DOCUMENT RESUME

ED 228 405 CE 035 473

AUTHOR Baker, Joe G.
TITLE R&D and Technological Change in Coal Mining.
INSTITUTION Oak Ridge Associated Universities, Tenn.
SPONS AGENCY Bureau of Mines (Dept. of Interior), Washington, D.C.; Department of Energy, Washington, D.C.
REPORT NO ORAU-211
PUB DATE Feb 83
CONTRACT DE-AC05-76OR00033
NOTE 65p.
PUB TYPE Information Analyses (070)

EDRS PRICE MF01/PC03 Plus Postage.
DESCRIPTORS *Coal; Development; *Mining; Research; *Technological Advancement; Vocational Education
IDENTIFIERS *Impact Studies; *Research and Development

ABSTRACT

This report examines the issue of research and development (R and D) as well as technological changes in coal mining, focusing primarily on deep coal mining from 1970 to the present. First, a conceptual framework for classification of R and D as well as technological change is developed. A review of the literature that gives a mixed impression of technological change follows. Direct measures of technological change--labor productivity, production functions, and coal factor productivity--are examined. Evidence is provided that shows increasing inputs into technological change from research and development efforts during the 1970s. Determinants of technological change in coal mining (i.e., industry structure, long term contracts, and firm resources) are then discussed. Finally, an examination of the impacts of the 1981 Economic Recovery Tax Act (ERTA) leads to the general conclusion that the ERTA will stimulate coal industry R and D innovations. An appendix contains a summary of information received from the research directors of nine mining machine manufacturers concerning their company's past, present, and future R and D efforts and the effect of the ERTA. (YLB)

R&D AND TECHNOLOGICAL CHANGE IN COAL MINING

Prepared by

Labor and Policy Studies Program
Manpower Education, Research, and Training Division
Oak Ridge Associated Universities
Oak Ridge, Tennessee 37830

Project Staff

Author: Joe G. Baker
Consultant: Richard L. Hannah

Prepared for

Mining Research
Bureau of Mines
U.S. Department of Interior

Transferred from

Division of Coal Mining
U.S. Department of Energy

February 1983

This report is based on work performed for the U.S. Department of Interior and the U.S. Department of Energy under contract number DE-AC05-76OR00033.

Oak Ridge Associated Universities is a not-for-profit association of more than 50 colleges and universities. It is a contractor of the U.S. Department of Energy, conducting research and educational programs in the areas of energy, health, and the environment for DOE, other private and governmental organizations, and ORAU's member institutions.

This mission of the **Manpower Education, Research, and Training Division**, formed in 1977, is to enhance the knowledge and abilities of the professional and skilled work force involved in national energy, environmental, and health-related activities. The division is organized into four program areas that examine human resource issues, evaluate manpower requirements and training needs, assist in establishing manpower training programs, and provide opportunities for professional education and industrial craft training. The division's programs include the Assessment and Field Support Program, the Labor and Policy Studies Program, Professional Training Programs, and the Training and Technology Program.

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

NTIS price codes
Printed copy: A04
Microfiche copy: A01

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

R&D AND TECHNOLOGICAL CHANGE IN COAL MINING

ABSTRACT

This study examines the issue of R&D and technological change in coal mining, focusing on the period 1970 to present. First, a conceptual framework for classification of coal-related R&D and technological change is developed. This is followed by a review of literature related to technological change in coal mining and related areas.

Several measures of technological change are examined. Evidence concerning R&D expenditures and employment of technical manpower in coal mining is reviewed. Direct measures of technological change (i.e., labor productivity, production functions, and total factor productivity) are examined.

Determinants of technological change in coal mining (e.g., industry structure, long term contracts, firm resources, etc.) are discussed. The impacts of the 1981 Economic Recovery Tax Act on coal industry R&D and technological change are examined. The study also contains a summary of information received from the research directors of nine mining machine manufacturers.

ACKNOWLEDGMENTS

The author acknowledges the helpful comments and input of Ralph Avellanet of the Department of Interior, James Gander of the University of Utah, and Eileen Collins of the National Science Foundation. Gratitude is extended to the machine vendor research directors for information provided. The author is responsible for the study contents.

CHAPTER 1.

INTRODUCTION AND STATEMENT OF THE PROBLEM

INTRODUCTION

The coal mining industry changed substantially during the 1970s. This decade saw the entrance of oil companies into the coal business, the resurgence of coal markets, increased regulation, and a sharp, steady decline in worker output rates. These falling labor productivity rates increased the cost of production in coal mining, hindering somewhat its competitiveness with other fuels.

Before 1970, the coal industry had experienced remarkable growth in worker output rates, mainly because of increasing mechanization and technological change. This history of advancing technology, mechanization, and productivity dates back to the turn of the century and up to 1970 had been a dominant feature of the U.S. coal industry.

What happened to technological change and productivity growth in coal mining during the 1970s? Were there factors that hindered the adoption and development of new technology? Had the "learning curve," in effect, flattened out by the 1970s? What are the prospects for the future? These are some of the questions raised concerning the issue of technological change in coal mining. This report examines the issue of technological change in coal mining, focusing primarily on deep coal mining.

Technological Change

Technology is society's resource of knowledge regarding the industrial arts. Technological change is the growth of that resource. Basically, economists define technological change as any change that permits the same level of output (e.g., coal) to be produced with less input (e.g., labor, energy, and capital) or enables the former level of inputs to produce a greater output. This technological change can take the form of new production methods (e.g., continuous miners), new techniques of organization and marketing (e.g., mine mouth plants and long-term contracts), and new methods of management (e.g., miner incentive plans).

While technological change is easy to define, it is difficult to measure. One way to measure or index technological change is with productivity rates--the ratio of output to input. One determinant of the rate of labor productivity change is technological change; a high rate of technological change usually (but not always) results in labor productivity growth. A better measure of technological change is total factor productivity, which measures the growth of output relative to all inputs (not just labor). Also, economists have tried to incorporate technological change into the measurement of production functions directly, or indirectly using cost functions (duality).

Other attempts at indexing technological change examine the amount of money spent on research and development, the number of scientists and engineers employed, the number of patents granted, and other indirect measures. While these variables do not measure technological change per se, they all are related to technological change and provide evidence of its advance.

Another variable is the adoption of a new technology by industry after its development. Even though a new technique of production is developed, factors such as profitability, union work rules, government regulations, or uncertainty can prevent it from being put to widespread use. Direct measures of technological change such as total factor productivity implicitly take the rate of adoption into account; indirect measures such as R&D spending do not.

STATEMENT OF THE PROBLEM

While technological change cannot be blamed for the sharp decline in worker output rates for coal mining in the 1970s, it has not advanced sufficiently to overcome those factors forcing worker productivity down. Indeed, some argue that the rate of technological change slowed or halted during the 1970s. This could be the result of the learning curve flattening out; i.e., earlier technological change in the form of mechanization (continuous miners, large draglines, etc.) and organization (mine mouth plants, long-term contracts, etc.) may have resulted in great productivity gains as they were adopted and perfected by industry, but that rate of change did not continue. Most policy recommendations for reversing the productivity decline in coal mining rely to some extent on developing new technology.[1] The General Accounting Office report states:

> Available data indicate that technological innovation slowed in both underground and surface mines in the late 1960s. Neither underground nor surface technologies have changed significantly in scope or concept. In addition, by 1969 almost 96 percent of underground coal production was mechanically loaded.[2]

The issue of technological change has become even more important in light of the recent realignment of federal support for R&D. The policy of withdrawing R&D support for new technologies that industry could pursue if interested and emphasizing support of long-term, high-risk R&D that has a possibility for high payoff will have implications on the rate and type of technological change in coal mining in both the short run and long run. Also, recent changes in the tax treatment of private sector R&D as embodied in the Economic Recovery Tax Act of 1981 (ERTA) could affect coal industry R&D.

In light of the above, this paper examines three issues that are related to coal industry technological change:

1. What is the historical evidence concerning the rate of technological change in coal mining during the 1970s?
2. What factors appear important in explaining the rate of technological change in coal mining? Is there evidence of a learning curve?
3. How will the tax provisions of the Economic Recovery Tax Act of 1981 affect technological change in the coal industry?

The analysis contained in this paper is based mainly upon existing literature and data. Although many of the statistics examined relate to coal mining in general, including mining machine vendors, the emphasis of this report will be on deep coal mining.

NOTES

1. See, for example, General Accounting Office, *Low Productivity in American Coal Mining: Causes and Cures* (Washington, D.C.: USGPO, 1981), p. 8; and Emory-Ayers Associates, *Analysis of Labor Productivity Decline in the U.S. Bituminous Coal Mining Industry* (Washington, D.C.: USGPO, 1981), p. ix.

2. General Accounting Office, *Low Productivity*, p. 8.

CHAPTER 2.

EVIDENCE OF TECHNOLOGICAL CHANGE IN COAL MINING

INTRODUCTION

This chapter reviews evidence about the growth in technological change in coal mining during the 1970s. Several measures of technological change are examined; most of them compare technological change in the 1970s to change in previous periods.

The first section below develops a conceptual framework for classifying R&D and technological change in the coal industry. This is followed by a review of literature on issues related to coal mining technological change. Finally, evidence of technological change in coal mining is examined.

CONCEPTUAL FRAMEWORK OF COAL-RELATED R&D AND TECHNOLOGICAL CHANGE

R&D and technological change can be directed over a range of economic activities. Perhaps the major division is between demand side activities and supply side ones. Demand side activities include better ways to construct boilers, conversion of coal into liquids or gases, or a new process that uses coal as a raw material. Supply side R&D would be more concerned with better exploration methods, new mining techniques, and improved transportation of coal. In this paper we are concerned mainly with supply side aspects, specifically R&D and technological changes that improve the relationship between production inputs and coal output in the extraction stage.

Table 1 classifies R&D and technological changes by parts of the coal mineral cycle. Categories 1-3 are supply side activities, and 4 and 5 are on the demand side of the market. Each of these categories could be further broken down into subcategories as is number 2. The entries "Direct," "Indirect," and "Negligible" refer to the influence of that classification (e.g., applied exploration R&D) on the relationship between inputs to coal output in extraction. "Indirect" means that the relationship between inputs and coal output can be changed, but only by freeing inputs that were devoted to other activities and are now used to produce coal. Thus, safety-related R&D and technological change could reduce the inputs required to produce a given level of mine safety, allowing those inputs saved to be devoted to coal extraction.

TABLE 1. CATEGORIES OF COAL-RELATED R&D AND TECHNOLOGICAL CHANGE

Category	Possible Effect on Relation of Inputs to Coal Output: R&D — Basic	R&D — Applied	R&D — Development	Technological Change
1. Exploration	Indirect	Indirect	Indirect	Indirect
2. Extraction				
a. Output-related	Direct	Direct	Direct	Direct
b. Environment-related	Indirect	Indirect	Indirect	Indirect
c. Safety-related	Indirect	Indirect	Indirect	Indirect
3. Coal preparation	Indirect	Indirect	Indirect	Indirect
4. Processing/ conversion	Negligible	Negligible	Negligible	Negligible
5. Uses	Negligible	Negligible	Negligible	Negligible

"Negligible," appearing in the demand side categories, means that technological change has little, if any, effect on the input-coal output relationship. Possiblilities here could include technological change that shifts the coal consumption mix to coal types that are more or less favorable geologically, which would in turn effect the input-coal output relationship. "Direct" means that the R&D and technological change influence the relationship between a given level of inputs and the forthcoming coal output, *ceteris paribus*. Basically, this paper is concerned with category 2a.

The R&D columns are inputs into the production of technological change, which is the output. Basic research is research for the sake of knowledge, rather than for a specific purpose such as improving coal output. Applied research is directed at solving a specific problem while developmental research is aimed at the application of this solution on a practical scale. Once successful R&D has been completed, this new technology must be diffused throughout the industry to result in technological change, i.e., a change in the relationship between inputs and output.

In the remainder of this report, this classification scheme will be used to provide a framework for examining issues related to technological change in coal mining.

LITERATURE ON TECHNOLOGICAL CHANGE IN COAL MINING

Coal industry issues of productivity, safety, and competitiveness prompted the completion of numerous studies of the coal industry during the 1970s. Several of these studies examined some facet of coal industry technological change and are reviewed here. In addition, many articles in technical or trade journals describe specific pieces of equipment or a specific technology being developed.[1] It is difficult, however, to draw conclusions about the rate of technological change in the industry as a whole from discussions of specific pieces of machinery, so these articles are not included here.

