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Productivity Change in U.S. Coal Mining

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with the assistance of Brian Kropp

Discussion Paper 97-40

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- PRODUCTIVITY CHANGES IN U.S. COAL MINING, by Joel Darmstadter with the Assistance of Brian Kropp (RFF Discussion Paper 97-40);

- PRODUCTIVITY GROWTH AND THE SURVIVAL OF THE U.S. COPPER INDUSTRY, by John E. Tilton and Hans H. Landsberg, RFF Discussion Paper 97-41 (forthcoming);

- THE FOREST SECTOR: IMPORTANT INNOVATIONS, by Roger A. Sedjo, RFF Discussion Paper 97-42 (forthcoming);

- CHANGING PRODUCTIVITY IN U.S. PETROLEUM EXPLORATION AND DEVELOPMENT, by Douglas R. Bohi, a book from Resources for the Future (forthcoming);

- PRODUCTIVITY TRENDS IN THE NATURAL RESOURCE INDUSTRIES, by Ian W. H. Parry, RFF Discussion Paper 97-39;

and

- UNDERSTANDING PRODUCTIVITY CHANGE IN NATURAL RESOURCE INDUSTRIES, edited by R. David Simpson, a book from Resources for the Future (forthcoming).

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Abstract

Labor productivity in U.S. coal mining increased at an average annual rate of slightly over four percent during the past 45 years. This report examines key factors contributing to that record - particularly, technological innovation in both surface and underground mining and concurrent geographic shifts in U.S. coal production. Health, safety, and environmental regulations introduced in the sixties and seventies, as well as labor unrest, interrupted long-term productivity advance; but the interruption was of limited duration. Although our principal focus is on worker productivity, steady growth in the relative importance of non-labor inputs underscores the need to consider total factor productivity. The report touches on the productivity record using that measure.

Key Words: coal mining, productivity, technological change

JEL Classification Nos.: Q41, L72, O31

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Foreword and Acknowledgments

This study of U.S.coal mine productivity is one of a number of case studies dealing with productivity and technological change in U.S. natural resource industries. (Companion studies deal with petroleum, copper, and forestry; in addition, a cross-cutting analysis considers these industries from a “top-down” macroeconomic perspective.) The work is being supported by a major grant from the Alfred P. Sloan Foundation, with additional funding from Resources for the Future.

In the preparation of this report, we benefited greatly from critical comments on an earlier draft provided by William Bruno, CONSOL, Inc. (Pittsburgh); Denny Ellerman, MIT; Hal Gluskoter, US Geological Survey (Reston); Richard Gordon, Pennsylvania State University; as well as our RFF colleagues, David Simpson and Ian Parry. Discussions at a productivity workshop in March 1997, at which that earlier draft was presented, proved helpful as well. Last, but certainly not least, we express our appreciation to those individuals in industry (both in their offices and production facilities), government, academic institutions, and trade associations who hosted visits from us or otherwise responded to our queries constructively and with generosity and patience. We especially want to thank, in addition to those already mentioned: Emil Attanasi and David Root, USGS (Reston); Steve Bessinger, CONSOL (Morgantown WV), Hector Choy, James Kliche and Terry Walsh, Thunder Basin Coal Co./ARCO (Wyoming); Eustace Frederick, retired CONSOL official; Andy Gaudielle, ARCO Coal Co. (Denver); B. D. (Willy) Hong, EIA; Charles Perkins, Bituminous Coal Operators Association; Tim Rohrbacher, USGS (Denver); Stuart Sanderson, Colorado Mining Association; Stanley Suboleski, A. T. Massey Coal Co.; Bruce Watzman, National Mining Association; and Rolf Zimmermann, CONSOL (Pittsburgh).

The fault for misinterpretation or errors in the use of any information or suggestions conveyed to us remains ours, of course. We hope readers will alert us to additional changes and corrections they feel are necessary.

Summary

This report reviews changes in U.S. coal mine productivity over the past 45 years -- a time-span long enough to encompass trends prior to, and following, an unsettling 10-year period, beginning in the late sixties, marked by labor unrest and the impact of landmark health, safety, and environmental legislation. Unlike the companion study on the petroleum industry, which concentrates principally on productivity in the exploration for and development of new reserves, this study concentrates almost exclusively on coal extraction from given reserves. The reason for this emphasis is that, notwithstanding limited expandability of coal of requisite quality in particular regions, the overall coal situation in the U.S. is one marked by vast, economically exploitable, reserves. (See section 7.)

Over the 4-1/2 decades 1950-95, coal mine labor productivity increased at an average annual rate of slightly above four percent; and that record includes a decade (1970-80) during which the level of productivity actually declined. To the extent that one regards that decade as something of an aberration, the underlying long-term rate of coal mine productivity improvement appears especially strong and steady. (See section 1.)

Labor productivity improvement has resulted from the interplay of geographic shifts and technological innovation. A pronounced shift in regional concentration of coal output from the (largely) underground mines of Appalachia and elsewhere in the East to the (largely) surface mines of the West implies in itself -- given the latter region's substantially higher productivity *levels* -- national productivity improvement even without any regional improvement. In fact, both surface and underground mining experienced dramatic labor productivity increases. Surface mining benefited from increased deployment of large electrified draglines. Underground mining benefited from the spread of continuous and, especially, longwall mining techniques. With information technology rapidly becoming an integral part of their operation, both surface and underground mines have seen the productive use of computers and remote control processes. (See sections 2 and 3.)

Steady labor productivity improvement would not mean much if capital-intensive innovations like draglines and long-wall mining equipment required such large fixed investments as to mute the rate of *total factor productivity* (TFP) improvement. As it happens, TFP (capturing the inputs of labor, capital, and other resources) has grown markedly in its own right, contributing to a steady decline in inflation-adjusted coal prices over prolonged periods of time. (See section 6.)

One reason why the period of productivity in the seventies may be regarded as somewhat anomalous is that the world oil market upheavals of the period triggered both rising coal demand as well as an expansion of coal production capacity on the expectation that the oil "crisis" might be the forerunner of enduring energy turmoil. The result, for both reasons, was

the entry of less efficient mines and miners. But that period also saw the enactment of major federal legislation (the Coal Mine Health and Safety Act of 1969 and the Surface Mining Control and Reclamation Act of 1977), compliance with which unquestionably caused at least a transitory penalty in productivity growth. The new laws (described in section 4) sought to strengthen protection against, among other things, explosive gas mixtures and vulnerable roof support systems in underground mines; and called for tightened reclamation of strip-mined lands. (As we elaborate in Section 8 of the report, coal mine gas concentrations represent a danger but, in some cases, an opportunity as well: a growing share -- now about five percent -- of U.S. natural gas production comes from coalbed methane.)

Labor unrest paralleled enactment and implementation of regulatory constraints, lowering output and compounding the negative effects on productivity noted above. Although U.S. coal mining has historically been beset with labor strife, the 1970s witnessed acute labor disruptions; these resulted in particularly large cutbacks in national coal production during 1971 and 1978. In the years since, declining oil prices have put strong pressure on the coal industry to remain competitive. The number of firms in the industry has declined, with many of the losses coming from the less efficient among those which had entered just a few years earlier. The number of mines and miners also fell. Among the employers and miners that remained, there emerged a growing perception of a mutuality of interest. Both groups see a constant threat to the role of coal on the national and world energy scene. Labor seems now to perceive labor-saving technology less as a threat to eliminate jobs, but rather as an opportunity to preserve those jobs that remain; labor strife has been, therefore, less of an impediment to productivity improvement. The fact that Western surface coal is largely mined by non-union labor should also be taken into account. (See section 5.)

U.S. coal mine productivity performance has been an important factor in giving the country a strong competitive position in world exports. Constant competitive pressure from established exporters (Australia, South Africa, Colombia) and the prospective emergence of a rationalized industry in Eastern Europe and countries of the former Soviet Union means that the productivity-trade connection is one the U.S. industry undoubtedly regards as a matter of strategic importance. (See section 10.)

The report does not attempt to project the future course of U.S. coal mine productivity, though it does address several issues likely to have a bearing on that question. For example, will returns to coal firms -- low by energy company standards in recent years -- be adequate to finance the large capital investments needed to sustain technological advance and, thereby, productivity advance in the years ahead? (See section 9.) Apprehension over future environmental constraints -- e.g. impeded access to Federally owned western coal lands or CO_2 emission limitations -- could prove to be another impediment. For what it’s worth, EIA’s projection of coal mine productivity improvement over the next twenty years, while a significant deceleration from the pace achieved following the industry’s emergence from the dismal 1970s, compares quite favorably with long-term productivity performance over the period 1950-95. And predicted productivity gains appear still healthy enough, in EIA's judgment, to maintain level, or perhaps even some continued decline in, real coal prices. (See section 11.)

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1. OVERVIEW OF PRODUCTIVITY CHANGE: PRE-1970S, 1970S, POST-1970S

The position of the coal industry in America's fuel and power picture remains one of prime importance. (See Figure 1-1.) Measured in Btu terms, the industry is the country's leading energy producer. Coal's one-fifth share of the nation's energy consumption is nearly as high as that of natural gas. Coal is the electric utility sector's principal fuel supplier, accounting for around 55 percent of electricity generated at power stations. The roughly nine percent of coal production that is exported yields annual proceeds of approximately $4 billion. Notwithstanding the industry's increasing obligation to accommodate health, safety, and environmental regulations, coal appears to retain an important competitive edge in its ability to continue serving its traditional markets -- especially the electric power sector, whose sustained coal purchases have provided most of the momentum for the industry's viability in recent decades. Absent significantly more restrictive environmentally-related "downstream" constraints -- stemming, for example, from possible restrictions on greenhouse gas emissions -- DOE's Energy Information Administration projects coal to retain its ranking importance, amidst stable or declining real prices, into the first several decades of the 21st century. Unquestionably, an important source of the industry's success has been its productivity record and the technological and other factors underlying that record.

The broad trends in coal mine productivity, highlighted in Table 1-1, provide a springboard for the detailed analysis in ensuing sections. Underground and surface mining reveal roughly parallel labor productivity trends over the past 45 years: a record of strong advance in the 1950-60 decade, maintained in the following decade by surface mining, but with some deceleration of growth in underground mines; decisive absolute declines in both sectors during the 1970s; and strong recovery for both since 1980, though it was only midway in this last period that the peak productivity levels attained by underground mining in 1969 and by surface mining in 1975 were again achieved. The nineties have seen some deceleration in the rate of productivity increase, but with a pace that still compares well with that achieved over four and a half decades.

Averaged over that 45-year time span, coal mine labor productivity -- i.e. physical output per miner hour -- shows an impressive annual rate of a bit over four percent. The fact that, over the same period, inflation-adjusted coal prices declined by nearly one percent yearly suggests that labor productivity and other efficiency improvements contributed importantly to containing production costs. The role of those other improvements is captured more explicitly

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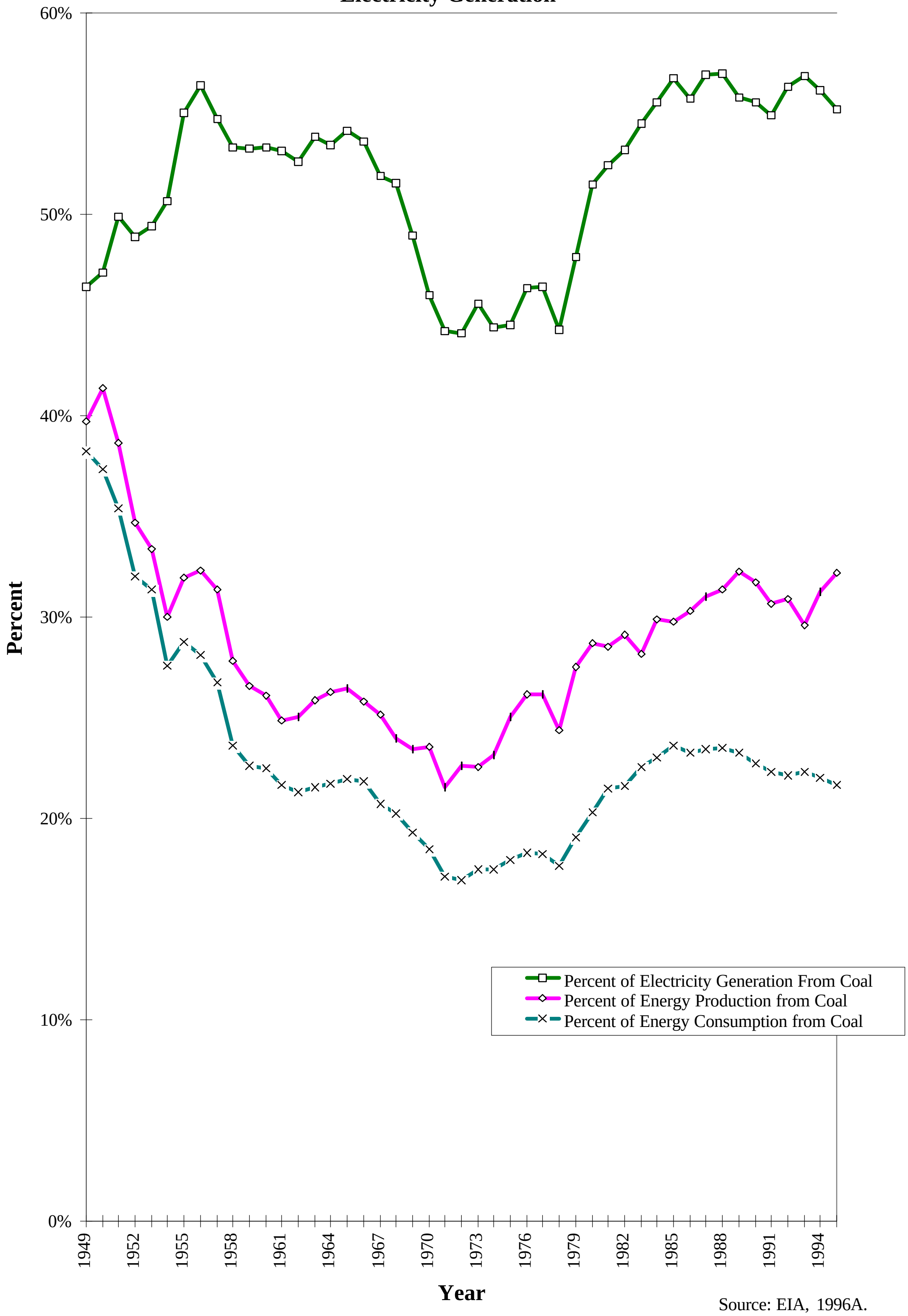
Figure 1-1
Share of Coal in U.S. Energy Consumption and Production and in Electricity Generation



Source: EIA, 1996A.

