0.12	0.05
DAY	214.73	35.15
EXPWORK	19.36	18.94
CONWORK	-1.79	4.25

Table C-20. Descriptive Statistics, State-Level Non-Appalachian Surface Mines, 1970-1975

Variable	N	Mean	Standard Deviation
PRD	98	47.29	34.77
CAP	98	301.30	324.08
CAP^2	98	194,747.60	409,542.10
CLEAN	98	1.17	9.74
RATIO	90	9.67	7.53
RECLAIM	98	0.42	0.49
DUMS2	98	0.17	0.38
DAY	98	262.42	52.82
SPLAG	93	142.69	249.12
DUMS1	98	0.16	0.37
CONWORK	98	-2.71	7.38
EXPWORK	98	128.50	1,033.93
INJRATE	98	0.28	0.68
LT6	98	33.27	25.93

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APPENDIX D - STATISTICAL APPENDIX TO MINE-LEVEL DATA

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Table D-1. Descriptive Statistics, Illinois Deep Mines, 1965-1976 (N = 299)

Variable	Mean	Standard Deviation
AVG	16.57	6.76
CAP	49.50	45.10
CAP^2	4478.87	8464.00
INJRATE	0.27	0.27
CMHSA	47.03	59.08
IDLE	0.12	0.33
EXPWORK	14.68	46.83
CONWORK	-2.01	6.75
SEAM	80.97	17.83
STRIKE1	0.07	0.26
STRIKE2	0.07	0.26
NEW	0.11	0.31
OLD	0.64	0.47
DPR	83.80	40.63
D1975	0.14	0.34

Table D-2. Correlation Coefficients, Illinois Deep Mine Data, 1965-1976

	AVG	CAP	CAP^2	INJRATE	CMHSA	IDLE	EXPWORK	CONWORK	SEAM	STRIKE1	STRIKE2	NEW
CAP	0.468											
CAP^2	0.344	0.913										
INJRATE	-0.010	-0.049	-0.012									
CMHSA	-0.228	0.182	0.068	-0.026								
IDLE	-0.333	-0.358	-0.194	0.070	-0.101							
EXPWORK	-0.053	-0.047	-0.072	-0.099	0.019	-0.114						
CONWORK	0.104	0.115	0.071	-0.229	-0.037	-0.135	0.093					
SEAM	0.330	0.456	0.284	-0.191	-0.007	-0.163	0.062	0.110				
STRIKE1	0.003	0.017	0.003	0.041	-0.019	-0.110	0.011	-0.103	-0.036			
STRIKE2	-0.086	0.080	0.034	-0.073	0.515	-0.030	0.075	0.071	0.001	-0.081		
NEW	-0.145	-0.218	-0.152	-0.109	-0.059	0.250	0.211	0.033	-0.084	0.018	-0.017	
OLD	-0.060	0.050	0.110	0.107	-0.093	-0.032	-0.301	-0.077	0.054	-0.074	-0.032	-0.475
DPR	-0.289	0.147	0.040	-0.046	0.540	-0.103	0.020	0.000	0.022	-0.012	0.115	-0.058
D1975	-0.232	0.115	0.025	-0.055	0.320	-0.125	-0.039	0.078	0.042	-0.116	-0.113	-0.050

	OLD	DPR
DPR	-0.073	
D1975	-0.022	0.755

Table D-3. Descriptive Statistics, Illinois Deep Mines, 1965-1969
(N = 112)

Variable	Mean	Standard Deviation
AVG	18.37	7.82
CAP	39.90	48.30
CAP^2	3905.38	9751.32
INJRATE	0.28	0.31
IDLE	0.19	0.39
EXPWORK	11.76	54.65
CONWORK	-1.31	4.22
SEAM	81.03	17.59
NEW	0.13	0.34
OLD	0.72	0.44
DPR	53.99	31.31

Table D-4. Correlation Coefficients, Illinois Deep Mine Data, 1965-1969

	AVG	CAP	CAP^2	INJRATE	IDLE	EXPWORK	CONWORK	SEAM	NEW	OLD
CAP	0.473									
CAP^2	0.302	0.919								
INJRATE	0.106	0.058	0.044							
IDLE	-0.348	-0.322	-0.185	-0.042						
EXPWORK	-0.068	-0.042	-0.050	-0.075	-0.100					
CONWORK	0.145	0.154	0.099	0.079	-0.284	0.067				
SEAM	0.251	0.418	0.236	-0.124	-0.175	0.108	0.135			
NEW	-0.041	-0.209	-0.140	-0.058	0.333	0.102	0.053	-0.068		
OLD	-0.206	0.119	0.124	0.081	-0.246	-0.298	-0.061	-0.158	-0.635	
DPR	-0.096	0.000	0.000	-0.032	0.077	0.124	-0.181	0.008	-0.015	-0.034