A study completed by the Department of Labor in 1979 appraised major technological changes emerging in five energy industries (including coal mining) and discussed the expected impact of these changes on productivity and occupational structure.[2] Major areas of coal mining technological change discussed in this report for the 1970s were more extensive use of computers, combining longwall mining with room and pillar, continuous mining, slurry pipelines, innovations in integration of reclamation with mining in surface mines, advances in preparation processes, and improved maintenance. The report concluded that ". . . near term productivity performance could benefit from an increased demand for coal, advances in equipment design and automation, [and] improved linkage of production and haulage systems . . .[3]." Occupational structure was expected to shift toward technicians and operators, and job content to change for a number of occupations. However, the study offers little insight into the rate of technological advance during the 1970s as a whole.

A more historical perspective on coal industry technological change is provided in a Department of Labor publication prepared at the request of the President's Commission on Coal.[4] This chartbook examines major structural and technological changes in coal mining from 1950 to 1979. In deep mining, there is a mild slowdown in the rate of adoption of both continuous mining and longwall mining from 1960 to 1970 and after 1970. However, in terms of capital stocks per worker, the report concludes:

> The coal industry of the last two decades has been characterized by relatively rapid mechanization, as shown by the growth of real capital stocks. This is intensifying with new technologies and the enforcement of new mine regulations, with a view toward stronger coal demand. This trend is associated with the increase in surface mining, which is considerably more capital intensive than underground mining. Gross capital stocks (constant dollars) per production worker rose two and one-half times from 1960 to 1970. However, there was little change in the first half of the 1970s as employment rose sharply, particularly in underground mining.[5]

This implies that the capital-labor ratio changed from the 1960-1970 period (increasing capital per worker) to the 1970s period (falling or constant capital per worker). Such a shift could have resulted from capital-saving technological change, changes in relative input prices of capital and labor, or legislated changes in the production process. The changes in capital per worker that are due to a change in the mix of surface and deep mining are not of interest to our inquiry. The study also contains data from the National Science Foundation indicating that public and private funds for coal-related R&D increased from $50 million in 1973 to $250 million in 1978, an annual growth rate of 38 percent.[6] Because these data were for all (demand and supply) types of R&D, they give little evidence of the changes in extraction-related R&D.

A 1979 study for Fossil Energy, DOE, by Walton et al. examined the extent to which long-term (defined as greater than one year) contracts affect the adoption of new technology and improvements in the mining of coal.[7] "Adopt" means to buy or acquire, which implies that the technology already exists. In terms of our conceptual framework in Table 1, successful R&D has been conducted and the remaining step is to diffuse this new technology throughout the industry. The study defined three classifications of technology:

1. <u>Evolutionary technology</u>: improvements in existing equipment models or increased capacities.

2. <u>Transitional technology</u>: the adoption of existing or proven forms of technology to new areas or applications.

3. <u>Innovative technology</u>: concepts and systems not readily available and unproven for use in seam conditions prevalent or currently unminable for a coal producer.

These three types of new technology differ in terms of risk, potential payoff, and closeness to integration into production. Because of differences in these technology types, decisions to undertake or adopt any one of them are made on different criteria. In addition to technology types, many other factors determine whether a firm will adopt a given technology.

From their interviews and field visits with coal company representatives, lending institutions, utilities, and the Federal Energy Regulatory Commission and from data collected in a review of long-term contracts, Walton et al. found the following parameters were important in the decision by a firm to adopt a new technology:

1. Management philosophy. How the management of a coal firm views new technology is an important factor in its adoption. Walton et al. found that many managers of the 1950s and 1960s displayed a risk-avoiding, lean management style.[8] The new managers, especially those from utilities and oil firms, changed this perception in favor of new technology.

2. Current profits. The authors believed that coal companies with very high profits or those with losses would be more willing to adopt a new technology. This implies that the "in-betweens" have less incentive to adopt.

3. Market situation. A strong market with high prices and growing demand is favorable to the adoption of new technology.

4. Capital availability. Ease of capitalization is an important factor in the adoption of new technology. The price of funds or internal costs are important factors in capitalization.

5. Competition. Competition results in technological adoption as firms attempt to minimize costs. Walton et al. found that deep mining competition with surface mining has benefited the adoption of deep mine technology.

6. Long-term contracts. Using the type of contract and coal supplier, the authors determined the relationships in Table 2. For evolutionary and transitional technology adoption, a long-term contract is generally supportive because it assures a market and price and removes some uncertainty from the decision to adopt. For innovative technology, however, the authors felt that the risk associated with innovative technology runs counter to the stability of a long-term contract and public utility commissions would impose restraints to adoption.

TABLE 2. EFFECT OF LONG-TERM COAL SUPPLY CONTRACT ON THE DECISION TO ADOPT NEW TECHNOLOGY

Technology Type	Coal Supplier Type: Independent	Coal Supplier Type: Captive
Evolutionary	Strongly supportive	Generally supportive
Transitional	Strongly supportive	Neutral effect
Innovative	Disincentive	Strong disincentive

Source: D. Walton et al., The Effects of Long-Term Coal Supply Contracts on Technology Adoption and Improvements in the Mining of Coal (Washington, D.C.: USGPO, 1979), p. xii.

What is the bottom line, then, for adoption of new technology in coal mining during the 1970s? The entrance of oil and utility companies into coal mining would seem to have had a favorable influence because of their different management philosophies and capital availability. However, oil companies entered coal mining to diversify, and utilities entered to assure a market source. Because of cost pass-through arrangements, utilities may not have been that concerned with lowering production costs through technological change.

Profits and coal markets were growing in the 1970s, which may have favored the adoption of new technology. Surface mining was growing relative to deep mining, which according to Walton et al., may have encouraged adoption of new deep mine technologies.

The growth in long-term contracts during the 1970s may have acted as an incentive to adopt evolutionary and transitional technology, but discouraged innovative technology. The high costs of money may also have deterred technological adoption. In summary, the Walton et al. study provides little information on the growth in technological adoption during the 1970s, although the list of factors important in a firm's decision to adopt a new technology is useful.

In a 1975 article, economist Edwin Mansfield, a noted expert on technological change, examines the relationship between firm size and technological change in bituminous coal mining.[9] From discussions with industry personnel, Mansfield estimates that R&D in coal mining is small, and a large portion of the R&D that does occur is related to coal conversion.

From articles in trade journals and discussions with government agencies, Mansfield compiled a list of the significant technological innovations in coal preparation (number 3 in Table 1) from 1919 to 1958 and determined which companies first introduced each innovation commercially. From these results, Mansfield concludes that the four largest coal producers carried out a disproportionately large share of innovations (i.e., in excess of their market share). However, the most innovation relative to size occurred in the sixth largest firm. Also, Mansfield concludes that the smaller firms did more technological innovation from 1919 to 1938 than from 1939 to 1958.

In addition to analyzing the introduction of a technological innovation, Mansfield also examines how quickly the use of an innovation spreads from firm to firm. Examining the percentage of firms adopting shuttle cars, trackless mobile loaders, and continuous mining machines from 1940 to 1965, Mansfield concludes that the diffusion of an innovation is a function of the expected profitability of the innovation and the firm size (larger firms use new techniques more quickly).

Turning to R&D, Mansfield argues that the reason for the small amount of R&D and innovation by the bituminous coal industry (relative to other industries) was that the coal industry was composed of a large number of small firms, which carry out relatively less R&D than large firms. In this light, Mansfield views the acquisition of coal firms by petroleum firms as beneficial because the petroleum firms would devote expertise and capital not otherwise available to try and solve problems, especially in the area of coal conversion. This conclusion is based upon discussions with R&D executives in the coal, petroleum, and electrical equipment industries.

A study by the Department of Energy concerning competitiveness of the coal industry supports Mansfield's statements.[10] The authors of this study argue that because of a large number of small, independent companies and a declining market during the 1950s and 1960s, coal industry R&D was low. Petroleum firms brought to the coal industry large centralized research departments with technical knowledge that could often be transferred from one energy area to another (for example, fluid flow research applied to coal transportation). Using data from company files, the authors estimate that from 1974 to 1978, 41.1 percent of total private R&D coal expenditures were made by petroleum companies.

Richard Schmidt believes that one problem with technological change and innovation in the coal industry is the conservative approach of operators and miners.[11] Schmidt argues that because there is little advantage to being first to innovate, the high risks of new technology (capital, safety, and health risks) require proof of performance before an innovation is adopted. Schmidt also argues that the variability of the underground working environment and the inability to forecast the effects of the application of new technology also hinder technological innovation.[12] Finally, Schmidt argues that the above factors, combined with practices in the coal industry such as long-term contracts and mine lifetimes of 30 years, limit the ability of the industry to implement new technology, more so than other industries.[13]

A 1982 article by Marovelli and Karhnak agrees with Schmidt on these points.[14] Marovelli and Karhnak argue that the principal deterrent to technological innovation in deep coal mining is the variability of the coal seam. Other factors that contribute to the long lead times (20 years or more) for innovation include high capital cost, a tendency for operators to stick with proven methods, uncertainty of new methods, and the fact that a change in one mine subsystem (e.g., haulage) may require changing the entire system.

Marovelli and Karhnak review two studies of deep mine mechanization in England and Germany that indicated "extreme mechanization" resulted in dubious economic and productivity benefits. One explanation is that machines have proved to be less adaptable to difficult or changing mine conditions than have people working manually. This contention is shared by some American operators who feel that increased mechanization leads to increased probability of a shutdown.

Marovelli and Karhnak see four major reasons why longwall mining has not been readily accepted in the U.S.: (1) the U.S. has shallow deep mines, where room and pillar (the major competing technology) is economical; (2) engineers and workers have limited experience with longwall; (3) high capital cost; and (4) mine contracts in the U.S. usually require regular shipments to customers, and a mine with a single longwall face runs the risk of defaulting if a breakdown interrupts production. Despite these barriers, the authors foresee increased use of longwall mining in the U.S.

In 1981 the National Research Council (NRC) completed a study of issues related to technological innovation in mineral industries.[15] The objective of this study was to make recommendations on how the United States might better use R&D skills and resources to improve the rate of development and application of new technologies to mineral supply. The study was completed on the premise that R&D in the front end (supply side) of the mineral cycle has been lagging, and as a result the U.S. mineral industry has declined relative to foreign industry. While the study provides some facts and figures to back up this premise for the total mineral industry and for nonfuel minerals, it does not provide data to show that the coal industry has followed the trends of the mineral industry as a whole.

NRC outlines two major areas as sources for the lagging investment in R&D in the mineral industries: the nature of the industry and the policies and actions of the U.S. government. The nature of the industry affects R&D investment in numerous ways; all of which apply to coal mining:

1. Deposit-centered industry. Mineral industries that are ore deposit centered, (i.e., where a firm's competitiveness depends upon the type, grade, and location of its deposit as in coal) tend to concentrate on acquisition of preeminent deposits rather than development of new technology.

2. Nature of the product. Prices are determined by the market and in the short term are independent of production costs. Added costs for environmental purposes or taxes are difficult to pass on to consumers. Also, new innovations may only marginally reduce costs in the future.

3. Nature of raw materials. The raw materials (i.e., coal seam) vary, with each deposit having its own characteristics. This is a disincentive for innovation because technology applicable to one type of deposit may not apply in another.

4. High capital cost. Construction of new facilities involves long lead times and high capital cost. Most companies are unwilling to add to this risk by investing in radically new technology.

5. Manpower. Graduate student enrollment in the mineral sciences has been low and has not improved in recent years. This has resulted in low supply of the professionals needed for an active R&D program.

6. Company organization and philosophy. Most mineral companies are staffed primarily for production as opposed to R&D. Also, there is a reluctance to develop technology for marginal deposits because competitors may use this technology to obtain a more favorable market position.

7. Technology transfer. Processes and equipment used in mining are usually not proprietary, and ease of technology transfer acts as a disincentive to companies to develop new technology.

The policies and actions of the U.S. government that have resulted in lagging R&D in mineral industries have their impact by reducing the rate of return on investment or by increasing uncertainty. Environmental regulations have reduced the effort toward innovation by the diversion of R&D funds and manpower to coping with environmental problems and by the uncertainty of future standards. Moreover, the lack of a stable U.S. energy policy, concerns about future prices of energy (which affect the design of mines and mills), and changing or unclear health and safety regulations all increase uncertainty. The federal tax policy on depreciation rates has not been sufficient to encourage investment during inflationary periods (although the 1981 Economic Recovery Tax Act will change this), and lack of investment retards technological change.