Table 1-1. Productivity Highlights

A. Average Annual Percent Changes in Labor Productivity (Based on short tons/miner day)

	1950-59	1960-69	1970-79	1980-95	1950-1995
U.S.: Total	6.5	4.0	-1.9	6.6	4.1
Surface	4.0	4.5	-3.2	6.3	3.3
Underground	6.3	2.6	-3.5	6.0	3.2
Appalachia: Surface	3.4	3.3	-5.3	3.8	1.6
Underground	6.3	-2.0	-3.2	6.3	2.3
Interior: Surface	5.5	2.9	-3.9	4.3	2.4
Underground	7.4	6.8	-5.0	5.8	4.0
Western: Surface	2.3	6.7	-1.3	5.2	3.4
Underground	2.8	1.8	-1.3	8.8	3.6

B. Labor Productivity Levels, 1995 (Short tons/miner hour)

	Surface	Underground				Total
			Room-and-pillar			
		Longwall	Continuous	Conventional	Total	
US	8.48	3.85	3.14	2.69	3.39	5.38
Appalachia	3.88	3.39	2.94	2.67	3.08	3.32
Interior	6.39	3.75	3.76	3.67	3.76	4.97
Western	18.93	6.92	4.12	2.60	6.35	15.68

C. Percent of Production, 1995

US	61.6	18.3	16.6	3.3	38.4	100.0
Appalachia	14.8	12.0	12.0	3.2	27.3	42.1
Interior	9.6	2.5	4.2	0.0	6.7	16.3
Western	37.2	3.9	0.4	0.1	4.4	41.6

D. Comparison of Labor and Multifactor Productivity Growth Rates

	Labor Productivity		Multifactor Productivity	
Time Period	Based on Short tons	Based on Btu	Based on Short tons	Based on Btu
1970-1980	-1.7	-2.4	-3.5	-4.1
1980-1994	6.5	6.2	3.3	2.8

Sources and Notes: Bureau of Mines, *Minerals Yearbook*, various years 1950-1976, unpublished EIA data for 1977-78; EIA, *Coal Production* various years 1979-1992; EIA, *Coal Industry Annual* various years 1993-1995; Regions are defined as follows: Appalachia includes AL, Eastern KY, MD, OH, PA, WV and TN. Interior includes AR, IA, IL, IN, KS, Western KY, LA, MO, OK and TX. Western includes AK, AZ, CO, MT, ND, NM, UT, WA and WY. To construct estimates for Appalachia and Interior for 1950-1980, a rough breakdown was made between East and West Kentucky, which are part of Appalachia and Interior respectively. All growth rates are compound growth rates. Multifactor productivity growth rates are from Parry (1997).

in the estimates presented in panel D of the table. These show that multifactor productivity (i.e. productivity based on *all* factor inputs -- labor, capital, intermediate goods) tracks the long-term trend recorded by labor productivity alone, though, with nonlabor inputs rising faster than labor inputs, the more comprehensive productivity measure shows markedly slower rates of increase.

The table, of course, exhibits only the aggregate and composite manifestations of many economic, technological, and policy crosscurrents at work during much of this period. Key among these, though in no *a priori* order of importance, were:

- The enactment of federal, health, safety, and environmental statutes -- principally the Coal Mine Health and Safety Act of 1969, the Surface Mine Control and Reclamation Act of 1977, and the Clean Air Act of 1970.
- Acute labor unrest, particularly during the 1970s.
- Major technological advances -- e.g. the growth of longwall underground mining and the use of ever-larger excavation equipment in strip mines, in both cases aided by increased computerization and sophisticated control systems.
- A market environment during the oil upheavals (coupled with labor strife) of the 1970s in which coal demand -- both for current consumption as well as precautionary inventory buildup -- experienced a significant increase, with consequences for the scale of, and employee experience in, mining operations -- that is, the extent to which the entry of small, normally marginal, mines and the influx of less skilled miners are likely to have held back productivity advance.

While unraveling their quantitative effect turns out to be complicated, as we shall see in subsequent sections, it is easy to speculate on the general bearing these and other factors had on coal mine productivity change, positively or negatively, transitionally or more enduringly. Health, safety, and environmental safeguards, irrespective of their longer-term benefits and the ability of the industry to adapt to them in due course, could not help but depress productivity levels and growth early on in the wake of their implementation.[1] On the other hand, impressive technological developments signaled the prospect of strong productivity boosts in both open-pit and underground mines. In the latter case, for example, note in Table 1-1 how longwall mining, with its comparatively high underground productivity level, increased its share of underground coal production from 27 percent in 1983 to 47 percent in 1995.

Amid these developments, one must also note the *aggregate* coal mine productivity implications of geographic shifts. Between 1970 and 1995, Western coal production increased its share of nationwide output from 6 to close to 40 percent; and since Western coal is dominated by high-productivity surface mining, that shift in itself translates into higher overall coal mine productivity growth. (See Figure 2-1 for more detail on regional production shifts.)

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[1] If one were to value the benefits of these safeguards as positive “spillovers” of safer and cleaner coal mining practices -- as some have urged -- measured productivity need not show the extent of the downward effect referred to.

Indeed, note from panel A of Table 1-1 that, for several of the periods shown, *nationwide* productivity growth *exceeds* the growth rates for the two sectors (underground and surface) comprising the national total. This somewhat striking phenomenon simply reflects the strength of that westward shift. During the last decade, however, the extent of that shift has slowed perceptibly.

A Note on Coal Mine Productivity Concepts

The choice of alternative coal mine productivity measures is dictated by the purpose of the analysis and availability of data. In the present study, availability–in terms of disaggregated detail and time series length–was the overriding basis for the productivity indicator used. Except for selective attention to a total factor (or multifactor) productivity measure, our indicator of choice is short tons of coal per unit of labor input. But it is useful to recognize the appropriateness of alternative productivity measures in order to indicate the effect that use of those variants would have on observed long term trends.

Output Measures

Although most widely used, an unadjusted estimate of physical output in the numerator of the productivity ratio can somewhat distort the analysis. Such an output measure is more accurate for a homogeneous product like petroleum, which has experienced relatively little change over the years in the average energy content per barrel of oil or cubic foot of gas. In comparison, the average Btu content per short ton of U.S. coal has fallen from just under 25 million to just over 21 million from 1949 to 1995, a decrease of almost 15% (EIA 1996A). Compared to output expressed in quantity terms, this decrease in heating value implies a downward adjustment in the level and rate of change in productivity. On the other hand, since the reduced heat content associated prominently with a geographic shift in coal production to western surface mines was in large part spurred concurrently by the low sulfur content of the region's coal, an offsetting adjustment designed to reflect the lower heat content would be the reduced sulfur content. (An output series expressed in constant dollars could capture characteristics like energy and sulfur content; but it would be distorted by other factors causing price gyrations and therefore inappropriate for productivity measurement.)

Unless otherwise indicated, total production includes bituminous, sub-bituminous, lignite and anthracite. At times, to preserve historical consistency, anthracite (accounting for 0.5 percent of coal production in 1995) is excluded. Similarly, in citations from specialized studies, one cannot always be certain that the production total employed in the analysis conforms precisely to the above definition.

The Input Measure

Inputs into a labor productivity measure can be based on the number of employees, shifts or worker hours. Employee numbers -- in coal mining as in other industries -- are often the most readily available and go back the longest period of time, but, for analytical reasons, are far less satisfactory than a series based on hours worked. Somewhat related, shift length as a measure of input lacks consistency through time. From 1986 to 1995, the average number of hours per shift per miner has increased by 5 percent. Illustrative of that transformation at the individual mine level is the fact that in 1992, at the Freedom mine in North Dakota, the shift length changed from 3 eight hour shifts, 5 days per week, to 2 ten hour shifts, 6 days per week (*Mining Engineering* April 1995, p. 336). Latitudinal comparisons are distorted because there is no consistent measure of shift lengths across mines, regions or firms. Miner hours thus provide the most appropriate basic measure of labor input. The hours worked do not, however, include all employees of the coal industry. The employees that are included are those involved in the production, processing, preparation, development, maintenance and repair including engineering and technical professionals (EIA, *Coal Industry Annual 1995* 1996, p. 74). Typically, purely administrative and research functions -- whether at the mine or offsite -- are excluded from worker hours. A deeper analysis of labor input would take into consideration changes in skills and education.

As well, a more comprehensive series of total inputs would contain capital services and intermediate goods. A tentative effort to construct such a series yields the total factor input series charted in the accompanying figure.[2] The intermediate goods components of the total factor input series include energy, purchased services, and raw materials used. The capital series is constructed using a perpetual inventory method and contains the volume of structures, equipment, and land used.

Resultant Productivity Measures

The bottom panel of the accompanying figure shows various measures of productivity for the coal industry. These measures are the result of dividing various output series by various input series. Differences in the rates of change depend on the output and input variant used, but the common trend, as addressed in the main text, is productivity decline and stagnation during the 1970s, followed by a sharply increasing rate of growth for much of the period thereafter. The figure indicates that growth in output per miner and output per miner hour substantially exceed growth based total factor productivity. But this is as we would expect, since part of the boost to labor productivity is greatly increased capital.

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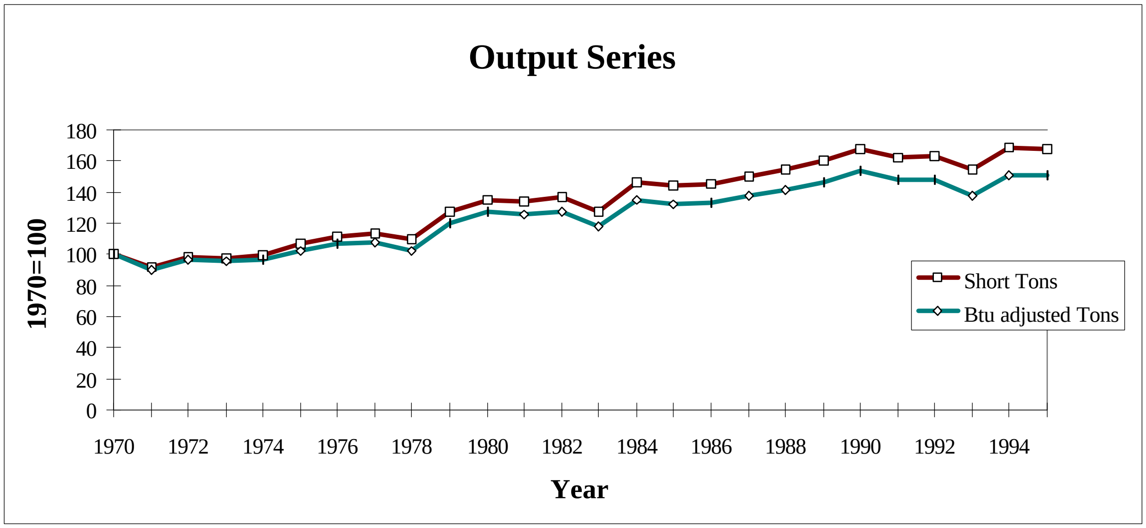
[2] For a complete discussion of the derivation of the total factor input series see Parry (1997).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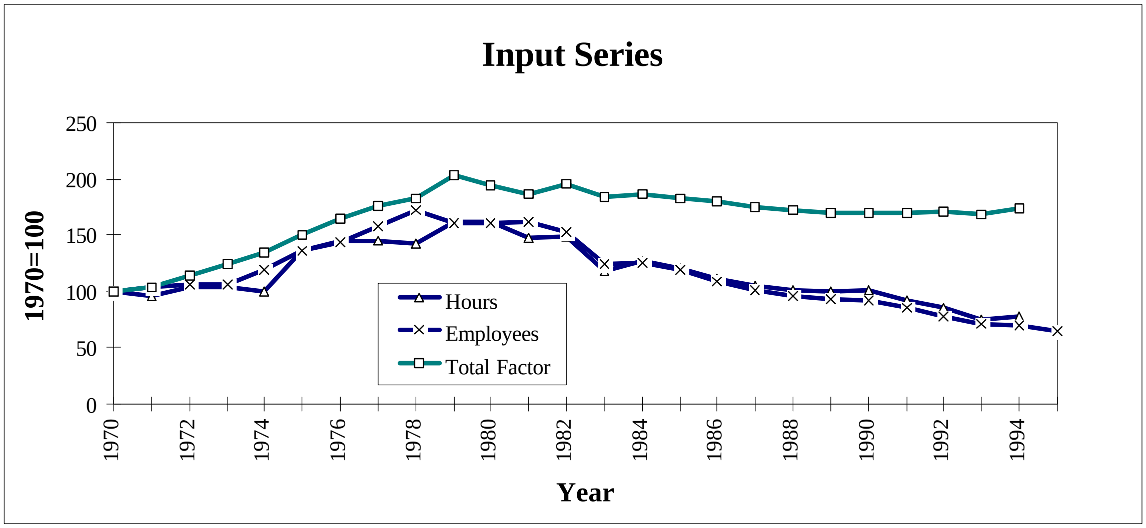
Year
Short Tons
Btu adjusted Tons