Table D-5. Descriptive Statistics, Illinois Deep Mines, 1970-1976 (N = 161)

Variable	Mean	Standard Deviation
AVG	15.05	5.38
CAP	56.61	41.12
CAP^2	4886.54	7316.59
INJRATE	0.27	0.26
CMHSA	87.35	54.39
IDLE	0.08	0.27
EXPWORK	14.69	33.00
CONWORK	-2.31	7.66
SEAM	80.80	18.08
STRIKE1	0.14	0.35
STRIKE2	0.13	0.34
NEW	0.09	0.30
OLD	0.58	0.49
DPR	106.72	34.85
D1975	0.26	0.44

Table D-6. Correlation Coefficients, Illinois Deep Mine Data, 1970-1976

	AVG	CAP	CAP^2	INJRATE	CMHSA	IDLE	EXPWORK	CONWORK	SEAM	STRIKE1	STRIKE2	NEW
CAP	0.603											
CAP^2	0.465	0.924										
INJRATE	-0.222	-0.216	-0.116									
CMHSA	-0.123	0.125	0.070	-0.071								
IDLE	-0.421	-0.364	-0.195	0.269	0.022							
EXPWORK	-0.084	-0.082	-0.111	-0.143	0.055	-0.125						
CONWORK	0.112	0.144	0.073	-0.426	-0.002	-0.075	0.135					
SEAM	0.417	0.515	0.342	-0.285	0.000	-0.191	0.002	0.177				
STRIKE1	0.122	-0.044	-0.017	0.058	-0.333	-0.120	0.022	-0.112	-0.046			
STRIKE2	-0.040	0.056	0.034	-0.112	0.496	0.014	0.151	0.104	0.006	-0.162		
NEW	-0.302	-0.246	-0.178	-0.167	-0.065	0.206	0.447	0.007	-0.094	0.042	-0.011	
OLD	0.010	0.063	0.126	0.146	0.017	0.065	-0.301	-0.072	0.208	-0.051	0.005	-0.393
DPR	-0.296	0.092	0.016	-0.078	0.212	-0.084	-0.093	0.135	0.053	-0.289	-0.072	-0.057
D1975	-0.261	0.082	0.009	-0.090	0.071	-0.124	-0.082	0.125	0.067	-0.242	-0.236	-0.055

	OLD	DPR
DPR	0.046	
D1975	0.042	0.903

Table D-7. Descriptive Statistics, Illinois Surface Mines, 1965-1977
(N = 408)

Variable	Mean	Standard Deviation
AVG	36.24	19.24
CAP	39.04	40.05
INJRATE	0.13	0.40
RATIO	12.87	5.91
IDLE	0.21	0.41
NEW	0.20	0.40
OLD	0.59	0.49
STRIKE1	0.08	0.27
STRIKE2	0.07	0.26
EXPWORK	8.06	28.56
CONWORK	-3.46	9.49
SPR	72.92	33.07
LCRA	0.38	0.48

Table D-8. Correlation Coefficients, Illinois Surface Mine Data, 1965-1977

	AVG	CAP	INJRATE	RATIO	IDLE	NEW	OLD	STRIKE1	STRIKE2	EXPWORK	CONWORK	SPR
CAP	0.435											
INJRATE	0.013	-0.038										
RATIO	-0.148	0.137	-0.002									
IDLE	0.023	-0.365	0.033	-0.238								
NEW	0.116	-0.297	-0.073	-0.337	0.435							
OLD	-0.131	0.287	0.066	0.325	-0.335	-0.614						
STRIKE1	0.011	0.016	0.053	-0.026	0.055	0.021	-0.021					
STRIKE2	-0.081	0.016	-0.021	0.074	-0.012	-0.050	-0.015	-0.084				
EXPWORK	-0.101	-0.022	0.014	-0.036	-0.047	-0.036	-0.107	-0.011	0.013			
CONWORK	0.004	0.170	-0.045	-0.015	-0.147	0.022	0.007	0.036	-0.013	0.103		
SPR	-0.222	0.010	-0.009	-0.015	0.043	0.015	-0.081	-0.029	0.039	0.073	-0.128	
LCRA	-0.229	-0.012	-0.058	0.048	-0.005	-0.031	-0.109	-0.239	0.354	0.080	-0.082	0.607