The NRC study also offers suggestions for improving innovation and technological change in the mineral industries. Foremost among these is the need for sustained economic growth. Other economic considerations include changing depreciation laws, altering environmental policies (for example, "pollution fees"), and changing patent laws. Institutional arrangements also need to be altered: The Bureau of Mines, which according to the NRC study has changed from a cooperative stance with industry to an adversarial one, needs to return to its former position. Also, the NRC indicated the "red tape" now necessary for cooperative R&D ventures should be reduced.

Summary of Literature

None of the literature reviewed offers firm evidence as to the trend in deep coal mining extractive R&D and technological change during the 1970s. The data presented in most of these studies either apply to both surface and deep extraction or to an even broader classification (demand and supply side R&D; or all mineral industries). Several of the studies offer some insight into the factors that influence and determine the level of R&D and adoption of new technologies in either mineral industries in general or coal mining in particular. Comparison of these determinants to changes in coal industry characteristics in the 1970s and expected future coal industry characteristics suggests what has happened and what could happen in deep coal mine extraction R&D and technological change.

COAL INDUSTRY RESEARCH AND DEVELOPMENT

A method that is often used to gauge the rate of technological change (or potential technological change) is to measure its inputs, i.e., R&D effort.

Economists have empirically established a close relation between the rate of R&D spending and the total number of inventions forthcoming or other measures of technological change.[16] Thus, the amount of research effort, measured by technical manpower or R&D spending, may serve as a good proxy for technological change. This section focuses upon measures of R&D effort in the coal industry. In addition, evidence about R&D by mining equipment vendors will be discussed.

R&D Manpower

Several sources provide data on energy-related manpower involved in R&D; however, none of these sources shows a trend long enough to support conclusions. Also, data only on technological change and innovation that improve coal output and productivity are difficult to find. Much of the R&D in the coal industry during the past decade was for health, safety, environment, and coal conversion (see Table 1). While breakthroughs in these areas could improve productivity measured by coal output, they are not aimed at this goal specifically. To the extent this is true, a weak relationship exists between the total amount of coal R&D and improvements in coal output rates.

A National Science Foundation/Department of Energy (NSF/DOE) survey of doctoral scientists and engineers completed in 1981 includes separate tabulations for those who spent a significant amount of time in energy- or fuel-related activities. NSF/DOE estimated 41,550 doctoral scientists and engineers spent time on these activities. Of this number, 6600 (15.9 percent) said that they spent a significant portion of their time in coal-related work. Over half (3800 or 57.6 percent) of these 6600 coal-related workers were involved in R&D, and 2300 of these were supported by federal funds. However, indications are that most of this effort was concerned with demand side R&D (i.e., uses of coal).

A 1979 DOE study examined DOE-funded fossil energy research in universities.[17] Data for this study came from DOE files of research proposals and contracts collected in 1978. Table 3 shows the results of this study in terms of total manpower involved. In coal-related R&D, the 9435 person-months translates to a total of 786.3 equivalent full-time positions. This represents approximately 77 percent of total fossil energy manpower in university research. The total university coal-related expenditure for this manpower was $28.8 million, which was 77.0 percent of the total fossil energy R&D figure of $37.4 million.[18] However, according to a DOE official, less than 5 percent of this R&D was for supply side activities.

TABLE 8. FACULTY AND STUDENT PARTICIPATION IN FOSSIL ENERGY RESEARCH, 1977-1978

Energy Research and Development Area	Faculty	Research Associate[a]	Graduate Research Assistant	Undergraduate Research Assistant	Technician	Total
Coal and coal products						
Person-months	1798	2069	3974	442	1152	9435
Percent	19.1	21.9	42.1	4.7	12.2	100.0
Petroleum						
Person-months	276	204	585	132	71	1268
Percent	21.7	16.1	46.1	10.4	5.6	100.0
Natural gas						
Person-months	45	0	81	0	11	137
Percent	32.8	0.0	59.1	0.0	8.0	100.0
Oil shale and tar sands						
Person-months	550	360	511	27	13	1461
Percent	37.6	24.6	35.0	1.9	0.9	100.0
Total, fossil energy						
Person-months	2669	2633	5151	601	1247	12301
Percent	21.7	21.4	41.9	4.9	10.1	100.0

[a] Includes postdoctoral fellows.

NOTE: Percentages may not add to 100.0 because of rounding.

Source: M. G. Finn, *University Manpower in Fossil Energy Research and Development: A Data Collection Feasibility Study* (Washington, D.C.: USGPO, 1979), p. 11.

Table 4 contains information on recent graduate B.S. and M.S. level scientists and engineers employed in coal-related activities in 1978, 1979, and 1980. These numbers are not the total scientists and engineers, but only recent graduates just entering into coal-related activities. While these figures are of little help in determining trends, they do indicate a substantial number of technical workers entering coal-related activities in the late 1970s. Again, we do not know what phase of the coal mineral cycle these workers are involved in.

A further indication of the amount of technical manpower in the coal mining industry can be developed from the decennial census, which can provide "snapshots" of the manpower composition in coal mining at 10-year intervals. Table 5 contains census data for 1950, 1960, 1970, and an estimate for 1980 (based on a Bureau of Labor Statistics survey). These data are for workers employed in bituminous coal mining (both surface and deep) and therefore are concerned with extraction and are more relevant than the data examined above. These data indicate that the percentage of workers who are scientists and engineers doubled from 1950 to 1980, with engineering manpower growing strongly from 1970 to 1980.

TABLE 4. RECENT GRADUATE B.S. AND M.S. SCIENTISTS AND ENGINEERS EMPLOYED IN COAL-RELATED ACTIVITIES, 1978-1980

	Year of Survey[a]		
	1978	1979	1980
Scientists	2,431	3,670	2,940
Engineers	938	1,140	1,145
Total	3,369	4,810	4,085

[a]Average of two years new entrants. For 1978, average of 1972 and 1976 graduates; for 1979, average of 1973 and 1977 graduates; and for 1980, average of 1978 and 1979 graduates.

Source: Unpublished data from the National Science Foundation/Department of Energy Survey of Recent Science and Engineering Graduates.

TABLE 5. SCIENTISTS AND ENGINEERS EMPLOYED IN COAL MINING (SIC 12), 1950-1980

	1950		1960		1970		1980[a]	
	No.	Percent	No.	Percent	No.	Percent	No.	Percent
Scientists	300	0.1	282	0.2	259	0.2	470	0.2
Engineers	2,310	0.6	1,531	0.9	1,258	0.9	3,700	1.5
All others	365,290	99.3	166,687	98.9	138,083	98.9	243,530	98.3
Total	367,900	100.0	168,500	100.0	139,600	100.0	247,700	100.0

[a]Estimated.

Source: 1950-1970 from U.S. Department of Commerce, Bureau of Census; 1980 from the Bureau of Labor Statistics.

In reference to Table 1, however, we do not know if this growth in technical manpower has come in demand- or supply-related R&D. Changes in occupational structure because of health, safety, and environmental concerns do not translate into an increase in technical effort for coal mining improvement.

In summary, the limited data available do not support the hypothesis that coal-related R&D manpower has declined. On the contrary, the trend data examined (new entrants and census data) indicate a growth in R&D manpower from 1970 to 1980 in coal mining. However, we do not know where this R&D effort is being directed. Indications are that much of the R&D (especially university-related) was for non-supply side activities. Also, the increasingly complex nature of mining, due in part to regulatory compliance, has probably increased the industry's technical manpower requirements for production activities.

R&D Expenditures

Using R&D expenditures as a measure of technological change suffers from the same drawbacks as using R&D manpower. Much of the R&D funds can be for non-production-related R&D (e.g., health, environment, and end uses) and therefore do not give a good measure of production-related technological change. However, the dollar expenditures reported here do break out R&D by major categories in most instances. Some experts feel that because of the nature of the coal industry, it does not carry out R&D to the extent of other industries.[19] Reasons for this include the structure of the industry, the existence of long-term contracts, the importance of a rich seam to productivity and cost, and the added uncertainty of new techniques that comes with varying mine geology. However, in this paper we are more concerned with the trends in R&D and their relationship to productivity rather than with the absolute level of R&D.

Table 6 details the budget authority for the coal mining research and development program of the Department of Energy, which had primary responsibility for extraction technology (underground mining planning and development, production systems, and mine logistics). This function has been transferred to the Bureau of Mines. Table 6 also includes the funding history of Coal Mining R&D's predecessor agency in the Bureau of Mines, Department of Interior. As shown in Table 6, the mining R&D program has been on a "roller coaster," with gigantic growth from 1974 to 1976 followed by a leveling of funding through 1979, and then rapid decline to the 1982 funding year. Given the long-term nature of some mining R&D projects, these rapid shifts in funding growth have clearly disrupted the program's effectiveness. However, they do indicate growth through the middle 1970s.

TABLE 6. COAL MINING R&D PROGRAM FUNDING HISTORY, FY 1974-1983[a]
(dollars in millions)

	Year									
	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
Historical dollars	7.9	46.5	55.1	57.5	57.7	58.5	49.1	33.2	10.5	5.0
Constant (1977) dollars	9.6	51.7	58.3	57.5	53.9	50.4	36.7	23.9	7.2	3.2[b]

[a]Excludes coal preparation R&D.
[b]Estimated.

Source: U.S. Department of Energy.

Table 7 contains federal obligations for all coal R&D (both supply and demand side), which includes the extraction R&D funding in Table 6. These data indicate basically the same trend as extraction R&D: rapid growth through the late 1970s, then rapid declines in real terms. However, total coal R&D grew from 1979 to 1980 (unlike extraction) and did not decline at as rapid a rate as the extraction R&D funding.

TABLE 7. FEDERAL R&D OBLIGATIONS FOR COAL, 1969-1982

Year	Current Dollars	1977 Dollars
1969	18.1	29.6
1970	16.7	25.9
1971	30.7	45.3
1972	32.9	46.6
1973	43.8	58.6
1974	78.0	95.2
1975	276.2	307.6
1976	330.3	349.7
1977	490.7	490.7
1978	526.3	490.0
1979	535.0	446.6
1980	637.0	487.9
1981	554 (estimate)	388.6
1982	359 (estimate)	232.4

Source: National Science Foundation, *Federal R&D Funding by Budget Function* (Washington, D.C.: National Science Foundation, various years); and idem, *An Analysis of Federal R&D Funding by Function, Fiscal Years, 1969-1979* (Washington, D.C.: USGPO, 1978).

The National Science Foundation has been sponsoring annual surveys of R&D in industry since 1953. Form RD-1 of this survey is mailed to approximately 1100 firms annually, and requests information on energy-related R&D, defined as ". . . all R&D spending whose purpose is to increase energy resources and capabilities, including the development of energy equipment."[20] The results of these surveys from 1973 through 1979, with detailed results for coal-related R&D, are included in Table 8. The reader is cautioned that these data are based on a limited sample. It should be kept in mind that this is coal-related energy research by all industries, not just research by the coal industry alone. Also, the R&D dollars are broken into both federal and private sources. These figures are in real (1977 dollars) terms.

Total coal R&D grew at an annual rate of 26.2 percent from 1974 through 1979, compared to a 17.1 percent growth rate for all energy R&D. However, most of this growth was the result of federal funding, which grew at an annual rate of 66.0 percent during this period. Private funding for coal R&D grew at an annual rate of 10.9 percent from 1974 to 1979, compared to total private R&D for all energy of 18.3 percent annually.

TABLE 8. PRIVATE SECTOR EXPENDITURES FOR ENERGY RESEARCH AND DEVELOPMENT BY ENERGY SOURCE, 1973-1979
(1977 dollars in millions)

Year and Funding Source	All Energy Sources	Total Fossil	Coal: Total	Coal: Synthetic Fuels	Coal: Mining	Coal: All Other
1973						
Total private	1343.7	579.5	65.6	a	a	a
Federal funded	a	a	a	a	a	a
Private funded	a	a	a	a	a	a
1974						
Total private	1480.5	618.8	79.3	25.6	4.9	48.8
Federal funded	588.3	15.9	11.0	a	a	7.3
Private funded	892.2	602.9	68.3	a	a	41.5
1975						
Total private	1589.3	611.4	109.1	41.2	8.9	59.0
Federal funded	690.5	34.5	24.5	a	a	16.7
Private funded	898.8	576.9	84.6	a	a	42.3
1976						
Total private	1705.0	640.5	133.4	74.1	10.6	48.7
Federal funded	753.8	67.8	49.8	a	a	19.1
Private funded	951.2	572.7	83.6	a	a	29.6
1977						
Total private	1930.0	695.0	177.0	116.0	9.0	52.0
Federal funded	914.0	129.0	87.0	58.0	4.0	25.0
Private funded	1016.0	566.0	90.0	58.0	5.0	27.0
1978						
Total private	2817.2	800.7	a	a	a	a
Federal funded	1110.7	156.4	a	a	a	a
Private funded	1706.5	644.3	a	a	a	a
1979						
Total private	3258.0	905.5	253.5	189.9	0.9	62.7
Federal funded	1188.2	208.5	138.7	115.7	0.0	23.0
Private funded	2069.8	697.0	114.8	74.2	0.9	39.7
Annual 1974-1979 Growth Rate (%)						
Total private	17.1	7.9	26.2	49.3	-28.8	5.1
Federal funded	15.1	67.3	66.0	a	a	a
Private funded	18.3	2.9	10.9	a	a	a

[a]Not separately available but included in totals.