Input Series
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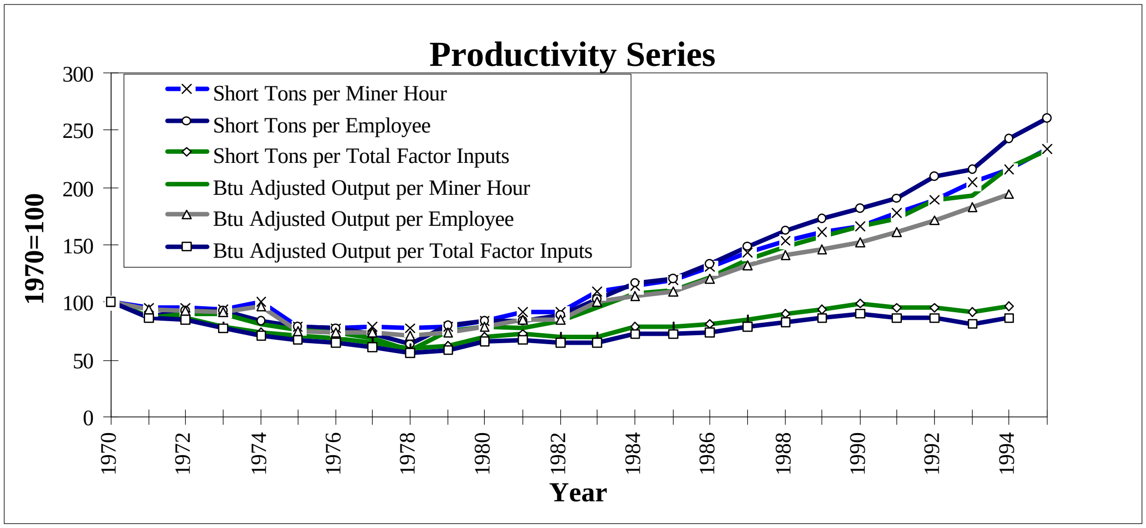
Year
Hours
Employees
Total Factor


Productivity Series
1970=100
Year
Short Tons per Miner Hour
Short Tons per Employee
Short Tons per Total Factor Inputs
Btu Adjusted Output per Miner Hour
Btu Adjusted Output per Employee
Btu Adjusted Output per Total Factor Inputs

2. TECHNOLOGICAL CHANGE: SURFACE MINING

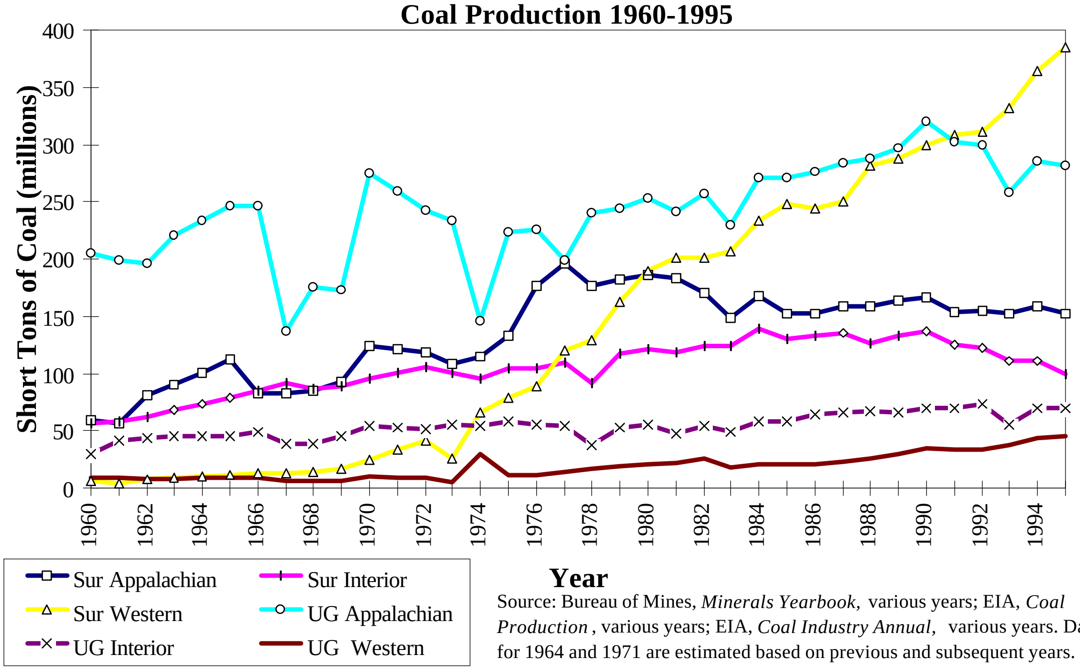
By 1974, surface mining had decisively surpassed underground extraction in its share of total U.S. coal production. Relative shares, at decadal benchmarks, are shown below (EIA 1996A):

	Underground	Surface
1950	75%	25%
1960	67	33
1970	56	44
1980	41	59
1990	41	59
1995	36	64

By nationwide standards, surface coal -- centered on production in Western states, as evident in Figure 2-1 -- is relatively low in energy content. But even when expressed in Btu terms, surface mined coal still makes up around 56 percent of the U.S. aggregate. In spite of the relatively low calorific value of Western surface-mined coal, the dual attributes of high productivity and low sulfur content -- the latter factor becoming a significant consideration after passage of the 1970 Clean Air Act -- endow the region with a strongly competitive coal industry. Figure 2-2, shows that prices at the mine are reflective of that fact: in 1995, coal prices averaged $10.15 per short ton in Western states, $18.81 in the Interior coal-mining region, and $27.45 in Appalachia. Although Western coal's principal market remains the West itself, the West's price advantage was decisive enough to allow the region to compete, on a *delivered* price basis, in markets a thousand or more miles to the East. For example, in early 1996, some 30 percent of coal deliveries to Michigan's electric power stations originated in the three states of Wyoming, Montana, and Utah. In fact recent analysis by Stanley Suboleski gives a 930 mile distance advantage to Western surface mines over Appalachian underground mines, after adjustment for operating costs, royalty payments and taxes, and assuming equal quality of coal (*Mining Engineering*, July 1995, p. 659; additional information on transport costs appears in *Mining Engineering*, Dec. 1995, p. 110.)

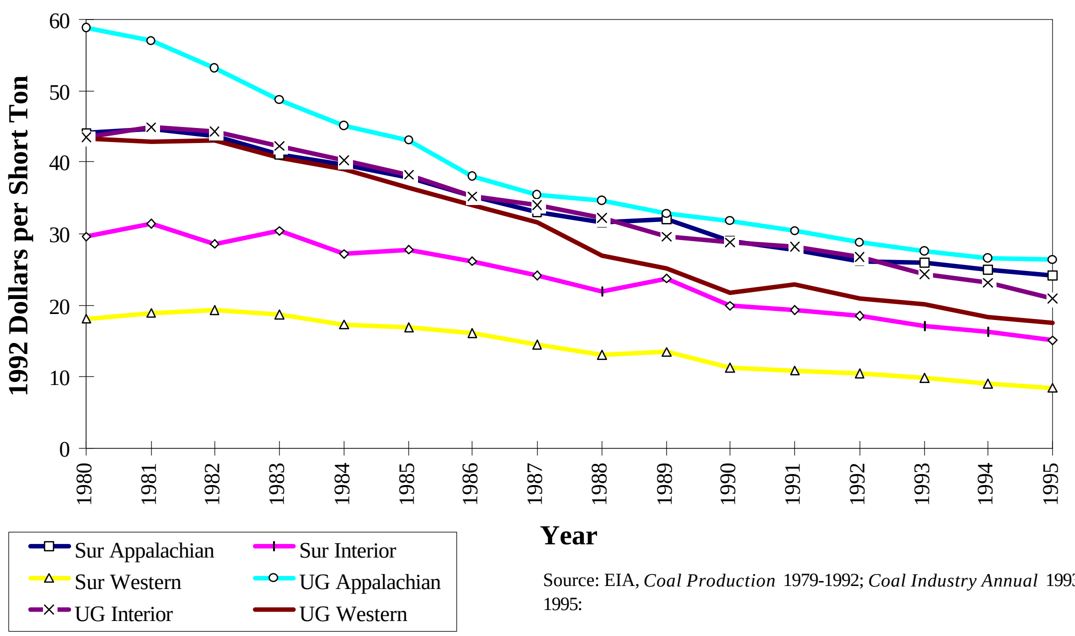
The West's successful penetration of Eastern markets dates basically from a quarter century ago. Until 1970, coal tonnage moving from west to east of the Mississippi was essentially zero. In 1971, 4-1/2 million tons were shipped and by 1976, the volume was up to 26 million tons. (Energy Modeling Forum 1978) What lay behind this rapid expansion were -- interrelatedly -- the increased importance of environmental concerns, especially the low-sulfur provisions of the 1970 Clean Air Act, which would have been costly to accommodate exclusively with Appalachian coal; the startup of transport by unit trains, dedicated solely to carrying coal; and, notwithstanding lack of competition in rail transport out of the area, the

Figure 2-1
Coal Production 1960-1995



Source: Bureau of Mines, *Minerals Yearbook*, various years; EIA, *Coal Production*, various years; EIA, *Coal Industry Annual*, various years. Data for 1964 and 1971 are estimated based on previous and subsequent years.

Figure 2-2
Coal Prices 1980-1995



Source: EIA, *Coal Production* 1979-1992; *Coal Industry Annual* 1993-1995:

stability during the 1970s, in real terms, of average rail freight charges, then still under ICC regulatory control and the continuing decline of all forms of coal transportation costs in the 1980s and 1990s. (In 1990 dollars, rail transportation costs have declined from 24 mills/ton-mile in 1979 to 15.4 mills/ton-mile in 1993) (EIA 1995A). In order to increase output from the Powder River Basin, the two main railroads that haul coal out of the area,[3] Burlington-Northern-Santa-Fe and Union Pacific-Southern Pacific, have significantly increased investment into this region by not only increasing track miles, but also increasing the number of double and triple track miles laid.

An additional factor that has contributed to the increased production of western coal is the increased demand for electricity. Some electric utilities established coal-producing subsidiaries or joint ventures in the West to provide coal. Other electric utilities went so far as to build power plants at the mine mouth with the coal company committed to supplying the lifetime requirements of the utility plant. The only mines large enough to meet the lifetime requirement of the power plant were large Western surface mines (EIA 1992).

Productivity has without doubt been a central element in the trend towards surface mining generally and the exploitation of Western open-pit mines in particular. By 1994, the level of labor productivity in Western surface mines -- dominated by Wyoming, the nation's largest coal-producing state -- was over 3-1/2 times as great as nationwide coal mine productivity overall and over 2-1/2 times as great as productivity in Western longwall mining -- itself impressively high by the national norm. (See Table 1-1.)

Specific factors aside, productivity change in surface mining has been driven by phenomena it shares with underground mining. That is, years during which productivity recorded poor performance or a decline were strongly affected by the transitional need to adapt to significantly changed environmental and related regulations. Periods of strongly advancing productivity -- the predominant experience during most of the last 45 years -- are associated with continued technological improvement, in the scale and character of the capital inputs into the extraction process as well as the skills of the personnel responsible for operating that equipment. An exceptionally dramatic case in point is ARCO's Black Thunder mine in the Powder River Basin of Wyoming, whose annual output of some 40 million tons with a cadre of only 500 workers (including those at the coal face and others) underscores the marriage of machinery and skills that is the hallmark of a modern surface mining operation. (Nationally, surface mines produce an average of under 60,000 tons annually, with output per miner about one-quarter the level of Black Thunder).

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[3] In the seventies, Burlington Northern (now merged with Santa Fe) was the only shipper; presently, the other shipper is Union Pacific (with which Southern Pacific has merged). Additional competition may be in the offing. The Dakota, Minnesota, and Eastern Railroad Corp. has announced plans to try and secure financing for a "$1.2 billion, super-freight hauling line" connecting the coal fields of northeastern Wyoming with the Midwest (*Wall Street Journal* 1997).

In its simplest characterization, surface mining involves the extraction of coal that is exposed once the overburden of earth or rock has been removed. Typically, the coalbed lies within several hundred feet of the surface. If that description implies a mining operation that is deceptively straightforward, the following passage should dispel any such notion.

> Underground coal mines tend to differ mainly in terms of seam thickness with virtually the same type of equipment and mining plan in each (the exception being the division between longwall and non-longwall mines). Surface mines, on the other hand, tend to differ by mining methods (single-pass contour, multi-pass contour, mountaintop removal, and area stripping, for example) as well as by mix of equipment (such as large draglines vs. small draglines, truck-shovel, front-end loaders, dozers, or combinations of this equipment in the same operation). Operating methods add more variety. For example, the dragline may work on the highwall side or the spoil side; it may also, through the use of extended benches, effectively work in between. Likewise, spoil may be casted using explosives, a dragline bench may be dug entirely by the dragline, or a significant part may be prestripped. (Mutmansky and others 1992, p. 2080)

The particular way in which a coal extraction technology is deployed depends on the topography of the mine site -- specifically on whether the location lends itself to “area mining” or “contour mining.” Area mining is used in near-level terrain. Draglines are the dominant technology used to remove the coal and overburden in the area. Once the coal is removed, the overburden is replaced and then the process is repeated until the entire extraction area can no longer be profitably mined. Contour mining is mostly used in mountainous and hilly terrain. The most common variation of contour mining is block-cut mining. In this technique a box or block cut is made as close as possible to the center of the mining area. The coal is removed from this area, then the overburden from the second area is used to fill the hole from the first area, and so on. Again, draglines dominate the production process.