Table D-9. Descriptive Statistics, Illinois Surface Mines, 1965-1969 (N = 183)

Variable	Mean	Standard Deviation
AVG	40.60	21.73
CAP	38.78	39.82
OLD	0.66	0.47
SPR	52.52	29.71
IDLE	0.20	0.40
CONWORK	-2.37	6.78
RATIO	12.63	6.33
EXPWORK	5.82	16.75
NEW	0.20	0.40
INJRATE	0.13	0.49

Table D-10. Correlation Coefficients, Illinois Surface Mine Data, 1965-1969

	AVG	CAP	OLD	SPR	IDLE	CONWORK	RATIO	EXPWORK	NEW
CAP	0.449								
OLD	-0.301	0.193							
SPR	-0.029	0.112	0.054						
IDLE	0.087	-0.360	-0.373	0.042					
CONWORK	0.132	0.176	0.010	-0.195	-0.198				
RATIO	-0.182	0.063	0.243	-0.023	-0.139	-0.041			
EXPWORK	-0.094	0.073	-0.110	0.185	-0.018	0.122	0.009		
NEW	0.207	-0.286	-0.715	-0.054	0.435	-0.007	-0.317	0.019	
INJRATE	-0.098	-0.029	0.115	0.053	0.045	0.054	0.033	-0.020	-0.105

Table D-11. Descriptive Statistics, Illinois Surface Mines, 1970-1976 (N = 225)

Variable	Mean	Standard Deviation
AVG	32.69	16.14
CAP	39.25	40.33
OLD	0.53	0.49
LCRA	0.70	0.45
SPR	89.51	25.56
IDLE	0.22	0.41
CONWORK	-4.34	11.15
RATIO	13.06	5.56
EXPWORK	9.88	35.31
NEW	0.20	0.40
INJRATE	0.13	0.32
STRIKE1	0.15	0.35
STRIKE2	0.13	0.34

Table D-12. Correlation Coefficients, Illinois Surface Mine Data, 1970-1976

	AVG	CAP	OLD	LCRA	SPR	IDLE	CONWORK	RATIO	EXPWORK	NEW	INJRATE	STRIKE1
CAP	0.452											
OLD	-0.021	0.364										
LCRA	-0.191	-0.032	-0.038									
SPR	-0.267	-0.088	-0.075	0.519								
IDLE	-0.031	-0.369	-0.307	-0.042	0.031							
CONWORK	-0.118	0.176	-0.013	-0.014	-0.028	-0.126						
RATIO	-0.096	0.204	0.414	0.046	-0.064	-0.330	0.005					
EXPWORK	-0.103	-0.061	-0.101	0.046	-0.017	-0.063	0.109	-0.064				
NEW	0.023	-0.305	-0.546	-0.055	0.094	0.436	0.038	-0.357	-0.060			
INJRATE	0.200	-0.048	0.011	-0.136	-0.100	0.021	-0.131	-0.053	0.040	-0.037		
STRIKE1	0.112	0.021	0.017	-0.647	-0.327	0.067	0.077	-0.054	-0.035	0.032	0.096	
STRIKE2	-0.049	0.020	0.022	0.255	-0.183	-0.024	0.015	0.096	-0.004	-0.069	-0.036	-0.165

Table D-13. Descriptive Statistics, Large Ohio Deep Mines, 1965-1977

Variable	N	Mean	Standard Deviation
PROD	226	18.35	10.03
SEAM	227	57.41	8.29
CONT	227	0.80	0.39
IDLE	227	0.05	0.23
DRIFT	227	0.25	0.43
CAP	227	3809.29	2358.36
CAP^2	227	20048091.29	23175248.60
CMHSA	227	0.69	0.46
DUMS2	227	0.08	0.28
CONWORK	227	-0.05	0.13
PLAG	214	663.67	250.50