Source: National Science Foundation, *Research and Development in Industry* (Washington, D.C.: USGPO, various years).

When one disaggregates the figures by function, the mining R&D looks weak. Most of the growth in coal-related R&D expenditures occurred in the synthetic fuel area, which grew from 25.6 to 187.7 million from 1974 to 1979. This implies that measures of R&D that do not separate supply from demand side R&D, such as technical manpower, may be reflecting this demand side growth. The growth rate for mining R&D for 1974-1979 is -28.8 percent; however, firms reported that most of this decline occurred from 1977 to 1979, when reported mining R&D funds fell from $9 million to $0.9 million. Mining R&D expenditures doubled from 1974 to 1977, increasing from $4.9 million to $10.6 million, their highest reported level. Even in the peak year 1977, mining R&D made up only 7.9 percent of total reported coal-related R&D expenditures.

The data from the NSF survey indicate that total coal-related R&D expenditures grew at a rapid rate during the 1970s both in absolute terms and relative to other energy-related R&D. However, most of this R&D growth was in expenditures for synthetic fuels, with mining R&D growing more slowly through 1977 and declining thereafter. Also, mining R&D makes up a small portion of the total coal R&D expenditures, ranging from 8.1 percent of the total in 1976 to 0.4 percent of the total in 1979.

The most comprehensive information on coal R&D expenditures is contained in a 1981 study completed by Bituminous Coal Research, Incorporated, (BCR) for the Fossil Energy Group of DOE.[20] The purpose of this research was to determine the extent and areas of R&D in the coal mining industry (both equipment and extraction activities) in 1978. Information was obtained by a survey of coal producers and mining equipment manufacturers.

BCR estimated that total R&D expenditures by coal producers in 1978 was between $64 and $74 million, or an average of $0.15 per ton. These figures differ considerably from the NSF estimate of $9 million in 1977 and $0.9 million in 1979; the difference may be due to sample size. Deep mine producers spent an average of $0.23 per ton, and surface mine producers an average of $0.09 per ton for R&D. Approximately 30 percent of these R&D expenditures were for non-mining activities--health and safety, environment, and reclamation. R&D expenditures also varied by ownership, with coal company-owned producers spending the most for R&D ($0.40 per ton), followed by oil-owned ($0.25 per ton), steel-owned ($0.10 per ton) and utility-owned ($0.09 per ton). The largest producers (4 million tons or more) spent $0.15 per ton, the smallest producers (less than 1 million tons) spent $0.39 per ton, although the response rate for the smallest producers was only 5 percent and therefore may not be representative of all small producers.

BCR indicated that equipment producers spent $50.4 million for coal R&D in 1978. Approximately 8 percent of this was for health, safety, environment, and reclamation, although company spokesmen indicated that much of the research in general was in response to regulations or health and safety issues. Most equipment manufacturer research was product improvement.

The data in the BCR report allow a crude comparison between coal mining R&D and industrial R&D in general. In 1978, coal producers R&D expenditures were estimated at from $64 to $74 million. Total sales for coal mining in 1978 were $14.49 billion (665.127 million tons multiplied by an average price of $21.78 per ton).[22] This computes to an R&D expenditure rate of from 0.4 to 0.5 percent of total sales. For industry in general, the rate of R&D expenditure in 1978 was estimated at 2.0 percent of total sales.[23]

In August 1982, ORAU telephoned nine mining machine manufacturers concerning their R&D programs (see Appendix A). These companies, which included the major manufacturers of mining machinery, were asked about trends in their past, present, and future R&D programs that were related to deep mine productivity. Of the nine, seven said they had expanded their programs in the 1970s, and two said their programs were essentially stable in the 1970s. Of the seven who expanded R&D in the 1970s, two said that in the late 1970s their programs had tapered off. The present status of the programs indicated much less growth, with only four indicating expanding R&D programs, two indicating stable programs, and three indicating decline. The companies indicated that the 1982 slump in the coal industry has severely curtailed R&D effort. If these data can be viewed as representative of the industry as a whole, they indicate that mining machine vendors were engaged in aggressive R&D during most of the 1970s. Moreover, this R&D was related to improving productivity in deep coal mines, the area of interest in this study.

In summary, the available data do not support a decline in the overall coal-related R&D effort, measured by expenditures, during the 1970s. However, the NSF survey data and vendor information indicate large declines in R&D in the late 1970s. As with technical manpower data, it is hard to judge how much of these R&D expenditures were relevant to productivity. The vendor R&D data and the federal government budgets both present fairly unambiguous evidence that the

R&D effort directed toward the productivity of deep mine extraction was increasing, at least during the early 1970s. The other data are not quite so useful.

DIRECT MEASURES OF TECHNOLOGICAL CHANGE

As discussed in Chapter 1, technological change is defined as any change in the production process that permits the same level of output to be produced with less inputs, or greater output with the same inputs. The previous sections in this chapter examined factors associated with technological change, such as the number of scientists and engineers employed. In this section various direct measures of technological change are examined. The term "direct" is used because these measures directly compare the relationship between inputs and outputs in the production process.

A major problem with direct measures of technological change is that the relationship between inputs and output can be influenced by many factors other than technological change, such as work stoppages, capacity utilization, prices, mine geology, and institutional changes, e.g., the Coal Mine Health and Safety Act and reclamation legislation. If one could measure all outputs of coal mining (e.g., clean air, reclaimed land, healthy workers, tons of coal) and compare these to inputs, this problem could be circumvented. However, many of these outputs are difficult or impossible to quantify and one must rely on those that are measurable.

Labor Productivity

Changes in labor productivity (the ratio of output to labor input) has long been used as a measure of productivity in general and of technological change. The rate of technological change influences labor productivity as does the extent to which capital equipment or other inputs are used as complements to or as substitutes for labor (usually dependent on the relative prices of labor and other inputs). Other factors include economies of scale, percentage of capacity used, work stoppages, and managerial ability. Because labor productivity is affected by so many other factors, changes in it are a poor measure of technological change. Nevertheless, it is worthwhile to review labor productivity trends in coal mining.

Figure 1 shows the labor productivity trends for surface mining, deep mining, and mining in general from 1950 to 1978. The industry experienced sharp increases in labor productivity, peaking in 1969 with declines thereafter. Reasons identified in previous studies for this decline after 1969 include regulation, increasing coal prices, work stoppages, and the entrance of small producers into the industry.[24]

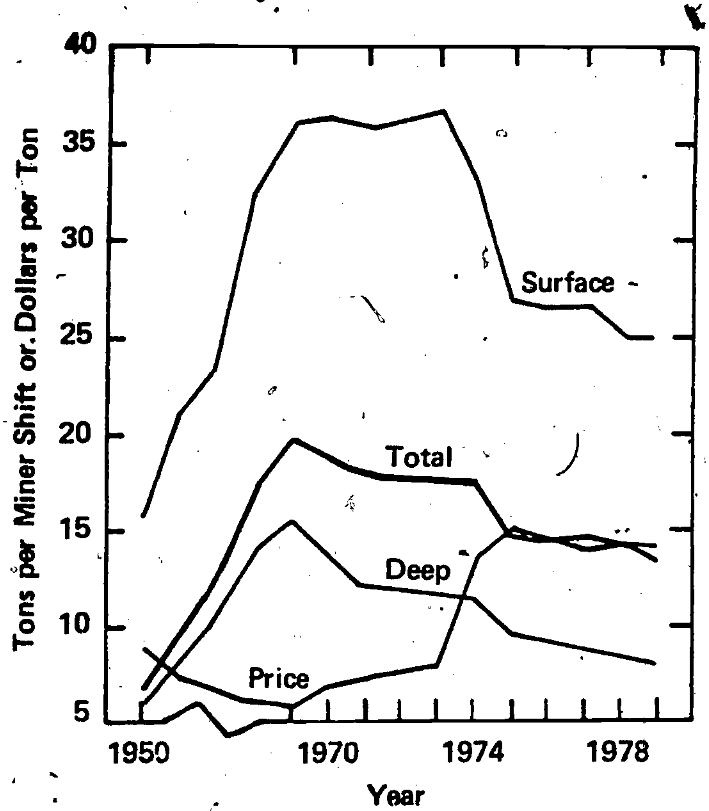
While this decline is not related to technological change, at least part of the pre-1969 growth in labor productivity is. This period saw new means of organization that allowed mines to be constructed at a technically optimum scale. Although there were really no new "breakthroughs" in mine technology, the pre-1969 period was characterized by rapid diffusion of more productive techniques: continuous mining grew from 0.8 percent of total deep mine output in 1950 to 49.7 percent in 1969; conveyor use grew from 48.1 percent of deep mine output in 1960 to 72.7 percent in 1969.[25] Other factors influencing labor productivity included few work stoppages, the steady demand of the coal utility market, and the elimination of small mines. Coal price deflation also forced efficiency in the industry.

Production Functions

Production functions are schedules or equations that relate inputs to output. Changes in production functions have been used as measures of technological change. In addition to the ones discussed above, production function measures suffer from many other problems. Assumptions must be made about the form of the function in most cases (economies of scale, substitution, etc.). Usually the measure of technological change is the "residual" (that part of output increase that is unexplained) and has not been measured directly. Because of measurement and statistical problems, many factors are excluded, such as worker health, education, and improved allocation of resources. Also, measurement of inputs is difficult, especially for capital equipment. However, production function measures have the advantage of including all inputs relative to outputs, which is preferred to the labor productivity measure.

Only one study of the coal mine industry production function is useful in interpreting technological change in coal mining during the 1970s.[26] This production function estimation is based on data for the period 1962-1977 for coal mining in general.

Figure 1. Labor Productivity and Real Price in Coal Mining, 1950-1979



Source: U.S. Department of Energy, *Bituminous Coal and Lignite Production and Mine Operation* (Washington, D.C.: USGPO, various years).

The most interesting result of this estimation is the indication that over time more input was required to produce a given output, which is inconsistent with advancing technological change but consistent with other changes and occurrences in the industry (e.g., regulation, work stoppages) during the late 1960s and 1970s. Unfortunately, because of the inability to include or control for these other changes, the results of this production function estimation cannot provide reliable information concerning technological change.