Even while appreciating the need to discriminate among the various features brought out in the preceding paragraphs, one can readily identify some of the broad characteristics and general forces underlying surface mine productivity change and levels. Unlike underground mining, there has not been the dramatic change in type of technology used, i.e. movement from room-and-pillar mining to longwall mining. The technological process that has occurred to increase productivity has been the progressive improvement of existing equipment augmented by the introduction and gradual enhancement of some new technologies. Thus, the last several decades have seen the evolution of the extraction process from one relying primarily on truck-shovel technology to one employing draglines in conjunction with truck-shovels. At the same time, the capacity of the equipment has been growing, with draglines, for instance, progressing from mobile, diesel-powered units to more powerful “walking” types connected to the electricity grid. In recent years, various phases of surface mine production have also been facilitated by computerization. For example, dragline operations can be positioned and directed with computer-aided analyses of seam thickness and characteristics, global positioning systems have been applied to the truck fleet to improve its performance; while post-production costs can be contained by computerized systems in coal-processing and unit train-loading stages.

Improvements in the equipment used in surface mining have also contributed to improved productivity at the coal face. Increased computing power has allowed manufacturers to more efficiently design, test and build equipment. Not only have manufacturers improved the overall level of equipment, but by building equipment to suit specific geological characteristics of coal seams, recovery has also been enhanced. These improvements in technology have allowed draglines to "fill faster, more easily and more completely." (White 1995) One estimate of the increased productivity from improved surface equipment ranges from 10 to 25%. This estimate includes improvements to draglines, shovel trucks and the interaction between the two (Pippenger 1995).

In short, the complementarity of computerization with advances in the scale and nature of the equipment represents a development of key significance. Information technology and instrumentation -- coupled to vast increases in horsepower of equipment -- has facilitated the logistical coordination of a variety of stages in the mining operation: cutting, conveying, loading, transport and a myriad of other activities that occur at a modern surface mine.

The economic benefits of these technical advances are, of course, enhanced when coupled to favorable geologic features -- notably, a low "stripping ratio" of overburden to coal, a characteristic particularly associated with Powder River Basin coal beds, referred to earlier. The stripping ratio refers to the amount of overburden that needs to be removed in order to gain access to a given amount of coal. Often expressed in physical volume of material per ton of coal, it is sometimes expressed as well as a ratio comparing the thickness of overburden with that of the coal seam. Intuition would point to the stripping ratio as one important element governing total factor productivity and, thereby, production cost in surface mining. A 1989 nationwide sample survey of 39 surface mines (as reported in the cited study by Mutmansky and others) sheds empirical light on the importance of the stripping ratio: the lower its value, the lower average coal production cost.[4] The converse -- the risk to profitability of a high stripping ratio -- is lent at least anecdotal support by the experience of American Electric Power's Muskingum (Ohio) mine, which -- now closed -- should, in the judgment of one observer, never have been opened, given its high stripping ratio.[5]

In Section 1, we saw that surface mining labor productivity had advanced strongly throughout the coal producing regions of the country. The rate of increase was greatest in the West, but significant as well in Appalachia and the Interior region. Whether conditions are favorable for continued nationwide productivity performance of similar or more modest

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[4] The statistically-significant R^2 value is 0.36.

[5] Comment made at the March 1997 workshop at which a prior version of this document was reviewed.

dimensions is problematic. (We revert briefly to this point in Section 11.) Experts have raised questions, in particular, as to whether Eastern coalbeds can be brought into production without the incurring of heavy upfront capital expenditures and the backend reclamation requirements to the extent seemingly feasible in the West. The benefits of scale economies may also be starting to pinch. Experience with ever-larger dragline deployment in mountainous parts of Appalachia appear to have led to some dampening in enthusiasm for significant surface mine expansion. Retreat from the large dragline/surface mine option would have special appeal to firms whose alternatives include startup of a large capacity longwall operation.

3. TECHNOLOGICAL CHANGE: UNDERGROUND MINING

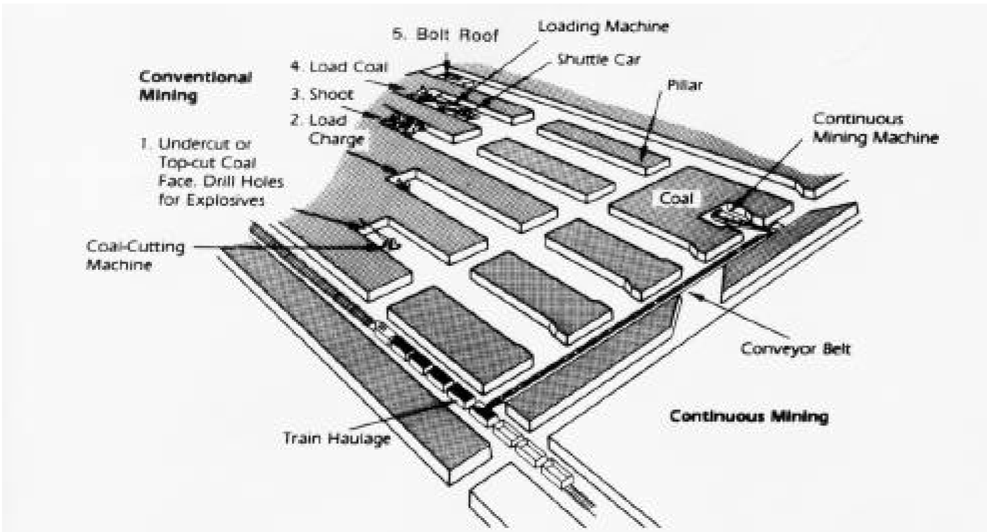
Some Technological Basics

Although a variety of factors have contributed to the strong productivity record achieved in underground mines within the last several decades, perhaps the most significant of these has been the emergence of longwall mining technologies. In 1995 longwall mines produced 189 million short tons of coal, about 45 percent of underground coal production, in contrast to their 20 percent in 1983. (See Table 1-1.) To appreciate the significance of this development, we need to keep in mind that the norm throughout most of the coal industry's history has been the "room-and-pillar" extraction method. Here, the mine roof is supported primarily by pillars of coal dividing the "rooms" which have been cut into the coalbed and where mining takes place. (Fig. 3-1 helps bring things to life.) To be sure, even room-and-pillar mining has seen notable technological progress; witness the steadily increasing use of "continuous" mining machines which -- dating from around 1950 -- extract and remove coal from the face in a single operation, in contrast to "conventional" methods employing a series of separate blasting, removal, and loading operations.

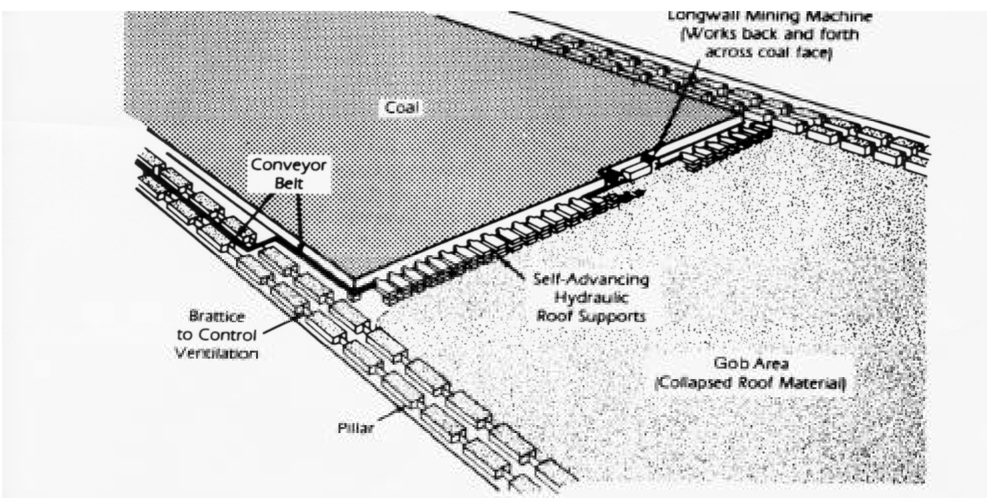
In fact, the arrival, nearly 50 years ago, of the continuous miner was in its way more of a technological leap forward than the ensuing introduction of longwall extraction. The latter -- whose significance we discuss momentarily -- represented a jumping-off from continuous mining machines, described by Schurr and Netschert (1960, p. 312) in their pioneering study as "a technological revolution comparable to the earlier introduction of 'mechanization.' " It was the prospect of thinning coal seams which, according to Schurr and Netschert, provided further stimulus to finding ways ensuring greater coal recovery than seemed possible under room-and-pillar practices. Although alarm over thinning seams turned out to be premature -- the potential of Western surface mining had barely begun to be tapped -- development of longwall mining technology was given an important spur forward.

Figure 3-1. Underground Mining Systems

(a) Room-and-Pillar Mining



(b) Longwall Mining



Source: EIA 1995B, p. 4.

As it happens, longwall mining, with an average recovery rate of around 57 percent, succeeds in extracting only a modestly higher proportion of the coal in place than does room-and-pillar mining.[6] However, the longwall recovery operation tends to be substantially more efficient. [In what follows, considerable reliance was put on EIA (1995B.] Longwall mining involves extraction of virtually all the coal contained on a wide rectangular panel, using equipment that allows the roof over the mined-out area of the mine to collapse. (While longwall mining is, no more than room-and-pillar mining, spared the eventuality of subsidence, the problems it poses are lessened under longwall conditions, where subsidence is more easily controlled.) The area covered by a longwall mining operation has expanded over the years; by 1993, 82 percent of longwall units had a width exceeding 600 feet compared to just 12 percent in 1984 An important factor facilitating that development was the improvement in longwall extraction equipment, especially an approximate doubling in horsepower of both cutting machines and face conveyors. These days, a typical dimension is that of a wall panel measuring some 800 feet wide, with the length of the longwall unit extending about 7000 feet, all at a height averaging 7 feet. Coal is extracted at a depth -- i.e. thickness -- of about 3-1/2 feet. After an initial "blocking out" of a longwall unit (using continuous mining machinery in a room-and-pillar operation),

> (e)xcavation of the coal in the panel is an almost continuous operation. Working under the steel canopies of hydraulic, movable roof supports, a coal cutting machine runs back and forth along the 800-foot face, taking a cut ranging anywhere from a few inches to 3-1/2 feet deep during each pass. The cut coal spills into an armored chain conveyor running along the entire [width] of the face. This face conveyor dumps the coal onto belt conveyors for transport out of the mine. As the cutting machine passes each roof support, the support is moved closer to the newly cut face to prop up the exposed roof. The roof is allowed to collapse behind the supports as they are advanced towards the face. Mining continues in this manner until the entire panel of coal is removed (EIA 1995B, p. vii).

Significant adoption of longwall mining in the United States dates only from the 1950s and 1960s, when the introduction of coal-cutting machines pioneered by the Germans served as a spur to American R&D (in part supported by the U.S. Bureau of Mines) and efforts at commercialization. (Additional discussion of the international context appears in Section 10.) Prior to that time, longwall mining -- although understood in principle and employed sparingly -- could not compete with room-and-pillar mining; indeed, its labor intensiveness in early applications was the very antithesis of its labor-saving characteristics today.

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[6] For room-and-pillar recovery rates to approximate those in longwall mining requires a practice called “retreat” mining. Here, once coal has been extracted from the rooms, it is removed from the pillars before the roof is allowed to fall.

Table 3-1. Ratio of Longwall to Room-and-Pillar Labor Productivity Levels, Selected States and Regions, 1983 and 1993

	1983	1993
Alabama	1.06	1.33
East Kentucky	0.85	1.35
Pennsylvania	0.91	1.62
Virginia	0.73	1.01
West Virginia	1.14	0.97
Illinois	1.25	1.12
West Kentucky	___	0.75
Colorado	0.84	1.54
Appalachia	0.98	1.10
Illinois Basin	1.19	1.00
West	1.11	1.51
U.S.	0.98	1.19

Source: EIA 1995B, pp. 39-40. (West Kentucky had no longwall production in 1983.)

Productivity

The relatively high labor productivity levels commonly achievable in a contemporary longwall, compared to room-and-pillar, mining operation (see Table 3-1) is strongly related to the highly mechanized nature of the operation, including opportunities for a significant degree of computerization and substantial continuity in the extraction process.[7] In addition to improving the cutting process, longwall miners, by using a continuously hauling conveyor system as opposed to a relatively more labor intensive shuttle car system with continuous miners, are able to increase the rate at which coal is taken to the mine mouth. All these factors combine to make longwall mining surprisingly non-labor-intensive. In a prototypical Eastern mine producing three million tons annually and employing 350 workers, only about 10 percent of the work force operates at the longwall face itself. Less hypothetically: CONSOL's Enlow Fork longwall operation in Pennsylvania -- the nation's largest underground mine, with longwall dimensions of 1000 by 10000 feet -- produces 8-9 million tons annually with a workforce of some 300 persons. (On an annual output-per-miner basis,

[7] However, note from Table 3-1 that longwalls' superior labor productivity does not extend over all states and regions.

this works out to over four times the national underground average; but Enlow Fork appears to be a top performer in labor productivity.)

While the growing dimensions and horsepower of longwall mines went hand in hand with rising productivity, they were not the only factors at work. Improvements in mobile roof supports ("shields"), which follow behind the longwall miners and allows the mined-out area (called "gob") to collapse, have allowed the longwall miner to increase the speed at which it moves through a coal face. Improved and computerized interaction between roof supports and cutting machines have decreased the number of mis-cuts that occur. This is not the only place where the progressive reliance on automated processes has had an effect on productivity. Parallel advances have increased the efficiency with which coal is transported from the coal face to the mine mouth.