Table D-14. Correlation Coefficients, Large Ohio Deep Mine Data, 1965-1977

	PROD	SEAM	CONT	IDLE	DRIFT	CAP	CAP^2	CMHSA	DUMS2	CONWORK
SEAM	-0.143									
CONT	-0.256	0.319								
IDLE	0.115	-0.092	-0.070							
DRIFT	0.317	-0.453	-0.332	0.119						
CAP	0.125	0.231	-0.057	-0.205	-0.279					
CAP^2	0.172	0.132	-0.147	-0.099	-0.157	0.951				
CMHSA	-0.506	0.035	0.324	0.041	-0.053	-0.148	-0.179			
DUMS2	-0.174	0.037	0.113	-0.009	-0.036	-0.050	-0.066	0.207		
CONWORK	0.030	-0.010	-0.011	-0.574	-0.051	0.056	0.012	-0.075	-0.023	
PLAG	-0.506	-0.024	0.232	-0.019	0.005	-0.125	-0.139	0.509	-0.030	-0.074

Table D-15. Descriptive Statistics, Large Ohio Deep Mines, 1965-1970

Variable	N	Mean	Standard Deviation
PROD	69	26.01	9.11
SEAM	70	56.97	8.32
CONT	70	0.61	0.49
IDLE	70	0.04	0.20
DRIFT	70	0.28	0.45
CAP	70	4333.17	2755.51
CAP^2	70	26260831.14	30209202.86
EXPWORK	70	0.56	3.37
CONWORK	70	-0.03	0.12
PLAG	57	443.87	9.30

Table D-16. Correlation Coefficients, Large Ohio Deep Mine Data, 1965-1970

	PROD	SEAM	CONT	IDLE	DRIFT	CAP	CAP^2	EXPWORK	CONWORK
SEAM	-0.253								
CONT	0.055	0.434							
IDLE	0.039	-0.152	0.022						
DRIFT	0.437	-0.418	-0.343	0.178					
CAP	0.002	0.396	0.130	-0.254	-0.421				
CAP^2	0.017	0.273	0.027	-0.175	-0.299	0.954			
EXPWORK	-0.170	0.074	0.077	0.006	-0.054	-0.171	-0.117		
CONWORK	0.060	0.061	-0.131	-0.486	-0.173	0.181	0.129	0.055	
PLAG	0.060	-0.077	-0.013	0.124	0.188	-0.089	-0.033	-0.185	-0.114

Table D-17. Descriptive Statistics, Large Ohio Deep Mines, 1970-1977 (N = 157)

Variable	Mean	Standard Deviation
PROD	14.99	8.47
SEAM	57.61	8.29
CONT	0.89	0.31
IDLE	0.06	0.24
DRIFT	0.23	0.42
CAP	3575.71	2126.30
CAP^2	17278079.90	18694174.39
CMHSA	1.0	0
DUMS1	0.12	0.33
DUMS2	0.12	0.33
EXPWORK	0.85	4.56
CONWORK	-0.06	0.13
PLAG	743.47	261.97

Table D-18. Correlation Coefficients, Large Ohio Deep Mine Data, 1970-1977

	PROD	SEAM	CONT	IDLE	DRIFT	CAP	CAP^2	DUMS1	DUMS2	EXPWORK	CONWORK
SEAM	-0.094										
CONT	-0.250	0.263									
IDLE	0.205	-0.072	-0.160								
DRIFT	0.283	-0.469	-0.337	0.100							
CAP	0.094	0.152	-0.137	-0.183	-0.212						
CAP^2	0.157	0.053	-0.234	-0.053	-0.078	0.959					
DUMS1	0.206	-0.009	-0.112	0.135	0.012	-0.078	-0.043				
DUMS2	-0.101	0.036	0.071	-0.021	-0.032	-0.026	-0.045	-0.145			
EXPWORK	0.160	-0.020	-0.278	-0.049	0.081	-0.144	-0.116	0.118	-0.040		
CONWORK	-0.035	-0.035	0.103	-0.601	-0.007	-0.021	-0.084	-0.038	-0.009	0.083	
PLAG	-0.395	-0.071	0.146	-0.041	0.037	-0.054	-0.063	-0.408	-0.152	-0.118	-0.069

Table D-19. Descriptive Statistics, Small Ohio Deep Mines, 1965-1977

Variable	N	Mean	Standard Deviation
PROD	352	9.94	8.38
SEAM	523	48.28	11.09
CONT	524	0.12	0.33
IDLE	524	0.62	0.48
DRIFT	524	0.84	0.36
CAP	473	60.53	89.87
CAP^2	473	11724.61	31067.26
CMHSA	524	0.22	0.41
DUMS2	524	0.01	0.12
CONWORK	524	-0.11	0.24
PLAG	405	503.12	163.16