Total Factor Productivity Indexes

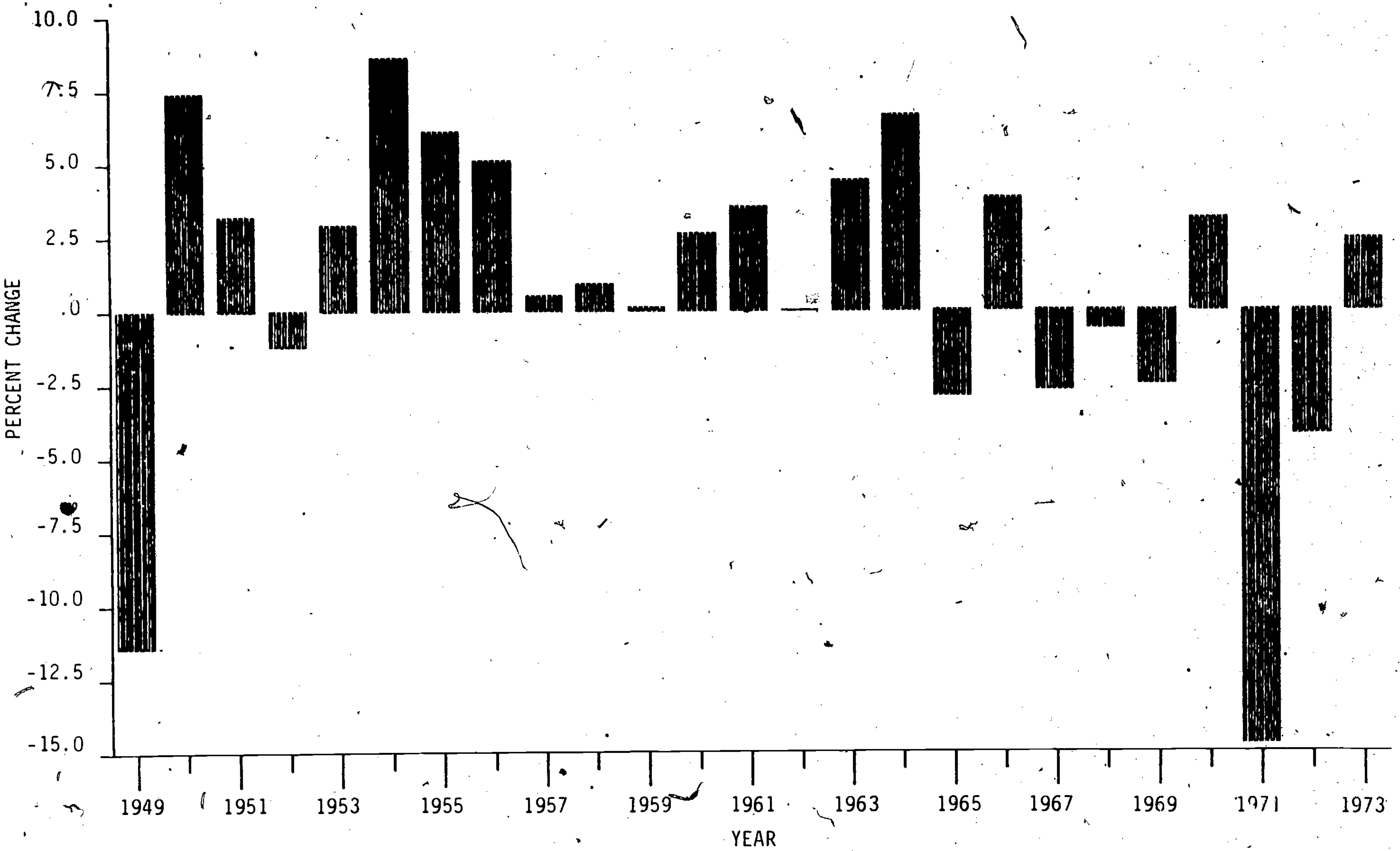
Total factor productivity indexes relate changes in output to changes in all inputs. Specifically, these measures compare the rate of change of output to the rate of change in inputs. The inputs' rates of change are combined into an index by weights, which are usually determined by cost shares in some base period or by moving averages. Total factor productivity indexes suffer from many of the same problems as production function measures; however, like production functions, they have the advantage of comparing all inputs to output. An added problem of total factor productivity indexes is that they place restrictions on the scale and input substitution characteristics of the production function.[27] Like production function measures, total factor productivity indexes attribute the "residual" (the difference between output change and input change) to technological change. However, excluded variables such as laws, seam characteristics, labor quality, etc., can also affect this index.

Figure 2 graphs the annual rate of technological change in coal mining for the period 1940-1973, using the total factor productivity method. All points above zero indicate possible positive technological change; points below zero indicate possible negative technological change. Of course, technological change by definition can never be negative. The term "negative technological change" as used here means that other factors (such as health and safety legislation) that worsen the relationship between inputs and output overwhelmed any technological change that had occurred. From 1950 to 1964, there was only one year (1952) without positive technological change. However, from 1965 to 1973, there were only three years (1966, 1970, and 1973) with positive technological change, indicating that technological change did slow after 1966. The institutional environment may account for the indicated drop in the rate of technological change after 1969. What is interesting in Figure 2 is the decline in the rate of technological change from 1966 through 1968, a period of little institutional change and a period in which labor productivity increased from 17.5 tons per worker-day to 19.4 tons per worker-day, a 10.9 percent increase. Also, 1973 shows a positive advance in technological change in coal mining, a year that experienced a fall in labor productivity.

SUMMARY

This chapter has examined literature and data related to technological change in coal-related activities during the 1970s. The literature reviewed gave a mixed impression of technological change in the 1970s. Some authors felt that changes in coal mine industry structure, (e.g., entrance of oil companies

Figure 2. Rate of Technological Change in Coal Mining, 1948-1973



Source: F. Gollop and D. Jorgenson, "U.S. Productivity Growth by Industry," in *New Developments in Productivity Measurement and Analysis*, J. Kendrick and B. Baccara, eds. (New York: National Bureau of Economic Research, 1980), pp. 17-86. The authors provided detailed tables of summary data appearing in the publication.

with their approach to R&D; increasing markets, long-term contracts, ease of capitalization and changing management philosophy) were favorable to R&D and technological change in coal mining. Others felt that inflationary pressure and tax laws, uncertainty from government regulation, and electric utility involvement, etc., may have depressed R&D and technological change in mining.

Input measures of technological change such as R&D expenditures and technical manpower give weak support to the view of increasing technological change in the 1970s. Available evidence on public and private R&D expenditures in mining show increases, at least through the middle 1970s. The little data available on technical manpower also indicate growth in scientists and engineers in coal mining during the 1970s. Of course, input measures of technological change in coal mining do not necessarily translate into technological change; also, indications are that much of the coal-related R&D was for non-production activities--coal conversion, environment, and health and safety, which would have at best indirect consequences on mining productivity. Evidence for the late 1970s and the 1980s indicate a decline in R&D inputs.

Finally, three direct measures of technological change in coal mining were examined: labor productivity, production function, and total factor productivity index. All of these measures supported the view that technological change slowed during the 1970s. However, none of these measures captures the output of non-coal commodities such as clean air, a safe working environment, and reclaimed land. Coal-related legislation in the late 1960s and the 1970s increased the output of these commodities, vis-à-vis coal; and as discussed above, there has been considerable R&D effort in these areas.

In sum then, the bulk of the evidence supports increasing inputs into technological change (i.e., R&D effort) during the 1970s. How much of this effort was translated into technological change is difficult to measure, given the data and especially the changing institutional environment in the industry. Also, the question of how this effort was distributed among the possible phases of the mineral cycle (Table 1) was largely left unanswered. The limited data available for the late 1970s and 1980s indicate declining inputs into technological change. The next chapter sheds some light on those factors that may affect the rate of adoption of new technology.

NOTES

1. See for example, the annual "Directory of New Technology," in *Coal Mining and Processing*.

2. Bureau of Labor Statistics, U.S. Department of Labor, *Technological Change and its Labor Impact in Five Energy Industries* (Washington, D.C.: USGPO, 1979).

3. Ibid., p. 10.

4. Bureau of Labor Statistics, Department of Labor, *Technology, Productivity, and Labor in the Bituminous Coal Industry, 1950-79* (Washington, D.C.: USGPO, 1981).

5. Ibid., p. 1.

6. Ibid., p. 7.

7. See D. R. Walton et al., *The Effects of Long-Term Coal Supply Contracts on Technology Adoption and Improvements in the Mining of Coal* (Washington, D.C.: USGPO, 1979).

8. Ibid., p. 5.

9. E. Mansfield, "Firm Size and Technological Change in the Petroleum and Bituminous Coal Industries," *Competition in the U.S. Energy Industry*, T. P. Duchesneau, ed. (Cambridge, Mass: Ballinger Publishing Company, 1975), pp. 317-45.

10. U.S. Department of Energy, "Coal Competition: Prospects for the 1980s," draft report (Washington, D.C.: USGPO, 1981), pp. 256-59.

11. R. A. Schmidt, *Coal in America--An Encyclopedia of Reserves, Production, and Use* (New York: McGraw-Hill Publications, 1979), p. 182.

12. Ibid., p. 194.

13. Ibid., p. 446.

14. R. L. Marovelli and J. M. Karhnak, "The Mechanization of Mining," *Scientific American 247(3):62-74 (September 1982)*.

15. *National Research Council, Committee on Mineral Technology Development Options, Issues Related to Improving Technological Innovation in the Mineral Industries* (Washington, D.C.: National Academy Press, 1981).

16. See E. Mansfield, *Industrial Research and Technological Innovation - An Econometric Analysis* (New York: Norton Books for the Cowles Foundation, 1968); W. S. Comanor, "Research and Technical Change in the Pharmaceutical Industry," *Review of Economics and Statistics*, 47(2):182-90 (1965); and K. Pavitt and S. Wald, *The Conditions for Success in Technological Innovation* (Paris, France: OECD, 1971).

17. M. G. Finn, *University Manpower in Fossil Energy Research and Development: A Data Collection and Feasibility Study* (Washington, D.C.: USGPO, 1979).

18. Ibid., p. 18.

19. See, for example, E. Mansfield, "Firm Size and Technological Change," p. 325; and R. Schmidt, *Coal in America*, p. 446.

20. National Science Foundation, *Research and Development in Industry, 1978* (Washington, D.C.: USGPO, 1979), p. 41.

21. Bituminous Coal Research, Inc., "Assessment of Research Projects and Expenditures by the Coal Industry," final draft report (Monroeville, Penn: Bituminous Coal Research, Inc., 1981).

22. These tonnage and price figures are from U.S. Department of Energy, Energy Information Administration, *Bituminous Coal and Lignite Production and Mine Operations, 1978* (Washington, D.C.: USGPO, 1980).

23. National Science Foundation, *Research and Development*, Table B-2.

24. See J. G. Baker and W. Stevenson, *Determinants of Coal Mine Labor Productivity Change* (Washington, D.C.: USGPO, 1979).

25. Bureau of Labor Statistics, Department of Labor, *Technology, Productivity, and Labor*, pp. 13-16.

26. J. G. Baker and W. Stevenson, *Coal Prices and Mine Productivity* (Oak Ridge, Tenn.: Oak Ridge Associated Universities, 1981), pp. 96-103.

27. See E. Mansfield, *Technological Change* (New York: Norton Books, 1971), p. 29; and L. Lave, *Technological Change: Its Conception and Measurement* (Englewood Cliffs, N.J.: Prentice-Hall, 1966), pp. 7-13.

CHAPTER 3.

DETERMINANTS OF TECHNOLOGICAL CHANGE IN COAL MINING

INTRODUCTION

The last chapter examined both inputs into technological change and the trends in technological change in coal mining. This chapter addresses questions of why firms devote effort to R&D and how the fruits of R&D are used.

Literature on the determinants of technological change in an industry and firm is reviewed. The literature on these topics is voluminous, and the review contained here is based upon summarizing efforts of other authors.[1] From this review, those characteristics that are important in explaining variation in R&D effort and adoption will be determined. Finally, those coal industry characteristics which are related to these determinants will be examined, and implications for the coal industry will be developed.

INDUSTRIAL STRUCTURE AND TECHNOLOGICAL CHANGE

Very few economists would argue that perfect competition is an efficient system to allocate resources for innovation and technological change.[2] By definition, each of the producers in a perfectly competitive industry is so small relative to the industry total that its actions cannot affect the product price. Conversely, each is also too small to capture more than a small fraction of the gains from technological progress it might produce--unless it could successfully charge its competitors for the right to use the technology. A major dispute separates those economists who follow the Schumpeter hypothesis that monopoly is an efficient system to generate technological change from those who argue that collective action, such as government financing, is a better system to advance technology.[3] One result of this debate has been considerable research devoted to the relationship between industry structure and technological change.

The bulk of the empirical evidence indicates that there is a positive relationship between research inputs (R&D expenditures, science and engineering manpower) and inventive output. A further question is, does the presence of basic knowledge (called "technological opportunity") or potential profit provide the stimulus to R&D effort? If technological opportunity is important, a policy of government R&D is preferred; if profit is the main driving force, then a more market-oriented approach is justified. The evidence supports both possibilities.[4]

Schumpeter's basic thesis was that a quest for extraordinary profits obtained through innovation was the propelling force behind technological change. The entrepreneur's function was to innovate; the reward for this innovation was profit. Innovation allowed the entrepreneur to achieve a temporary monopoly that in turn was eroded by other innovation. In this system, imperfect competition (where monopoly was possible) was preferred to competition where there was little incentive to innovate. Galbraith extended this and emphasized firm size as important, for only large industrial conglomerates generate the resources necessary for large-scale R&D efforts.[5] Large firms could also "hedge" against the risk of R&D by undertaking several different R&D projects simultaneously.