The automated technology of the roof support system takes 10-12 shields through a batch process that is controlled by one device. As described by Thomas Barczak, this process allows for increased speed in the movement of the longwall drilling machine, and elimination of the shield operator, in turn, increasing output and decreasing risk (*Coal* 1990, pp. 65-66). Additionally, improved automation of the roof support and longwall miner create an even and consistent repetition of the longwall cycle. Some experts estimate that avoiding even a few inches lost per longwall pass in a non-automated operation can result in savings of up to one day a week (Sanda 1991).

To some extent, longwall mines are also able to take advantage of a somewhat greater menu of possible mining locations relative to the room-and-pillar technique. Due to the more important role of roof supports, room-and-pillar mines are only able to work at depths up to 1,000 ft. At depths greater than this, the need to make the pillars larger generally causes the mine to become less efficient. Longwall miners, not needing the pillar roof supports, are able to work at mines of much greater depth, increasing effective utilization of the resource base, and hence increasing productivity through this exploitation of the intensive margin (EIA 1995C). At the same time, though, a prospective longwall site must meet certain necessary physical requirements -- among them, a large enough area, a solid coal formation, and structural features ensuring viable development of the roof.

In short, numerous factors distinguishing longwall, in contrast to room-and-pillar operations, helped boost productivity. Aside from increasingly computerized processes, the enlargement of longwall panels increased the quantity of recoverable coal and reduced the downtime associated with shifting equipment from mined-out to new panels. And as we have already noted, the capacity of equipment increased significantly, the doubling of horsepower during 1984-93 effectively capitalizing on the concurrent increase in face widths and allowing longwall extraction to tap into thicker seams in mines of increasingly large size. Between 1984-93, the proportion of longwall mines producing over one million tons of coal went from 47 to 70 percent. In 1993, only four percent of room-and-pillar mines exceeded the one-million mark.

These developments provided an important thrust to advances in longwall labor productivity, which, between 1983-95, more than doubled -- from 1.59 to 3.85 short tons per miner hour. Room-and-pillar productivity went up as well, but while (as seen in Table 3-1) the nationwide longwall productivity level was two percent below the room-and-pillar level at the start of the period, it was 19 percent higher at the end.

As with other aggregates, this average U.S. longwall vs. room-and-pillar productivity picture varies regionally, as witness the large gap for the West, contrasted with only a slight margin of advantage for longwall in Appalachia. EIA conjectures, in this connection, that the disproportionately large share of Appalachian coal destined for metallurgical and export markets involves a sufficiently greater degree of preparation as to engender some sacrifice in productivity and output.[8]

To be sure, longwall mining presents a number of problems along with its advantages. Size and capital intensity, already referred to, translate into large up-front investment requirements. Productivity during the start-up blocking-out phase -- a room-and-pillar operation -- is typically low. Longwall mining generates substantial amounts of dust and gas that need to be controlled.[9] However, in general, they have better ventilation than room -and-pillar mines. They also have superior safety performance due to reduced personnel at the cutting face. Nevertheless, even in regions where longwall productivity isn't that much superior to room-and-pillar operations, as in the Illinois basin and Appalachia, longwall mines are getting much of the new investment. Evidently, the potential for technologically-driven increases in future productivity growth is viewed as highly promising. The basis for such optimism is discussed in the concluding part of this section.

We commented earlier on the labor productivity performance in longwall mining. A literature search has failed to turn up a corresponding record based on total factor productivity (TFP). Given the enormity of the startup and deferred capital cost requirements, it would be useful to have a sense of what the relatively capital-intensive nature of a longwall mining operation signifies for that more comprehensive productivity measure. A very rough estimate of the ratio of annualized capital to labor costs in the prototypical Eastern longwall mine cited already is about 4-to-3. (Calculated from data shown in EIA 1995B, pp. 43-46.) The least that one can say is that longwall mining has largely demonstrated its economic viability in the context of the low coal price regime that has prevailed in the past fifteen years or so. If only by crude inference, that speaks positively of TFP's role, no less than that of labor productivity, in sustaining the industry's competitive strength over that period.

From the Past to the Future

However striking the productivity-enhancing technological developments in longwall mining over the past several decades, improvements have been evolutionary and incremental,

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[8] Though, as Richard Gordon has pointed out to us, even if such a “measured” productivity sacrifice were incurred, the fact that preparation yielded higher *quality* output would signify no necessary loss in “true” productivity.

[9] An industry observer questions whether longwall mining poses unique problems in this regard.

and more quantitative than qualitative in character. Even computerization with its obvious importance, has to a large extent had discrete rather than pervasive impact, as in the case where high-capacity shields (i.e. movable roof supports) governed by electrohydraulic control systems have replaced manual operations. Describing the current state of play and possibilities for the future, the EIA analysts write:

> Longwall equipment has gained significantly in power, robustness, and reliability, as measured by such quantitative parameters as horsepower and downtime; but despite these changes, longwall mining has retained its basic nature and operating characteristics. One new development looming on the horizon, however, has the potential to change the fundamental nature of longwall mining as it is practiced today: automation (EIA 1995B, p. 47).

Indeed, EIA's ensuing exposition illustrates various instances in which the use of robotics and substantially greater automated operations at the longwall face than at present have already begun to appear. As reported by EIA, the seemingly cornucopian benefits of increased automation claimed, for example, by a CONSOL expert for one of the company's mines

> ...include increased longwall availability, improved productivity, lower supply costs, improved clean coal yields, reduced exposure of workers to respirable dust, better utilization of available workers, improved management control and communication, increased coal recovery, improved roof control, reduced maintenance and ownership costs, improved trouble-shooting, and early warning of some equipment failures (EIA 1995B, p. 50).

While technological optimism can be contagious, it can also be hazardous -- if not to one's health, then to one's forecasting reputation. Nevertheless, the penetration of a much more pervasive degree of automation appears to offer the basis for significant future productivity improvement in longwall mining.

Of course, a number of complementary conditions and factors must come into play for longwall mining to meet such potential. Industry representatives canvassed by EIA elicited certain concerns and pointed to some uncertainties. For example, there may be "...economic limits to the continued expansion of the longwall panel. At some point, the additional capital costs of widening the face will exceed the benefits resulting from improved productivity." (p. 57) While firms with large and rich-seamed holdings expect to meet perceived capacity expansion needs via longwalls, producers with small or thin-seamed holdings are likely to opt for room-and-pillar development. In that case, the need for continuous miners with improved cutting rates becomes important. (The lack of such improvement can also hinder the degree of *longwall* expansion since, as noted earlier, continuous mining equipment is used in the development phase of a longwall project.)

There is, finally, the unpredictability of regulatory policy changes which could affect the economics, and therefore productivity, of both longwall and room-and-pillar mining. Dust control, methane recovery, groundwater integrity, and subsidence protection all pose greater or lesser uncertainty on the policy side. As just one example, subsidence is technically inherent in longwall mining (one implication of which is the risk of costly settlements with owners of surface property) but need not be inherent in room-and-pillar mining provided pillars are left standing rather than mined prior to collapsing. One can see where this could be at least one consideration in determining the economic balance of advantage between one or the other mining strategy.

4. HEALTH, SAFETY, ENVIRONMENT

Each of the three items bracketed together for the purpose of this discussion has distinct features and could be individually addressed. For example, one associates the health issue prominently with black lung disease or hearing loss, safety with roof cave-ins, subsidence or methane explosions, and environment with acid mine drainage or unreclaimed spoils from open-pit mining. What allows this across-the-board treatment are two considerations -- the first, conceptual; the second, policy related. From a conceptual point of view, the questions arises as to whether, and to what extent, some of the health-safety-environmental impacts of coal mining fit the notion of "externalities" -- at least for years preceding statutory requirements for dealing with such problems (see below). That is, were the costs of dealing with, or averting, these impacts borne by society at large or the affected individuals rather than being financially accounted for -- "internalized" -- in the operations of the mining firm? If the former, output and productivity of the firm and of the industry might, to some hard-to-quantify degree, be overstated because certain costly damages from coal mining failed to be reflected as an offset to the value of production. On the other hand, it is also likely that, if not environmental effects, then health and safety risks were known to workers who were able to command at least some wage "premium" as compensation for such risks. (Unlike the "company-town" milieu of the nineteenth century, labor was not wholly devoid of bargaining power.) Also, assuming that firms were not indifferent to having a highly skilled employee lost, they would have invested in some amount of health and safety protection, motivated in part by fear of litigation whose increased costs probably prompted firms to increase health and safety expenditures to avoid law suits. Insofar as both of these conditions were met -- and one can surmise that being the case to at least some extent -- internalization was correspondingly achieved and economic performance measures not entirely distorted.

On the policy side, landmark legislation introduced in 1969 and 1977 -- and the backdrop to these statutes clearly included the public concerns and perceptions stemming from the impacts just noted -- imposed major requirements across a broad range of coal mine operations impinging on health, safety, and the environment. The main federal initiatives were the Coal Mine Health and Safety Act (CMHSA) of 1969 and the Surface Mining Control and Reclamation Act (SMCRA) of 1977. (Additionally, and somewhat less directly, the

Federal Water Pollution Control Act of 1972, subsequently incorporated into the Clean Water Act of 1977, dealt with the impact of coal mining and preparation on water quality; while provisions in the Federal Clean Air Act of 1970 helped spur the shift to low-sulfur Western coals.) Among its numerous provisions, the CMHSA addressed such hazards to life and limb as explosive gas mixtures, the integrity of roof support systems, and respirable dust concentrations. Additional legislation, the Federal Mine Safety and Health Act, was passed in 1977. It provided for increased federal mine inspections and created the Mine Safety and Health Administration (MSHA) in the U.S. Department of Labor. Since this time, MSHA has taken over monitoring responsibilities of coal mine health and safety regulations. The two major items covered in the new legislation were coalface illumination standards and "walkaround" provisions, which obliges a worker to accompany a federal mine inspector. The accompanying box (Box 4-1) provides a brief description of some of the major events in the legislative history of coal mining.

Box 4-1.

1910 Establishment of the Bureau of Mines (BOM).

1941 Congress empowered BOM inspectors to enter mines.

1947 Congress authorized the formulation of the first code of federal regulations for mine safety.

1952 The Federal Coal Mine Safety Act provides for annual inspections in a limited number of underground coal mines, and gave the BOM limited enforcement authority.

1966 Congress extended coverage of the 1952 Coal Act to all underground coal mines.

1969 The Federal Coal Mine Health and Safety Act requires two annual inspections of every surface coal mine and four at every underground coal mine. The act also required monetary penalties for all violations, and established criminal penalties for knowing and willful violations. The safety standards for all coal mines were strengthened, and health standards were adopted.

1973 The Secretary of the Interior creates the Mining Enforcement and Safety Administration (MESA) as a new departmental agency separate from the BOM.

1977 Congress passes the Federal Mine Safety and Health Act and the Surface Mining and Control Reclamation Act (SMCRA). The Federal Mine Safety and Health Act consolidated all federal health and safety regulations of the mining industry, coal as well as non-coal mining, under a single statutory scheme. The act also created the Mine Safety and Health Administration (MSHA). Some of new regulations from SMCRA increased surface mining performance standards and regulations, provided for the assessment and collection of reclamation fees, and required restoration of mining acreage on federal lands.

Figure 4-1 plots 60-year trends in coal mine fatality and injury rates.[10] There has been a long-term decline -- though by no means an unbroken one -- in the fatality incidence rate, measured in fatalities per 200,000 work hours, for all coal mining since 1931. Following the adoption of the CMHSA in 1969, the rate of decline accelerated and continued throughout the 1970's. For example, the coal mining fatality rate declined from around 0.17 fatalities per 200,000 hours worked in 1969 to less than 0.04 fatalities per 200,000 hours worked in 1995 -- a drop of over 75 percent. What is not clear is how much of the drop was a continuation of the already declining rate or how much was due to the adoption of the Act. While the injury incidence rate, defined as the number of injuries per 200,000 hours worked, has also declined substantially since 1931, we do not see the same decline as the fatality rate. This is not surprising. While a fatality is a fatality, it could be the case that before adoption of the CMHSA, there was chronic underreporting of the number of injuries. One could argue that one element in the fatality- and injury-rate declines in recent decades was the shift to Western surface mines with their inherently safer worker conditions. However, it turns out that the trend plotted in Fig. 4-1 applies fairly consistently across the geographic landscape.

In the case of both fatalities and injuries, the long-term decline has been accompanied by substantial year-to-year variability. Very likely, fatality and injury variability is conditioned by the infrequent-event nature of the phenomenon, such as the 1968 Farmington WV disaster, which killed 78 miners. Even with this acknowledgment, it would be good to have a persuasive explanation for the rather conspicuous cyclical ups and downs for the injury plot since roughly the mid-seventies. But no ready answer suggests itself.

In one respect, the actual data most likely underestimate the actual effect of the CMSHA and its amendments. The legislation is not only designed to decrease immediate injuries and fatalities, but to also decrease them in the long run. Some of the regulations include limitations to noise and dust exposure and are designed to decrease the incidence of black lung disease and silicosis. While the cost of improving these health benefits are borne in short order by the firm, the health benefits from them are not felt for many years, and are not reflected in the MSHA data. Even if they were, the presumption that the benefits of the CMHSA exceed its cost does not command unanimity. One expert whose research leads him to a strong contrary viewpoint is Richard Gordon of Pennsylvania State University. His dissenting judgment was expressed at a workshop discussion of the present report.