Table D-20. Correlation Coefficients, Small Ohio Deep Mine Data, 1965-1977

	PROD	SEAM	CONT	IDLE	DRIFT	CAP	CAP^2	CMHSA	DUMS2	CONWORK
SEAM	-0.015									
CONT	0.389	-0.147								
IDLE	-0.034	0.027	-0.108							
DRIFT	0.159	-0.087	0.043	0.060						
CAP	0.597	0.007	0.400	-0.199	-0.025					
CAP^2	0.554	-0.011	0.371	-0.134	0.007	0.954				
CMHSA	0.194	-0.049	0.441	-0.000	0.085	0.278	0.252			
DUMS2	0.103	-0.020	0.137	0.000	0.054	0.106	0.076	0.229		
CONWORK	-0.185	-0.005	-0.017	-0.171	0.083	-0.056	-0.024	-0.017	0.016	
PLAG	0.150	-0.096	0.371	-0.090	0.026	0.191	0.148	0.532	0.118	0.088

Table D-21. Descriptive Statistics, Small Ohio Deep Mines, 1965-1969

Variable	N	Mean	Standard Deviation
PROD	287	9.17	7.75
SEAM	404	48.58	11.21
CONT	405	0.04	0.21
IDLE	405	0.62	0.48
DRIFT	405	0.82	0.38
CAP	382	48.32	74.64
CAP^2	382	7893.01	23322.51
EXPWORK	405	0.52	6.39
CONWORK	405	-0.11	0.24
PLAG	286	447.18	8.88

Table D-22. Correlation Coefficients, Small Ohio Deep Mine Data, 1965-1969

	PROD	SEAM	CONT	IDLE	DRIFT	CAP	CAP^2	EXPWORK	CONWORK
SEAM	0.021								
CONT	0.476	-0.113							
IDLE	-0.035	-0.006	0.013						
DRIFT	0.170	-0.068	0.075	0.096					
CAP	0.555	0.020	0.327	-0.230	-0.033				
CAP^2	0.521	-0.011	0.312	-0.157	0.015	0.950			
EXPWORK	0.102	-0.034	0.207	-0.075	0.022	0.179	0.190		
CONWORK	-0.195	0.007	-0.018	-0.189	0.076	-0.075	-0.062	0.038	
PLAG	-0.037	-0.007	-0.046	0.004	-0.056	-0.047	-0.060	0.030	-0.047

Table D-23. Descriptive Statistics, Small Ohio Deep Mines, 1970-1977

Variable	N	Mean	Standard Deviation
PROD	65	13.36	10.13
SEAM	119	47.26	10.54
CONT	119	0.40	0.49
IDLE	119	0.62	0.48
DRIFT	119	0.89	0.30
CAP	91	111.81	124.40
CAP^2	91	27808.89	48326.45
CMHSA	119	1.00	0
DUMS2	119	0.06	0.25
DUMS1	119	0.15	0.36
EXPWORK	119	0.27	0.79
CONWORK	119	-0.12	0.25
PLAG	119	637.58	255.23

Table D-24. Correlation Coefficients, Small Ohio Deep Mine Data, 1970-1977

	PROD	SEAM	CONT	IDLE	DRIFT	CAP	CAP^2	DUMS2	DUMS1	EXPWORK	CONWORK
SEAM	-0.126										
CONT	0.166	-0.216									
IDLE	-0.041	0.150	-0.347								
DRIFT	0.062	-0.154	-0.122	-0.088							
CAP	0.629	0.102	0.315	-0.092	-0.084						
CAP^2	0.572	0.087	0.280	-0.060	-0.063	0.963					
DUMS2	0.109	-0.019	0.052	0.001	0.089	0.070	0.026				
DUMS1	-0.148	-0.054	-0.031	0.103	-0.006	-0.055	-0.006	-0.117			
EXPWORK	-0.043	-0.090	0.078	-0.178	0.050	0.242	0.204	-0.019	0.018		
CONWORK	-0.100	-0.055	-0.003	-0.115	0.123	0.039	0.089	0.042	-0.134	0.169	
PLAG	0.134	-0.138	0.252	-0.160	-0.065	0.092	0.037	0.001	-0.297	0.203	0.139

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