These hypotheses have been broadened and tested empirically. One test has been on the relationship between firm size and innovative intensity; that is, do larger firms spend more on R&D relative to their size than smaller firms? Kamien and Schwartz found little support for a positive relationship between innovative intensity and firm size in their review of studies in this area.[6] However, Kamien and Schwartz recognized that (1) industries differ in the strength and direction of the relationship, (2) the studies suffer from omitted variable bias (i.e., they do not control for other factors that may explain R&D intensity), and (3) the studies pertain only to ongoing R&D effort as opposed to intermittent efforts. Limited evidence available for the coal mining industry does not support the firm size-innovation intensity relationship. In a 1978 survey of R&D conducted by coal-producing companies, Bituminous Coal Research found that coal companies producing over 4 million tons per year spent $0.15 per ton on R&D; coal companies producing at least 1 million tons but less than 4 millon tons per year spent $0.14 per ton on R&D; and companies producing less than 1 million tons per year spent $0.39 per ton on R&D.[7] Moreover, when only deep mine companies were examined, more was still spent per ton on R&D by the smaller companies. However, the BCR study had a very low response rate from small producers, increasing the likelihood of nonresponse bias. Although the BCR study also surveyed equipment vendors, no tabulations were made by firm size.

A related issue is that of inventive output: do larger firms account for more innovations relative to firm size than do smaller firms? Here, Kamien and Schwartz's review of the literature generally supports the relationship: the effect of firm size on innovative output is positive.[8] As firm size increases, total R&D effort increases; also, the results of R&D (relative share of innovations) also increases.[9] However, this pattern also has interindustry differences. The limited data available on the coal industry support the relationship. Mansfield found that the largest four coal producers carried out a disproportionately large share of coal preparation innovations in the period 1919-1958.[10]

Other tests of the Galbraith-Schumpeter hypotheses have examined the relationship between industry concentration (used by economists as a measure of imperfect competition) and innovative effort and output. Basically, Kamien and Schwartz found the results of this empirical work to be mixed, with little consensus on the relationship between research effort and industry concentration, or the relationship between industry concentration and innovative output.[11] However, there is agreement that the relationship may vary with "technological opportunity" (i.e., the existence of basic knowledge), which appears to affect the strength and direction of the concentration-innovation relationship.[12]

The structural elements of markets have also been examined. Comanor found that when barriers to entry were very high or very low, there was little incentive to do R&D.[13] Grabowski and Baxter found that in oligopolistic industries (industries dominated by a few firms) a firm would respond with R&D spending to the R&D spending of its rivals and that conformity of R&D effort among firms was positively related to the level of industry concentration.[14] However, it should be pointed out that these studies deal almost exclusively with manufacturing industries.

Two more comments need to be made. First, it appers that technological opportunity influences the strength of the relationships examined (i.e., relationship between firm size and R&D, concentration and R&D, etc.) although the exact nature is not known. Second, the level of R&D and innovation can increase profits and market share for the innovator and affect industry structure, instead of vice versa as assumed in most of the studies.

DETERMINANTS OF TECHNOLOGICAL CHANGE IN THE FIRM[15]

There are two basic theories of the determinants of technological change or innovation at the firm level. The neoclassical theory assumes that the decision maker makes price, output, and allocation decisions with the goal of maximizing profit (or minimizing cost). Thus the decision to innovate depends upon the expected profitability of the innovation (or expected effect on production costs). A major drawback of this theory in its abstract form is that the decision maker is assumed to have perfect knowledge; however, R&D by its nature is risky and uncertain.

The opposing theory is an offshoot of the Galbraith-Schumpeter hypothesis and could be termed the "resource base" theory.[16] This theory argues that a firm must have resources available or "organizational slack" to devote to R&D. Thus, R&D becomes more a function of past profits, sales, and growth than of the expected profitability of the innovation. However, Cyert and March also argue that crisis and failure generate search for solutions that usually involve R&D and innovation. In various views then, "very good times" and "very bad times" are related to R&D and innovation at the firm level.

Empirical support for the neoclassical theory has been slim, based mainly on the difficulty of incorporating "risk" in the model and of difficulties in application as one moves to more basic research and away from development.[17] However, at least one study found that potential demand for a product stimulated innovation.[18]

There has been much more empirical work on the resource base theories, usually involving statistical analysis using regression techniques to study the relationship of different measures of sales, profit, and employment to some measure of innovative output or R&D activity. The evidence supporting this theory is weak; the relationship exists in some cases, but disappears with redefinition of variables or different data sets.[19] As Kamien and Schwartz state, a weak correlation may not mean that resources lack importance; financial liquidity and profitability may be "threshold factors," necessary in some degree for R&D, but not linearly related to the level of innovative activity.[20] The limited data available on the coal industry support the resource base theories. Surveys of coal company representatives, lending institutions, utilities, and federal agencies indicate a consensus that past and present profits were important for innovation.[21] Also, the equipment vendor research (Appendix A) found similar results for mining machine manufacturers.

The studies by Walton et al. and the NAS (reviewed in Chapter 2) dealt respectively with determinants of adoption of new technology in coal mining and factors affecting R&D and innovation in mineral industries.[22] The Walton et al. study was based on interviews with personnel in trade associations, coal and utility companies, lending institutions, and government regulatory bodies. The NAS study was completed by nine committee members of diverse backgrounds and familiar with the minerals industry. To produce its findings, the committee interviewed a cross-section of mostly mineral industry executives and reviewed the literature.

Both studies agreed that company management philosophy and organization were important factors determining innovation and R&D. R&D and innovation are risky undertakings, and coal company management was perceived as risk-averse for several reasons: (1) coal is a resource base industry, and therefore companies are organized for production, not R&D, especially since a new technique may not work in different seam conditions; (2) the market is cyclical, and increased costs cannot be passed on to consumers (in contrast to electronics, for example); and (3) the long period of operation and high initial costs mean high risk. Also, the emergence of long-term contracts has encouraged stability and static conditions, rather than risky new methods.

Both studies also concluded that capital costs and available money were important determinants of innovation and R&D. If a company had sufficient internal funds, it was more likely to develop a new technology or adopt an innovation. However, borrowing these funds, especially at high interest rates, was a strong disincentive given the risky nature of R&D and innovation.

The studies agreed that company profitability and the market situation were important determinants of R&D and adoption of new innovations. A decline in the rate of return on investment limits the firm's ability to generate internal funds and to attract external funds. Stability of the market also reduces uncertainty, which has a positive influence on innovation and R&D. The NAS study in particular emphasized factors that have acted to depress the rate of return in mineral industries: government regulations concerning health, safety, and environment; static depreciation tax laws in inflationary periods; and complexity and delays in obtaining permits. The NAS study further argued that health, safety, and environmental regulations hurt innovation and R&D by increasing uncertainty as regulations and standards change, by designing regulations applicable to present technology (which discourages new technology), and by diverting the firm's labor and capital resources from new technological innovations and R&D to changing the present technology to meet regulations. In addition, a poor market for coal reduces demand for mining machinery, which affects the R&D programs of mining equipment vendors. The Walton et al. study noted that both competition and long-term coal contracts influenced the adoption of new innovations in coal mining. Competition from other fuel sources and competition between deep and surface techniques could spur adoption of new innovations. The effect of long-term contracts on adoption of innovations varies, depending upon the type of contract and the type of innovation (see Chapter 2).

DETERMINANTS OF TECHNOLOGICAL CHANGE IN COAL MINING

The literature on determinants of technological change reveals considerable uncertainty over the exact nature of the hypothesized relationships. Because this is still a very active area of economic research, future efforts may more accurately identify the relevant variables.

Some relationships do emerge from the work to date. Table 9 compares some of the major conceptual and empirical results of the technological change literature to coal industry characteristics. Specifically, changes in coal industry structure and firm characteristics during the 1970s are examined for their implications on innovation and R&D.

What this gives us is a mixed picture of the direction of the forces affecting technological change during the 1970s. Major positive forces include the growth in profit and sales, entrance of oil companies into coal mining, growth in firm size, changes in management philosophy, and appearance of long-term contracts (for some types of innovation). Major negative factors include long-term contracts (for some types of innovation), the high cost of money, depreciation laws and inflation, increasing uncertainty from inflation and government regulation, and the reduction in profits caused by inflation and government regulation. The problem of weighing these influences is further compounded by the type of R&D and innovation they are related to, i.e., supply side, demand side, health and safety, etc.

These relationships do imply the types of actions that could be taken to improve the environment for technological change in coal mining. These suggestions will be discussed in the conclusions section of this report.

TABLE 9. TECHNOLOGICAL CHANGE IN COAL MINING

Relationship	Empirical Support	Coal Industry Implications
1. Innovational intensity is positively related to firm size.	Weak	Average coal company size has increased only slightly during the 1970s; however, many larger oil, utility, and other conglomerates have taken over coal operations.
2. Technological change and innovation are positively related to firm size.	Strong-Mansfield found to hold for coal industry 1938-1954.	Given relationship 1 above, indicates an increase in innovation during the 1970s.
3. R&D and innovation are positively related to industry concentration.	Overall mixed	Slight decrease in industry concentration during 1970s, implying a negative effect on R&D and innovation.
4. Barriers to entry--motivation for R&D is less if either high or low barriers to entry exist.	Comanor (1967) found support	Barriers to entry in mining have historically been very low. However, during the 1970s, they may have increased somewhat due to increased regulation, shifts in consumption towards utilities, and competition from large surface mines. Comparatively, they are still low.
5. Resource base--innovation occurs when firms have growth in profits or sales.	Mixed--although the limited data on the coal industry indicates it is important for mining companies and vendors.	During the 1970s there has been a turnaround in sales, production, and profit over the 1960s. However, market has slumped in early 1980s. Also, profit and rate of return have been depressed by inflation (effect on depreciation) and regulation of the coal industry. Also, entrance of oil companies with financial resources for innovation had a positive influence.

TABLE 9. (Continued)

Relationship	Empirical Support	Coal Industry Implications
6. Resource base--innovation occurs when there is crisis and the firm seeks solutions.	Has not been rigorously tested.	Some of largest advances in technology in coal mining came during the depressed 1920s and 1930s--machine loading and machine cutting. From WWII to 1970, the coal industry was declining, and there were rapid increases in use of continuous miners and diesel draglines and shovels. The 1970s were prosperous, although the industry is still very competitive.
7. Management philosophy--attitudes towards R&D and innovation.	Has not been rigorously tested, although most writers feel it is important. The Walton et al. study found important in coal mining as did NAS study.	Schmidt argues that coal industry has a "wait-and-see" attitude because innovation does not have many advantages in coal mining and has many risks. However, Mansfiel[illegible] and the DOE competition study feel [illegible] the takeover of coal compan[illegible] by conglomerates during the 1970[illegible] (especially oil) shifted attitudes of management in favor of R&D. Also, many oil companies applied research labs and staffs to coal work. However, this is predominantly demand side R&D.
8. Long-term contracts--guaranteed market removes incentive to innovate; however, may provide stable market base for innovations	The Walton et al. study for DOE found the long term contracts were supportive of most types of innovation; however, for "innovative technology" (concepts and systems unproven), long-term contracts were a strong disincentive.	Growth in the use of long-term contracts in the 1970s had a positive influence for R&D and innovation of technology that is similar to existing technology--however, negative influence on "innovative technology."

NOTES

1. A major source for this chapter is M. Kamien and N. L. Schwartz, "Market Structure and Innovation: A Survey," *Journal of Economic Literature* 13(1):1-37 (1975).

2. Ibid., p. 2.

3. See J. Schumpeter, *Capitalism, Socialism, and Democracy* (New York: Harper and Row, 1950), p. 82, as cited in Kamien and Schwartz.

4. Kamien and Schwartz, "Market Structure," p. 6.

5. J. K. Galbraith, *American Capitalism* (Boston: Houghton-Mifflin, 1952), chapter 7.

6. Kamien and Schwartz, "Market Structure," pp. 14-18.

7. Bituminous Coal Research, Inc., "Assessment of Research Projects and Expenditures by the Coal Industry," final draft report (Monroeville, Penn.: Bituminous Coal Research, Inc., 1981), pp. 46 and 55.

8. Kamien and Schwartz, "Market Structure," p. 19.

9. R&D effort is the absolute level of effort (e.g., total R&D expenditures) as opposed to R&D intensity (e.g., R&D expenditures as percent of sales). Ibid., pp. 18-19.