The SMCRA, administered by the Office of Surface Mining (OSM) in the U.S. Department of the Interior, significantly strengthened surface mining performance standards and regulations previously governed by rules established in various coal-producing states. The legislation provided for the assessment and collection of reclamation fees, cooperative

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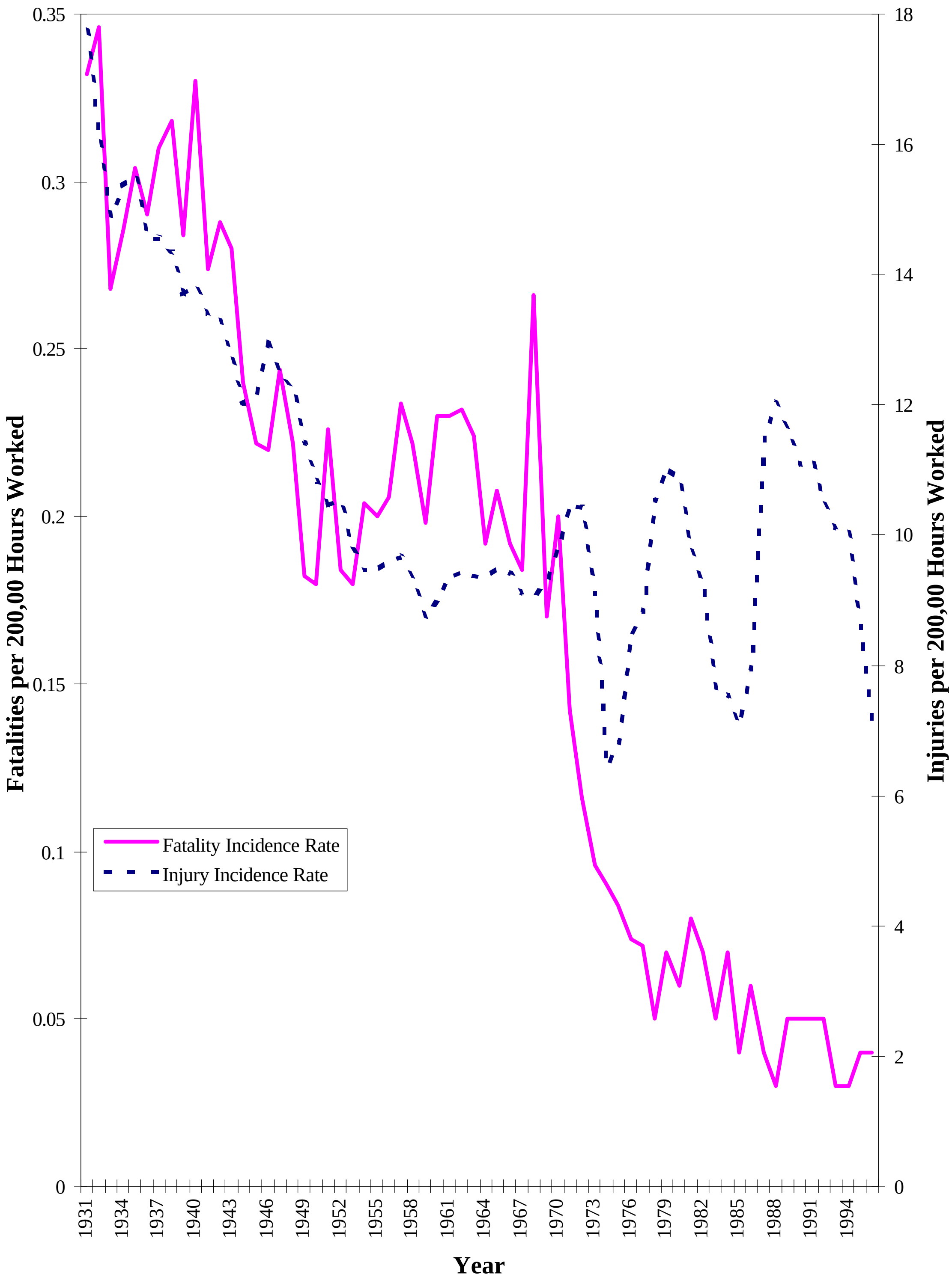
[10] Injuries are those resulting in days lost as well as disruptions in work schedules without days being lost.

Figure 4-1
Injury and Fatality Rates in U.S. Coal Mines, 1931-1996



Note: Data for 1996 are based on the first quarter of 1996 and are preliminary.

Source: MSHA, [electronic file].

agreements with Indian tribes on their coal-producing property, restoration of mining acreage on federal lands, designation of lands unsuitable for coal mining (e.g. because of proximity to national parks), and numerous other provisions, some of them highly complex. (The act also contained certain provisions applicable to underground mining, such as requirements to guard against subsidence -- a potential threat to surface structures and facilities.) Many provisions of the law turned out to necessitate years of adjudication and resolution. In part, this arose from the fact that the heart of the SMCRA involves federally approved state implementation rules. From time to time, in response to federal oversight, states have been required to upgrade their enforcement activity.

Notwithstanding the seemingly comprehensive nature of the SMCRA, one should have no illusion about the degree to which open-pit mines can be restored to pre-existing surface conditions, even where, as in the Powder River Basin of northeast Wyoming, conscientious efforts are undertaken to revegetate the disturbed land cover. To the extent that this is true, some external spillover effects will continue to prevail in surface mining. However, it should be noted that the ease of reclamation varies greatly by region, being far more successful in Eastern states with adequate rainfall than in the High Plains.

What might one expect to have been the productivity consequences of these new regulatory departures -- ignoring, that is, the likelihood that, at least to a limited degree, practices engendered by the new policies simply served as a counterweight to some "unrecorded" mining externalities of the past? That is, due to the possible overstatement of pre-existing productivity performance, perhaps not all of the decline in measured productivity should be attributed to the effect of the new regulations. For starters, it is worth appreciating that even costly steps to limit health, safety, and environmental damage can enhance a worker's performance. A miner confident of working under conditions that are not a threat to either health or safety may well be a more productive miner. That said, it isn't hard to see how compliance with the new policies would, at given levels of output, mean at least a one-time net increase in the level of costs and therefore a penalty in efficiency. For, even if compliance did not require additional workers to meet the new standards or require current workers to work in a less "productive" way -- thus exacting no penalty in labor productivity -- the need for more non-labor inputs (equipment, materials, energy) would show up as a downward effect on total factor productivity.

What, then, is the empirical evidence on the productivity effects of the new regulatory climate dating from the 1960s and 1970s? What follows are findings from a sampling of studies.

(a) One of the early efforts to probe the issue was a 1981 report of the U.S. General Accounting Office (GAO 1981). Acknowledging the difficulty of disentangling the effects of poor labor-management relations (see Section 5) from those due to the new health-safety-environmental statutes, the GAO found that regulations pursuant to the CMHSA -- e.g. compliance with roof control, ventilation and dust control, and various kinds of environmental monitoring -- were "a major cause of productivity decline" in underground mines between 1970 and 1973. But, notwithstanding this one-time permanent productivity loss, by the latter 1970s, the regulations were "no longer significant causes of productivity decline" (p. 73).

Nor would one think that they would be causes of further *relative changes in* productivity. GAO also found that even prior to the enactment of federal surface mine legislation in 1977, enough states had begun tightening their reclamation laws after 1968 to bring about a *net* decline in labor productivity -- particularly in Eastern coal producing states -- “net” because, in its statistical analysis, the GAO allowed for the fact that surface mine investments, such as in bulldozers and carryall scrapers, were used both to boost the output of production workers as well as to deploy “nonproductive” workers in reclaiming the land.

(b) Another early analysis was prepared by Joe G. Baker and his associates at Oak Ridge Associated Universities for the U.S. Departments of Energy and Labor (DOE 1979). Consistent with GAO’s findings, this study concludes that the CMHSA is the dominant factor explaining deep mine labor productivity decline from 1970 to 1973, “with its strongest influence occurring in 1973 when the mine inspection work force began to level off and mine inspections reached an all time high of more than 70,000. Evidence suggests that after 1973 deep mine labor productivity decline was less related to the CMHSA” (p. iii). (Negative post-1973 productivity effects appear to have been the result of high market prices bringing lower productivity firms and mines into operation.)

(c) For his treatment of coal mining, Edward F. Denison (1985, pp. 66-68) consulted a variety of published sources as well as the judgments of industry and academic experts. He confined his analysis of coal mine productivity to the impact of the 1969 CMHSA. He concluded that while the act’s productivity growth impacts were pretty well over by 1976, those impacts were substantial for the period 1968-1977. For that time span, as against BLS’ estimate of actual labor productivity in coal mining falling at 3-1/2 percent yearly, Denison finds that, absent CMHSA, it would have *risen* around 3.1 percent per year. Underlying that calculation was his estimate that, by 1977, compliance with the act necessitated an increase in the coal mine work force of from 132 thousand to 240 thousand.

(d) Firms obliged to meet new regulatory provisions found themselves having to spend more money for labor and other inputs. If unable to recoup higher unit costs through higher sales prices, there would be a squeeze on profits. As it happened, some companies had long-term sales contracts allowing re-negotiation in the event of unanticipated changes in their legal environment. The re-negotiation entailed the need to demonstrate the cost impact of such policy changes. In one such case -- though as part of a broader review -- Consolidation Coal Co. (now CONSOL, Inc.) developed its position through a wide-ranging internal analysis of the cost-benefit implications of the 1969 CMHSA (and certain amendments) (CONSOL, Inc. 1980). Not surprisingly, the report finds significant company productivity losses attributable to provisions of the CMHSA -- whether due to resources needed for direct compliance with the act and/or personnel to offset production losses caused by the act. CONSOL calculates productivity losses in terms both of labor input (coal production per man-day) and a closely related rate corresponding more to a capital productivity measure -- tons per machine shift, usually an 8-hour period. Employing the latter productivity measure, CONSOL acknowledges that compared to a 1969 pre-CMHSA productivity level for reference, not all of the decline to the actual 1977 productivity level can be ascribed to the CMHSA. For example, labor problems presumably caused some of the decline. Also, technological advances -- principally, increased use of continuous and longwall equipment --served to offset some of the Act's effect on productivity. Still, the CMHSA is viewed as responsible for about 60 percent of the drop (CONSOL, p. 71). Turning to the unit cost consequences of this productivity decline, CONSOL concludes that the CMHSA accounted for at least 40 percent of the company's unit cost increase between 1969 and 1979. A summary breakdown leading to that result appears in Table 4-1.

Table 4-1. Major Categories of Cost Increase at CONSOL's Underground Coal Mines

1979 v. 1969

	Net Increase	
Cause	**Dollars per Ton**	**Percent of Total Increase**
PRODUCTIVITY DECLINE (GAIN)		
Health and Safety Act	$ 8.58	40%
Longwall Mining	$ (5.54)	(26)%
Other Factors	$ 6.60	31%
TOTAL PRODUCTIVITY RELATED	$ 9.64	45%
OTHER FACTORS AND INFLATION (Including increased taxes, black lung, labor agreements, and environmental costs)	$11.72	55%
TOTAL NET INCREASE	$21.36	100%

Source: CONSOL, Inc. 1980

This brief survey points pretty much to a consensus view that regulatory policies to protect health, safety, and environmental values had a substantial downward effect on coal mine productivity, at least for a limited span of years. Early resumption, after 1980, of impressive productivity growth and technological advance serves to at least attenuate, if not dismiss, the argument by Gordon and some others that the output and productivity penalty prompted by the regulations of the 1970s failed to meet a benefit-cost test. It is worth noting, however, that, even though overall productivity advance may continue at a satisfactory pace while overall external effects remain low, emerging technologies may pose unique problems requiring the vigilance of industry and regulators. As an example, longwall mining technology has dramatically reduced the number of miners required at the mine face and contributed to accelerated productivity growth. Yet, since those workers remaining at the longwall face appear to be subjected to higher noise levels and dust concentrations -- with the mine as a whole confronting elevated methane concentrations at the faster extraction rates employed -- for innovative technology not to be a mixed blessing, managing the externalities dilemma remains an ongoing challenge. (See Organiscak and others 1996.)

5. LABOR ISSUES

Introduction

Although labor problems have been a recurrent feature of coal mining's history in the United States, their impact has generally been limited to short-term dips in output rather than basic disruptions having serious spillover effects on the wider economy. The decade of the 1970s was a case where labor unrest in the industry came close to producing such unsettling consequences. The strike of 1971 translated into a production drop of 52 million short tons (or 8-1/2 percent) over 1970. Later in the decade, a strike beginning in December 1977, but extending well into 1978 caused an annual decline of nearly 30 million tons -- this at a time when the oil-market upheavals beginning in 1973-74 had substantially increased both domestic and foreign demand for American coal. While the labor productivity declines occurring during the 1970s had multiple causes -- as discussed in other sections -- labor unrest was clearly a significant contributor, and probably not just for the two specific years in which the greatest labor strife took place. Recall (from Table 1-1) that coal mine labor productivity dropped at an average annual rate of almost two percent during the decade. In underground mining, where the labor unrest was principally centered, the productivity decline averaged out to 3-1/2 percent yearly.

A Brief Look at the Coal Mine Labor Scene

In probing the impact of labor market unrest on productivity, one is justified in concentrating on the underground sector of the coal mine industry. For a variety of reasons, surface mining has not been seriously touched by the problem; indeed, that very fact -- contributing to the competitiveness of Western coal -- might have exacerbated labor problems in Eastern underground mining by increased pressure to remain competitive. Although the effect of unionization on productivity has been a subject of some debate (see below), the fact that surface mines are largely non-unionized -- hence, less prone to work stoppages -- seems to have forestalled the productivity penalty engendered by frequent strikes. Other factors include the fact that, relatively speaking, surface mining is strongly capital-intensive; relies on skills similar to those in the construction and excavation industries with their comparatively large pool of experienced workers; and, in offering relatively safe working conditions and high wages, makes for more stable worker-management relations. So, talking about the productivity consequences of fractious labor relations -- especially during the 1960s and 1970s -- essentially means talking about the underground mines east of the Mississippi at which the United Mine Workers were organized. In the mid-1970s, these supplied nearly 90 percent of the nation's underground coal and roughly two-thirds of total coal production.