10. Edwin Mansfield, "Firm Size and Technological Change in the Petroleum and Bituminous Coal Industries," in *Competition in the U.S. Energy Industry*, T. P. Duchesneau, ed. (Cambridge, Mass:. Ballinger Publishing Co., 1975), p. 339.

11. Kamien and Schwartz, "Market Structure," pp. 21-23.

12. Ibid., p. 22.

13. W. S. Comanor, "Market Structure, Product Differentiation, and Industrial Research, " in *Quarterly Journal of Economics* 81(4):639-57 (1967), as cited in Kamien and Schwartz.

14. H. G. Grabowski and N. D. Baxter, "Rivalry and Industrial Research and Development," *Journal of Industrial Economics* 21(2):209-35 (1973), as cited in Kamien and Schwartz.

15. This section draws on N. M. Kay, *The Innovating Firm: A Behavioral Theory of Corporate R&D* (New York: St. Martins Press, 1979).

16. The basic theories are discussed in R. M. Cyert and J. G. March, *A Behavioral Theory of the Firm* (Englewood Cliffs, N.J.: Prentice-Hall, 1963), and E. T. Penrose, *The Theory of the Growth of the Firm* (Oxford: Basil-Blackwell, 1959), as cited in Kay.

17. Nelson suggests that the formal neoclassical model of the firm is unsuited for dealing with the problems of R&D and innovation. See R. R. Nelson, "Issues and Suggestions for the Study of Industrial Organization in a Regime of Rapid Technical Change," in V. R. Fuchs, ed., *Policy, Issues, and Research Opportunities in Industrial Organization* (New York: National Bureau of Economic Research, 1972), as cited in Kay.

18. J. Schmookler, *Invention and Economic Growth* (Cambridge, Mass.: Harvard University Press, 1966), as cited in Kamien and Schwartz.

19. See for example, C. Freeman, "Research and Development: A Comparison Between British and American Industry," *National Institute Economic Review*, May 1962, pp. 21-39; and F. M. Scherer, "Firm Size, Market Structure, Opportunity, and the Output of Patented Inventions," *American Economic Review* 55(5):1097-1125 (1965), as cited in Kamien and Schwartz.

20. Kamien and Schwartz, "Market Structure," p. 26.

21. D. Walton et al., *The Effects of Long-Term Coal Supply Contracts on Technology Adoption and Improvement in the Mining of Coal* (Washington, D.C.: USGPO, 1979), p. 7.

22. D. Walton et al., *Long-Term Contracts*, and National Academy of Science, Committee on Mineral Technology Development Options, *Issues Related to Improving Technological Innovation in the Mineral Industries* (Washington, D.C.: National Academy Press, 1981).

CHAPTER 4.

THE ECONOMIC RECOVERY TAX ACT OF 1981 AND COAL INDUSTRY INNOVATION

THE ECONOMIC RECOVERY TAX ACT

In August 1981, Congress passed the Economic Recovery Tax Act (ERTA) to ". . . encourage economic growth through reduction of the tax rates for individuals, acceleration of capital cost recovery of investment in plant, equipment, and real property, and incentives for savings, and for other purposes."[1] Several of the major provisions of the law are aimed at affecting research and innovation:

1. Research and experimentation credit. ERTA provides a 25 percent tax credit for R&D expenditures in excess of the average amount of R&D expenditures in a base period (the base period is generally the previous three years). This credit applies to expenditures between June 30, 1981, and 1986 and includes wages and supplies for "in-house" research, 65 percent of contracted research, and 65 percent of grants to universities and qualifying scientific institutions for basic research.

   Assuming that a firm spent $3 million over the previous 3 years for R&D, the base would be $1 million. Thus if a firm increased this to $2 million in the next year, it would get a tax credit of $250,000 (25 percent of the $1 million increase) to apply to taxes that year, to get a refund for taxes paid during the last 3 years, or to apply to taxes over the next 15 years. The minimum base expenditures a firm can claim for the tax credit is 50 percent of current expenditures.

2. Accelerated cost recovery system (ACRS). This provision of ERTA allows firms to depreciate assets at a faster rate than in the past. Depending upon asset types, the cost of the asset can be recovered over 3, 5, 10, or 15 years. This effectively lowers the cost of assets, encouraging investment.

3. University research. Firms are given larger tax deductions than in the past for contribution of new equipment to universities for research.

The remainder of this chapter will discuss the impact these tax code changes may have on coal industry research and development.

ERTA AND THE COAL INDUSTRY

Despite a rather extensive literature on the relationship between tax policy, innovation, and investment, there is virtually no quantitative evidence on the effects of tax change on R&D.[2] Although the existing evidence indicates that changes in tax policy can have a positive effect on innovation, the level of effect is likely to depend upon conditions such as business confidence and market opportunity.[3]

The neoclassical theory of the firm argues that decisions to innovate or invest in R&D are made in order to maximize profit. Given this, a reduction in the cost of innovation through tax policy would have the same effect as reducing the cost of production inputs such as capital and labor--that is, it would increase their use.

Two studies that provided preliminary estimates of the long-run price elasticity of R&D (i.e., the percentage change in R&D spending resulting from a 1 percent change in R&D cost) have been completed. Nadiri and Schankerman estimate this elasticity at 0.3 (i.e., a $1 reduction in R&D cost will result in an increase of $0.30 in R&D expenditures); while Goldberg estimates the elasticity at 0.9.[4] As Collins point out, however, these results are tentative and both are for market-induced, net-of-tax cost reductions, which may have different effects from tax-induced changes.[5]

The following factors appear important in determining the nature of the relationship between tax change and innovation.[6]

1. Size and structure of tax benefit. Obviously, the size of the tax credit is important in determining the impacts. The proposed ERTA credit is large; effectively reducing additional R&D cost by 25 percent in most instances. The structure, i.e., applying to increases in R&D expenditures, is effective. However, R&D is only one stage in a lengthy process from original R&D to commercial application, and as Gallagher points out, estimates indicate that R&D accounts for only 10 to 20 percent of the total cost of innovation.[7] Given this, a 25 percent reduction in costs at the R&D stage would lower total innovation costs by only 2.5 to 5.0 percent. However, the R&D tax credit will also affect state taxes in those states where the taxes are based upon federal taxes. In some states, the combined effect of state and federal tax credits for R&D could allow firms to recover up to 80 percent of increases for R&D expenditures.[8]

2. Cash flow. Some firms may not have sufficient internal funds to conduct R&D, and borrowing outside funds may be difficult. Although the evidence discussed in the last chapter indicated that empirical support for a relationship between innovation and profitability or liquidity is generally weak, it is strong in the coal industry and a tax credit could reduce the tax drain on a firm's internal funds and possibly increase innovation. For the coal industry, the present slump in the coal market has limited available funds in some firms. For coal companies owned by large conglomerates, internal funds may not act as a "brake" on innovation.

3. Microeconomic conditions. As discussed in the last chapter, many economic factors affect the level of R&D and innovation at the firm level. Some of these factors could also affect the influence that a tax incentive will have on R&D and innovation.

One such factor is industry concentration, where R&D sometimes serves as a substitute for price competition.[9] In this case, the market strategy of the firm would dominate any response to moderate changes in the cost of R&D. However, the coal industry is dominated by price competition.

Risk and uncertainty also affect R&D and innovation, perhaps more so in coal mining because of geologic, regulatory, and safety-related uncertainty and the high capital cost, long-term nature of investment. This uncertainty may be too large to be overcome by a marginal change in the cost of R&D.

Finally, management and worker attitude can affect the amount of R&D and innovation carried out by the firm. If these attitudes are unfavorable to R&D, it is likely that changes in R&D cost will have little affect on R&D by the firm.

4. Macroeconomic conditions. Some writers have argued that the general economic climate may be a more important determinant of R&D than the tax incentives themselves.[10] If business is good and markets are strong, the effect of a tax policy will be enhanced; if markets are weak, the tax policy will be less effective. In coal mining, markets have generally been very good during the last decade. Although there is presently a glut of coal and depressed prices, most forecasts predict that coal output will continue to grow through this century. However, the coal industry has suffered historically from overproduction and depressed prices. Even in the face of growing output, price depression and low rates of return on investment may discourage R&D and innovation, although vendor R&D would grow as mining equipment sales increased. Also, if ERTA leads to

economy-wide improvements in inflation rates, growth, and profitability, it is likely that these conditions will encourage R&D and investment in coal mining.

5. Investment and innovation. Evidence exists that the rate of technological change depends upon the rate of investment in plant and equipment.[11] As stated by Mansfield:

> This is due to the fact that R&D by itself is generally of little value to a firm, because it is usually only one stage of a long process leading to a successful innovation. A major, and often the most expensive, stage of the process involves the construction of a new plant, new equipment, or both. Because of this complementarity between R&D, on the one hand, and new plant and equipment on the other, increases in the rate of investment in plant and equipment tend to raise the profitability of many R&D projects whose findings could not be used effectively, or perhaps at all if the rate of investment in plant and equipment were lower.[12]

The ACRS of ERTA is aimed directly at increasing investment by lowering the cost of new equipment. If this provision affects coal industry investment, it will likely enhance the effects of the tax credit for R&D.[13] Using a cost model simulation of a deep coal mine, ORAU found that the rate of return jumped from 14.5 percent to 16.1 percent when ACRS was used.[14] Tax credits for R&D will benefit R&D-intensive industries the most; while ACRS credits will benefit capital-intensive industries the most. If this observation holds, then ACRS may be more important for the coal industry than the R&D credit.

6. Other considerations. Perhaps the biggest problem with ERTA at present is a lack of guidelines and ratings on exactly which expenditures qualify under the act for special treatment.[15] Because of this, many firms may be holding back on projects until more clarification on the new code becomes available, resulting in companies foregoing R&D and the tax credits from R&D.

Another potential problem for the act and mining in particular is how federal grants for R&D are handled. R&D under federal contract is not eligible for tax credits. Given the long history of cooperation between the coal industry and the federal government in mining R&D, this provision may be more harmful to the coal industry than to other industries in general.

Evidence

This section reviews the results of three surveys of firms concerning the effect of the ERTA research and experimentation tax credit. Two of these surveys are applicable directly to the coal industry; the third applies to industry in general.

Skelly and Loy contacted persons involved in trade associations, tax accounting, equipment manufacturing, and mining in the coal industry and asked them what impact they felt the tax credit would have.[16] Officials at the National Coal Association and the American Mining Congress viewed R&D expenditures as too minor an element of company budgets for the tax credit to cause noticeable increases. Tax counsels for mining companies and equipment manufacturers believed it was too early to estimate the extent of the benefits. Joy Manufacturing saw minimal benefits because of its high base level of R&D; Peabody Coal saw no benefit because it was losing money; Phillips Coal's R&D budget is consolidated into Phillips Petroleum's R&D budget; and Consolidation Coal Company's 1982 budget was not affected by the tax credit. In sum, Skelly and Loy felt that the overall effect of the tax credit would be minimal.

ORAU contacted the R&D directors of nine mine equipment manufacturers (see Appendix A). Each research director was asked if the tax credit had any effect on his company's R&D program or budget. Only one director said the tax credit had a positive effect, while eight indicated that the tax credit had no effect. Reasons given for the lack of impact of the tax credit were that (1) mine equipment sales are rock bottom, and companies cut back on R&D when sales and profits are down, (2) R&D projects are done on their own merits rather than for tax advantages, and (3) the tax credit is taken at the corporate level and not by the mine machinery division. Potentially, the tax credit would be more effective if sales and profits were up.

In September 1981, NSF surveyed 11 companies who spend major amounts on R&D to determine the effect of the 1981 Economic Recovery Tax Act on their R&D programs.[17] NSF estimates that these 11 companies account for approximately one-third of all company-funded R&D expenditures in the United States. NSF indicated that there was general agreement among the R&D officials that the provisions of ERTA relating to R&D activities would not have any appreciable effect on 1982 spending. However, the R&D officials believed that R&D activities were likely to be favorably affected in the following years. Another comment typically offered was that the overall tax bill would create a good business climate, which in turn would benefit R&D. In particular, the ACRS depreciation provisions were seen as very beneficial.

Some firms felt that the expected tax benefit was small in light of overall company expenditures, and thus would have little impact. Another comment offered was that tax considerations were secondary in setting R&D; the companies undertook that level of R&D they felt was worthy. Also, two companies indicated that they were having definitional problems with the law.