A comprehensive account of the labor unrest-productivity connections in the 1960s and 1970s, as well as the labor-management climate that prevailed in previous decades, appears in the General Accounting Office report, cited earlier (GAO 1981). Until the second half of the sixties, strike activity had for some years been relatively subdued. In a period where stagnating coal demand and low prices impelled firms to try and increase efficiency, "the UMW cooperated with the coal operators and gave them the free hand needed to survive depressed market conditions" (GAO, p. 14). By the late sixties and particularly after 1970, when the price of coal started to rise and the industry became more profitable, these cost-minimizing objectives began to run counter to the UMW's pursuit of higher pay. While beginning to rise, wages were nevertheless seen as unfairly lagging the pay in other industries. In addition, the UMW sought greater health benefits against black lung disease, improved retirement provisions, and a safer workplace environment which, in a 1974 union contract, required the addition of helpers on mine-face equipment. It was a decade during which "(l)abor management relations in underground coal mining...can be described as a struggle between two long-time adversaries, neither willing nor able to recognize that the economic well-being of both is closely tied to the degree of cooperation between them" (GAO, p. 12). From a labor perspective, the struggle may have pitted traditional adversaries against each other. But with industry viewed as using its monopsonistic character to deprive workers of the wage premia coal-mine risks justify, the conflict was hardly viewed as one among equals. (For a discussion of this issue and how it may have resulted in "under-internalization" of the harm to which workers had been subjected, see ORNL/RFF, 1994).

The corrosive nature of labor-management relations in those years is illustrated by the fact that virtually all strikes between 1969-76 were not called in the course of contract negotiations but were wildcat walkouts. Over four successive five-year periods, the number of idle worker days, the total number of miner days worked and the percent of miner days lost due to strikes is shown below (in thousands):

Years	Idle Days	Total Miner Days	Percent of Days Lost
1960-1964	993	145,131	0.7
1965-1969	2,902	138,232	2.1
1970-1974	9,274	157,365	5.6
1975-1979	19,376	227,595	7.8

Source: Bureau of Mines, *Mineral Yearbook*, various issues; and EIA, *Coal Production*, various issues.

Given the increase in the number of days worked after 1965, one would expect to see an increase in the absolute number of idle days due to strikes. However, the significant increases in the percent of days lost over the next decade and a half makes it likely that labor-management disputes contributed to productivity stagnation during the 1970s. One must keep in mind that the 1975-79 period included the 109-day strike beginning in December 1977. Strikes did not cease with the end of the seventies, but they greatly abated. In October 1984, for the first time in 20 years, a threatened nationwide strike failed to materialize as the UMW and Bituminous Coal Operators of America agreed on terms for a long-term contract. A new, 5-year contract, signed in 1988, averted a walkout as well.

Productivity Aspects

How do these upheavals bear on labor productivity? On the one hand, even without work stoppages, the level of tension, discontent, and sullenness brought about by unending grievances with management probably can't help but condition workplace motivation and efficiency prior to and after a strike, especially one deemed by workers to have been settled on terms inimical to their interest. Technically speaking, however, the effect of strikes *per se* need not cause a loss in labor productivity. If a closed mine causes a proportionate decline in both production and worker-hours, labor productivity will not be affected, though deployment of overhead personnel and standby maintenance facilities and underutilization of capital that continues to have to be amortized probably does translate into some productivity penalty, arguably to a greater degree in total factor than in labor productivity. (See Fig. 6-1 and the accompanying text.)

There is some, but not copious, statistical evidence bearing on the labor productivity consequences of labor unrest. GAO sees the labor productivity decline of the 1970s closely tied to the poor labor-management relations of the period and particularly singles out the year 1974 when the union contract provision augmenting mine-face equipment operators with helpers is said to explain some 40 percent of the 13 percent labor productivity decline between 1974 and 1975. That is, of course, only one year's record. And the degree of featherbedding implied by the statistics might well be contested by some with a greater "hands on" feel for conditions at the mine face. But in its study, surveying that period, Oak Ridge Associated Universities (ORAU) ascribes 25 percent of the labor productivity lost between 1970 and 1975 to deteriorated labor-management relations[11] (DOE 1979, as cited by GAO 1981, p. 24).

Unfortunately, efforts to coax out more specific causes of this decline are ambiguous or inconclusive. Analysts have, for example, looked at the role of turnover, absenteeism, age distribution and experience, and job bidding (i.e. seniority preference) as possible explanations. (A cross-cutting question concerns union-vs. nonunion productivity performance, discussed

[11] This result was obtained through ORAU's regression analysis utilizing state-by-state variations in shifts lost to wildcat strikes "as a measure of labor discontent" with, in turn, a "strong damaging effect on productivity...." (GAO, p. 24).

briefly under a separate sub-head below.) The trouble is that these and other factors operate in a complex web of multi-directional effects that defy easy unraveling. Thus, absenteeism, to which GAO judgmentally ascribes some downward effect on productivity, might, when it occurs rampantly and without notice, be expected to disrupt work scheduling, thereby lowering productivity. But one can also imagine that there is a limit to a worker's effectiveness and morale in prolonged cramped, wet, and cold conditions, with shift assignments that encroach visibly on family life. Age distribution, which has also been found to have minimal consequences for productivity, illustrates these underlying cross-currents as well. Young workers' lack of experience -- and this cohort entered mines in large numbers as coal demand surged in the 1970s -- might have been expected to set back productivity; greater education might have served to compensate, but reliable time series data on trends in miners' education do not appear to be readily available. (To compound the intricacy: might the fact that younger workers are more vocal, self-confident, independent-minded, safety-conscious, and more prone to strike suggest an indirect pathway toward *reduced* productivity? It is a hypothesis that doesn't seem to have been explored.)

The Union-vs.-Nonunion Issue

The question of whether, in general, union membership means higher or lower productivity in underground coal mining presents a complicated sorting-out challenge. While some union demands, like the "helper" provision discussed above, may have lowered measured productivity, various other safeguards may have provided conditions for enhanced efficiency -- an ironic outcome, if workplace standards had a meaningful effect on *enhancing* profitability. And the fact that numerous presumed effects on productivity -- e.g. government health, safety, and environmental statutes -- coincided with the period during which labor unrest and union demands were at their height compounds the analytical task.

Predictably, the productivity implications of union membership has been of great interest to academics, government analysts, the industry, and of course, labor groups. To the authors of the ORAU study, an analysis of the 1970s produced no evidence of a productivity effect of unionization. The authors acknowledge their awareness of the widespread argument that unionized mines were less productive than other mines because of (1) union insistence on strict enforcement of CMHSA provisions, and (2) the fact of union-management relationships having changed from a cooperative one in the 1950s and 1960s to a confrontational one in the 1970s. But despite "empirical problems in comparing union to nonunion mines....[t]here was no statistically significant difference in tons per mine-shift, output, days active, or employment for the period 1973-1976. This result contradicts a survey of mine managers' attitudes in 1977 in which the 44 managers surveyed said they believed productivity was greater in nonunion mines" [The ORAU study (DOE 1979) as cited by GAO (1981, p. 13)].

Looking back on that period, company officials interviewed for the present study re-affirmed this earlier mine managers' judgment. A point made several times is that nonunion willingness to accept lengthier shifts, quite apart from signifying more *output per shift* (for the arithmetic reason that more hours are being worked) also means greater *output per worker-*

hour, since fewer shift changes mean reduced costs associated with the downtime consumed by those changes.[12]

Neither the GAO nor ORAU study attempts to isolate mine productive capacity as a variable that could explain union-vs.-nonunion productivity differences. Intuitively, one might have expected smaller, disproportionately nonunion mines of the time to have lacked the technology and equipment to match the productivity levels of the larger, disproportionately unionized mines. But if a scale factor is operative in recent underground mining experience, its presence is effectively masked in the aggregate numbers.

The following tabulation shows the comparative productivity levels in underground mining. The figures (from EIA, *Coal Industry Annual 1995*, 1996) are for 1995, expressed in tons per miner-hour worked:

	Union	Nonunion	Nonunion/union
Appalachia	2.92	3.23	1.11
Interior	3.64	3.95	1.09
West	4.69	7.38	1.57
US	3.14	3.63	1.16

On a per worker-shift basis, for reasons speculated on above, the ratios are substantially higher. (See data cited by Walker 1996, p. 66.). Whether this nonunion margin of advantage will induce unionized firms to take steps to improve efficiency, what those steps might be, and how unions would react are questions that go beyond the scope of this report. Comparative productivity *levels* aside, *rates* of productivity improvement during the last several years have been similar across both union and nonunion mines. Amidst a rediscovered mutuality of interest between labor and management, labor disturbances have been infrequent, suggests that this may, in fact, be turning into a minor or non-issue.[13]

6. THE ROLE OF LABOR AND NONLABOR INPUTS IN PRODUCTIVITY CHANGE

Preceding sections have mainly focused on estimates of *labor* productivity as the most readily available measure of coal mine productivity spanning extended time periods, multiple geographic regions, and different types of coal extraction. But neither levels nor rates of change in labor productivity capture fully the efficiency with which the entire range of inputs -- labor, capital, energy, materials -- is deployed in the production process. That more

[12] The same phenomenon apparently exists in the scaled-down British coal industry. Reduction in overmanning and greater shift flexibility have translated into greater productivity.

[13] In Appalachia, new mines opened in areas formerly dominated by union mines are predominantly nonunion.

comprehensive measure, *total factor productivity* (TFP), provides, among other things, a more meaningful clue than labor productivity alone to the real cost and therefore competitive position of the industry as a whole or segments within it. TFP was introduced briefly in Table 1-1, but in what follows, is accorded a more thorough look. Most of the discussion is based on an analysis and preliminary findings appearing in a 1996 draft report prepared by Denny Ellerman and Ernst Berndt (hereafter E-B) of MIT as part of an ongoing research project for EIA. (Ellerman and Berndt 1996)[14]

Recognizing that labor productivity data are, as noted, available on a much more disaggregated basis than TFP, E-B set out to test the extent to which labor productivity trends track, or can provide inferences about, the behavior of concurrent trends in TFP. For this purpose, they derive a TFP series based on the method developed by Dale Jorgenson and colleagues at Harvard University and a labor productivity series built up from mine-level data collected by the Mine Health and Safety Administration (MSHA). At an industry-wide level of comparison, a plot from E-B (in Fig. 6-1) shows the two productivity paths to generally move together directionally -- which is what one would expect -- though by no means in parallel fashion. (The output measure used in the figure refers to tonnage; the labor series has been adjusted for quality change, though that adjustment does not significantly alter the labor input trend.) Thus, during both periods of rising productivity shown in the graph (from around 1950 to the early sixties and from the late seventies to the present), labor productivity increased at a more rapid rate; while, during the decade of falling productivity in the 1970s, labor productivity decline was less sharp. For reasons that are not clear, preliminary data for the early nineties show a conspicuous lag in TFP relative to labor productivity growth.

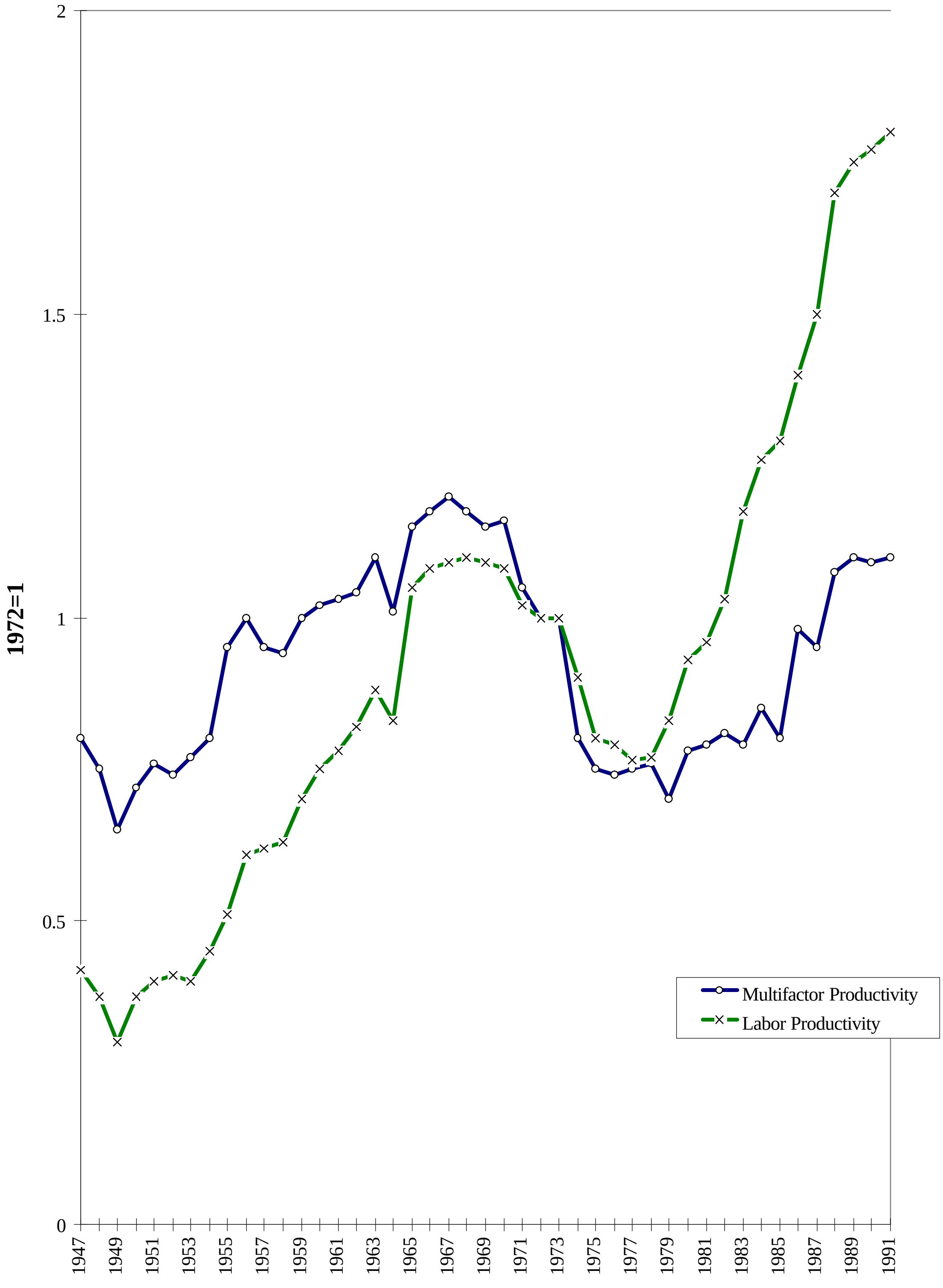
During extended periods of productivity rise, a faster rate of increase in labor productivity than in TFP is to be expected, since nonlabor inputs -- capital and other resources -- are growing faster than labor. But in years of productivity decline, as in the decade of the 1970s, the steeper relative fall in TFP arises from the fact that nonlabor inputs -- particularly fixed capital, which continues having to be serviced -- are not nearly as easy to reduce as miners, who can be laid off.