SUMMARY AND CONCLUSIONS

This chapter has examined the provisions of ERTA that could affect coal industry R&D and innovation. The general conclusion from the literature on tax policy and innovation may also apply to ERTA and the coal industry: although it is difficult to speculate on the size of the effect, all indications are that ERTA will stimulate coal industry R&D and innovation. Another issue is how these R&D benefits will be distributed between demand side and supply side uses.

The size of the effect will depend on basically three factors: (1) firm level (microeconomic) characteristics such as cash flow, industry structure, and management attitude; (2) macroeconomic characteristics such as business climate and interest and inflation rates; and (3) characteristics of the law such as size and structure of the tax benefit and the extent to which the law's provisions are understandable or ambiguous.

From the surveys of business and other officials concerning ERTA, several points emerge. First, the immediate effect of ERTA tax credits for R&D will be small, especially in the coal industry where markets are depressed. Second, the ACRS may have a more important impact on R&D and innovation than the research and experimentation credit of ERTA. Finally, the most beneficial aspect of ERTA on R&D may be in its contribution to the revival of the U.S. economy. This last point is a theme that appeared in the tax policy and innovation literature and the surveys of R&D officials: if the economic climate is not right, there is little that R&D tax incentives can do.

This point was especially strong in the ORAU discussions held with mine machine equipment vendors. Based on the results of that information, R&D effort closely follows the sales and profits of the industry. ERTA could potentially stimulate sales of mining machinery by increasing coal demand through its effect on the overall economic environment and by lowering mine investment costs through ACRS. The mining machine industry would be encouraged to increase R&D as sales increase, and the research and experimentation tax credit in this expansionary environment could be potentially very stimulative. In addition, this R&D would be supply side in nature and could reduce the cost of production and raise productivity.

NOTES

1. Public Law 97-34, *Economic Recovery Tax Act of 1981*.

2. Mansfield argues that because economists have until recently neglected the study of technological change and because estimating the effects of tax policies on R&D expenditures, is inherently difficult, little is known about tax policy and innovation. See E. Mansfield, "Tax Policy and Innovation," *Science* 215(12):1365-71 (March 1982).

3. See R. S. Kaplan, *Tax Policies of U.S. and Foreign Nations in Support of R&D and Innovation* (Washington, D.C.: NTIS, 1976); M. Visscher, *The Effect of Tax Incentives on Business Behavior* (Washington, D.C.: NTIS, 1976); and E. L. Collins, "Tax Incentives for Innovation--Productivity Miracle or Media Hype?" *Journal of Post Keynesian Economics* 4(1):68-74 (Fall 1981)

4. See I. M. Nadiri and M. A. Schankerman, "The Structure of Production, Technological Change, and the Rate of Growth of Total Factor Productivity," in T. Cowicy and R. Stevenson, eds., *Productivity Measurement in Regulated Industries* (New York: Academic Press, 1981); and Lawrence Goldberg, "The Influence of Federal R&D Funding on the Demand for and Returns to Industrial R&D," mimeographed (Washington, D.C.: The Public Research Institute, October 1979).

5. E. L. Collins, *Tax Policy and Innovation: A Synthesis of Evidence* (Washington, D.C.: National Science Foundation, 1981), p. 6.

6. This discussion follows Collins, *Tax Policy and Innovation*, pp. 6-8.

7. T. Gallagher, *Tax Policy and Industrial Innovation* (Washington, D.C.: Congressional Research Service, 1980), p. 8.

8. See I. Salem and S. Smiley, "New Tax Credit can be Powerful Incentive for R&D," *Legal Times of Washington*, 14(15):21 (September 15, 1981).

9. E. L. Collins, *Tax Policy and Innovation*, p. 6.

10. See E. Mansfield, "Tax Policy and Innovation," p. 1365.

11. See J. Schmookler, *Invention and Economic Growth* (Cambridge, Mass.: Harvard University, 1966).

12. E. Mansfield, "Tax Policy and Innovation," p. 1366.

13. Simulations of investment tax parameters in six macroeconomic models resulted in a wide variety of results, ranging from $1.4 billion to $13.1 billion dollars of additional investment after a doubling of investment tax credits. See R. Eisver, "Tax Policy for Investment: Implications for Innovation" in *Tax Policy and Investment in Innovation* (Washington, D.C.: National Science Foundation, 1981), p. C16.

14. See Joe G. Baker, *Causes and Effects of Escalating Prices for Deep Mine Machinery*, ORAU-210 (Oak Ridge, Tenn: Oak Ridge Associated Universities, 1983), pp. 30-35.

15. See, for example, "The Glaring Gaps in the Tax Act," *Business Week*, February 1, 1982, pp. 71-72; and I. Salem and S. Smiley, "New Tax Credit," p. 21.

16. Skelly and Loy, "The Economic Recovery Tax Act and the Mining Industry," draft report (Gaithersburg, Md.: Skelly and Loy, 1981).

17. National Science Foundation, "Results of a Survey of Major Industrial Firms Regarding the Impact of the 1981 Tax Legislation on their Research and Development Programs," mimeographed (Washington, D.C.: National Science Foundation, 1981).

CHAPTER 5.

SUMMARY AND CONCLUSIONS

When one examines the resources devoted to coal-related R&D during the 1970s (public and private R&D dollars and manpower), the data show an unambiguous growth during most of the decade. However, the direct productivity and cost function measures of technological change in this same period indicate little change and even a worsening of the relation between inputs and output.

Evidence suggests that the key to these contradictory trends is that the composition of R&D effort during the 1970s was weighted heavily toward activities that were not directly related to coal output, such as health, safety, environment, and coal conversion. Part of the reason for this was that legislation forced this emphasis, and part was economics and relative fuel prices. The result of this emphasis was that the increase in R&D effort was expended on activities unrelated to technical efficiency between outputs and inputs in the mining of coal.[1] One would not expect synfuels research, for example, to improve mine productivity, although health and safety and environmental R&D could have an indirect effect.

Changes in the output composition of the coal industry also affected mine productivity. Legislation concerning health, safety, and the environment dictated that the mine industry devote a larger portion of its limited capital and labor services to the production of these outputs at the expense of coal. If one could develop direct measures of technological change that included these outputs in addition to coal, it is possible that the 1970s experienced an increase in productive efficiency and a positive growth in technology. Mining equipment vendors were increasing supply side R&D during this period, as was the federal government. Thus, the translation of this supply side R&D into coal output-related technological change may have been hindered by the shifting composition of coal industry output (coal, health, safety, environment).

There were also several economic and institutional forces working against adoption of innovations and R&D in the 1970s. High rates of inflation and interest increased uncertainty and discouraged risk-taking. High capital costs, combined with inflation and high interest rates, discouraged investment, which is a necessary prerequisite for technological change. Regulations concerning health, safety, and the environment changed equipment standards and increased uncertainty, further discouraging innovation. These regulations were written with existing processes and technology in mind, which encouraged changes in present technology to meet new standards rather than the development of new technology. In addition, regulations diverted labor and capital away from R&D and innovation.

A major conclusion of this study is that coal industry characteristics do not favor the development of innovative technology (technology that departs radically from present methods and is unproven), and this effect is stronger than in other industries. These characteristics include management philosophy, geologic uncertainties, premium for stability in long-term contracts, utility rate regulation, and lack of economic benefits from "being first" in the innovation process. Also, coal mining involves large initial investments with returns accruing years in the future. These initial risks further discourage the use of unproven techniques.

Several characteristics of coal mining, however, do encourage less radical R&D and innovation. The takeover of coal firms by oil firms that began in the 1960s is one, although these oil firms may be oriented towards coal conversion R&D rather than suppply side R&D. Some new marketing conventions, such as mine mouth plants and long-term contracts, have removed uncertainty and provided a stable revenue base which may benefit R&D and innovation (although some argue that they also remove incentives to hold down production costs).

Although markets are depressed at present, the 1970s saw strong growth in coal company sales and profit, and projections indicate that coal output will grow throughout the 1980s. Growth in sales and profit provides firms with resources to undertake R&D and innovation and the investment required to translate this into technological change. Also, increasing coal sales increases the demand for mining equipment, which encourages equipment vendors to increase R&D. Finally, the research and experimentation tax credit and ACRS of ERTA may have large impacts on future coal industry R&D, although the present level of influence is minimal.

In terms of policy, perhaps one of the most important factors in encouraging coal industry R&D and innovation is a healthy, sustained rate of growth in the economy in general and the coal industry in particular. A healthy economy with lowered rates of inflation and interest would lower uncertainty, provide a financial base for R&D efforts, and encourage investment and vendor-related R&D. These benefits, tied to the effects of ERTA, would result in growth in coal industry R&D.

Even with sustained economic performance, the coal industry is unlikely to undertake innovative R&D because of industry characteristics that are unaffected by economic variables; i.e., variability of seam conditions, lack of benefits to first-time innovators, the timing of revenues and expenditures over the life cycle of a mine, and the inability of R&D to build new markets (unlike R&D in electronics). This gap in innovative R&D creates a possible area of public sector involvement.

NOTE

1. Link found that R&D for compliance with environmental regulations grew significantly during the 1970s and appeared to be negatively related to measured productivity growth in the chemical, machinery, and petroleum industries. See Albert N. Link, "Productivity Growth, Environmental Regulations and the Composition of R&D," *The Bell Journal of Economics* 13(2):548-54 (Autumn 1982).

APPENDIX A.

EXTRACTION R&D AND MINING MACHINERY VENDORS

In August 1982, the research directors at nine mine equipment manufacturers were contacted by telephone. Table A-1 lists the companies contacted, which included the largest of the mine machinery manufacturers.

TABLE A-1. VENDOR R&D COMPANIES CONTACTED

Acme Machinery	Joy Manufacturing
Fairchild	Lee-Norse
Fletcher Mining Equipment	Montgomery Mining Machinery
FMC	National Mine Service
Jeffrey Manufacturing	

Each research director was asked questions concerning his company's R&D effort during the 1970s, the present level of effort, future R&D, and the effect of the Economic Recovery Tax Act research and experimentation credit on research plans. These questions were applicable only to R&D involving deep mine coal extraction directed at improving mine productivity. The results follow.

Question 1. What happened to the level of deep mine coal extraction R&D conducted by your company in the 1970s?

Trend	Number of Companies	Percent
Increasing	7	78
No change	2	22
Decreasing	0	0

One company also indicated that growth in its R&D effort during the 1970s was very great. Two of the companies who indicated growth during the 1970s said that the level of effort tapered off in the late 1970s.

Question 2. What is the current status of your R&D program (i.e., since 1980)?

Trend	Number of Companies	Percent
Increasing	4	44
No change	2	22
Decreasing	3	33

One of the companies in the "increasing" category said its program was growing like "gangbusters" until the last two months, during which they had cut way back. Another company in the "increasing" category indicated that its growth in R&D since 1980 had been entirely due to a DOE contract and would not have occurred if it had had to use company funds. Most companies indicated that the decline in sales experienced in the industry had hurt their R&D programs.

Question 3. What do you foresee happening to your R&D effort in the future (within the next two years)?

Trend	Number of Companies	Percent
Increasing	4	44
No change	0	0
Decreasing	2	22
Don't know	3	33

Virtually all the companies indicated the future course of their R&D would depend upon sales, which are presently depressed. Companies expecting R&D to increase in the future also expected increasing sales; those who did not speculate as to direction of R&D effort indicated that it would depend on future sales.

Question 4. Has the research and experimentation tax credit of the Economic Recovery Tax Act had any effect on your company's R&D program or planning?

Trend	Number of Companies	Percent
Positive effect	1	11
No effect	8	89

Some of the companies commented on why the credit was not a factor. "ERTA had no impact--we don't do R&D if we don't have sales and profit." "ERTA had no effect--we are now doing a project that would have been done without ERTA, but now we are getting a tax credit for it." "ERTA doesn't matter--we need to make a profit first." "ERTA has no effect. We develop R&D on the merits of the idea." "ERTA doesn't matter--the tax credit is taken at the corporate level and not at the mine machinery division."

SUMMARY

Two major points emerge from these limited telephone contacts. First, the equipment vendors appear to engage in R&D in relation to the health of the market for their products. During the 1970s when coal markets were strong and demand for mining machinery was increasing, most vendors increased their R&D programs. In the late 1970s and especially in the early 1980s, a weak market resulted in cutbacks in R&D effort. Future industry R&D will depend heavily on the market for mining equipment.

The second major point is that the research and experimentation tax credit of ERTA will have limited, if any, effect on industry R&D as long as markets are weak. While the survey results suggest that for some firms the tax credit would never be an important consideration, a strong market combined with the credit might encourage other firms to increase their R&D.