Conceptually, differences in the rate of change between the two measures of productivity can be ascribed to one or both of the following phenomena:

- "factor substitution": changes in the shares among inputs -- say, more capital relative to labor, but without technological progress
- "factor bias": technological progress associated with one or more inputs, such as the consequences of improved equipment or enhanced labor skills

[14] TFP calculations also receive major attention in Ian Parry's comparative four-industry RFF study. (See Parry 1997.) To ensure consistency and improve comparability across the four industries (petroleum, coal, copper, forestry), Parry had to employ data sources and estimating procedures that differ to some extent with those employed in the individual monographs and in E-B. For example, E-B rely on mine-level data collected by the Mine Health and Safety Administration (MSHA), whereas Parry's estimates are based on Bureau of the Census statistics.

Figure 6-1
Multifactor and Labor Productivity, 1947-91



Source: Ellerman and Berndt, 1996. See text.

Econometric analysis performed by E-B (in turn based on Jorgenson's data) suggests to them that "factor substitution has not been a major factor in explaining labor productivity in the American coal industry. Most of the observed change of labor productivity is caused by technological change; and the differing rates of change in labor productivity and in total factor productivity reflect the pronounced labor-saving bias of technical change in the coal industry." (E-B, p. 13) E-B estimate that "technological progress continually reduces the demand for labor and improves labor productivity at a rate ranging from 2-3% per annum" (p. 12).

Given the heterogeneous nature -- regionally and in terms of mining technique -- of the American coal industry, E-B proceed to dissect labor productivity trends in eight regions. They do this in order to determine how these disaggregated trends compare with national labor productivity trends and whether they permit conclusions on labor productivity-TFP relationships at the regional scale. With respect to the former question, they decompose changes in national labor productivity so as to separate the effect of changing regional composition of coal production (Powder River Basin surface mining labor productivity levels, for example, being much higher than Appalachian underground levels) from the effect of regional changes in labor productivity. Additionally, they convert tonnage output figures into Btu's in order to adjust for heat-content differentials among regional coals. This part of the E-B analysis concludes that, while the respective impacts on national labor productivity change of compositional shifts, on the one hand, and regional productivity change, on the other, have varied in different periods, for the time-span 1972-94, "the shift to regions with higher labor productivity accounted for as much of the change as the improvement experienced at the regional level. Instead of increasing at an annual rate of 3.62 [i.e. the aggregate national rate reflecting both effects], the average improvement at the regional level was 1.85%" (p. 20). However, during the last 15 years or so, with a marked slowing of the westward shift in coal production, the compositional effect has subsided markedly.

What can be deduced from regional labor productivity trends about regional TFP? E-B believe that regional differences in levels and trends of labor productivity are probably good surrogates for TFP as well. Their chain of reasoning goes as follows: Assuming that the coal industry operates in a competitive environment -- both in its input purchases and output sales -- coal prices will track production costs which, in turn, reflect what is paid to all factor inputs. Since, as one moves from Appalachian underground mining to Western surface mining, mine-mouth prices decline roughly proportionately to the increase in labor productivity, an inference can be drawn that TFP regionally may bear the same relationship to regional labor productivity that is exhibited nationally (and was depicted in Fig. 6-1). To restate it somewhat differently: with enough competition, price is (inversely) proportional to TFP; thus, if price is proportional to labor productivity, it must follow that labor productivity tends to be proportional to TFP. But the authors readily admit that their judgments pertaining to the regional scale are quite tentative and invite shoring-up with strengthened research.

At the national level, however, their findings carry more certainty. To recap in E-B's words:

> Although factor substitution is present, the major determinant of the secular trend in labor productivity is change in technology. The pronounced labor-saving bias of technological progress in the American coal industry accounts for most of the observed difference between the rates of change of quality-adjusted labor productivity and total factor productivity. Furthermore, the rate of labor-saving bias has been remarkably constant, appearing equally in periods of rising and declining total factor productivity....a reasonable rule of thumb is that total factor productivity is changing at an annual rate 1.5 percentage points less than the rate of change in quality-adjusted labor productivity. (p. 33)

7. THE COAL RESOURCE BASE: CONSTRAINT OR NON-ISSUE?

Introduction

In this report, our primary concern with coal mine productivity revolves around productivity in *extraction* of the resource. In contrast, Douglas Bohi's companion study (Bohi 1997) on oil and natural gas centers exclusively on productivity in *the exploration for and development of new reserves.* The reason for emphasizing the exploration-development phase of petroleum activity arises from the fact that, particularly in the case of U.S. crude oil supplies, production has been unable at prevailing world prices to keep up with rising demand and thus unable to avoid a fairly steady decline in the magnitude of U.S. reserves over the past several decades. Clearly, enhanced efficiency in finding and developing -- perhaps even more than in producing -- oil and gas, cannot help but prove economically beneficial in this country and worldwide: reserves are stretched out to help meet increased energy requirements without undue upward pressure on real prices. Rising costs from depleting hydrocarbon resources may not be infinitely postponable but technological progress can significantly cushion the process.

Conceptual similarities aside, the situation is markedly different with coal. An abundance of U.S. resources and reserves ensures an overall capacity to produce coal decades, if not several centuries, into the future before encountering underlying resource constraints of major significance. Of course, somewhat analogous to petroleum, even with abundant reserves, improved recoverability above the roughly 50 percent factor that presently seems to constitute the nationwide norm can strengthen coal's competitiveness above levels otherwise prevailing. And a more-than-adequate total magnitude of national coal reserves doesn't preclude limits to coal expansion in particular regions; nor does it mean that there may not be problems in supplying coal with particular properties at today's prices. But, as we shall see, the overall reserve picture in coal is such as to justify foremost attention to productivity trends in its extraction.

Coal Resource and Reserve Concepts

Coal resource and reserve concepts developed by the U.S. Geological Survey and modified over the years by the Bureau of Mines and Energy Information Administration are similar to those applicable to petroleum. That is, they provide a schematic framework within which one can proceed from the most expansive (and thus most speculative) to the narrowest (and most certain) empirical assessment of coal resources and reserves. As with oil and gas, that movement from the broadest to the narrowest perspective is governed by the correspondingly greater degree of geologic assurance and/or the increasing degree of economic viability.

Where coal assessments differ from those for liquid hydrocarbons is that, in the case of the latter, what is "unproved" and "proved" tends to be sharply differentiated: loosely speaking, and notwithstanding the development of ever-more sophisticated exploration techniques (as detailed in Bohi's companion study), one has either found, or failed to find, the oil field. By contrast to the marked discontinuities one observes in oil exploration, coal doesn't have that "now you see it, now you don't" character; you're quite certain the coal is there, even though uncertainty over the extent of a deposit increases with the extent of the inferences employed in the assessment process. Thus, in proving up the extent of a potential coal seam, the combined effect of drilling, sampling, measuring, and observing permit quantification of the deposit to be made with a good deal of confidence, even if at some considerable distance from the drill hole. The greater that distance, the less certain the robustness of the assessment, but that certainty diminishes only gradually, lending estimates derived in this fashion a widely accepted degree of authority.

Some Estimates

The foregoing points provide a brief backdrop to numbers drawn from a recently released EIA report on U.S. coal reserves (EIA 1996B). As a general proposition, the report, like numerous earlier studies, affirms the "adequacy" of the U.S. coal resource and reserve situation. Table 7-1 is arrayed so as to show the effect of successively more restrictive measurement concepts. From a purely aggregate perspective, the number of primary interest is probably that of "estimated recoverable reserves,"[15] totaling some 274 billion short tons at the beginning of 1995, a magnitude supporting close to a three-century "cushion" at current output rates and still well over a century's remaining supplies if production were to grow at one percent yearly over the next 100 years. In energy terms, this translates into magnitudes substantially exceeding those estimated for oil and gas combined.

Some Caveats

While one would find a large reserve estimate more reassuring than a small one, an aggregate like the one cited in the preceding paragraph is, for a number of reasons, something of an abstraction. The devil being, as always, in the details, it is useful to try and identify ways in which particular policy directions or technical problems could limit the exploitation

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[15] The concept of estimated recoverable coal reserves can be viewed as analogous to proved recoverable reserves of oil or natural gas; in both cases, they are in principle conditioned by the assumption of recoverability at today's cost and technology -- "in principle," because there is reason to question how reliably those criteria are or can be applied in reserve estimation.

of estimated recoverable coal reserves, thus raising the cost (lowering the productivity) encountered in the process of developing new reserves. Consider some possible qualifiers. For example, the estimate presumes no serious hindrance on access. As Table 7-1 shows, EIA presently estimates some 16 percent of the demonstrated reserve base (DRB) to be inaccessible for a number of reasons. As the 1996 Kaiparowits Plateau decision, restricting coal development in southern Utah illustrates, it is always possible that similar future constraints dictated by land-use, transport, cultural, and other factors could significantly lower the accessible DRB. To further show the changing nature of the DRB, recent proposed rules by the Office of Surface Mining could limit the areas available to strip mining, but at the same time extend the rights of some land owners to extract coal from previously unavailable underground seams.

Table 7-1. Estimated Coal Resources and Reserves, 1995 (billion short tons)

Total resource base (identified & undiscovered)		3968.3
Less: undiscovered (or: "discoverable")		2237.4
Equals: identified resources (measured, indicated, & inferred)		1730.9
Less: inferred		1235.2
Equals: demonstrated reserve base (measured & indicated; specified depths & thicknesses)[a]		495.7
Less: inaccessible		79.4
Equals: accessible demonstrated reserve base		416.3
Less: unrecoverable		142.4
Equals: estimated recoverable reserves		273.9
Of which:	at active mines	21.0
	other	252.9

[a] USGS taxonomy applies a 1/4-mile radius to "measured" coal deposits, a half mile beyond that to "indicated," and a further 2-1/4 miles to capture the "inferred" category

Source: EIA, 1996B, pp. 5, 37

Tightened environmental statutes inhibiting the use of high-sulfur coals, enhanced health-and-safety regulations militating against underground coal, strengthened reclamation requirements on strip-mined coal -- all such strictures could shrink the magnitude of exploitable reserves shown in Table 7-1.

Then, too, for *economically recoverable* coal reserves to be an *economic* input into production processes presupposes locational characteristics which, while favorable today, may not be so in the future. During the first half of 1996, well over two-fifths of the coal delivered to coal-burning power stations in Illinois and Indiana originated in Wyoming, Montana, and Utah. Such favorable trade flows can change. On the other hand, portions of the billions of tons in reserves presently treated as technologically or economically unproduceable because of inaccessibility and/or lack of recoverability might have a future market if some existing reserves were to be declared off-limits for environmental or other reasons. But this would depend on the stimulus provided by higher prices and/or technological breakthroughs in producing coal.

Table 7-2. Estimated Recoverable U.S. Coal Reserves, By Sulfur and Btu Content, 1995 (billion short tons)

	Underground	Surface	Total
High sulfur, low Btu	1.3	10.6	12.0
High sulfur, medium Btu	21.9	13.0	34.9
High sulfur, high Btu	31.1	8.4	39.5
Medium sulfur, low Btu	21.0	36.9	57.8
Medium sulfur, medium Btu	4.6	1.8	6.4
Medium sulfur, high Btu	16.0	6.1	22.1
Low sulfur, low Btu	40.0	40.6	80.5
Low sulfur, medium Btu	3.7	0.9	4.7
Low sulfur, high Btu	11.3	4.7	16.0
Total	151.0	122.9	273.9

Source: EIA, 1996B, p. 100. (Low sulfur coal is defined as coal with less than 0.6 pounds of sulfur per million Btu, medium sulfur is defined as coal with 0.61 to 1.67 pounds of sulfur per million Btu, high sulfur coal is defined as coal with greater than 1.68 pounds per million Btu. Low Btu coal is defined as coal with less than 20 million Btu per short ton, medium Btu coal is defined as coal with 20 to 23 million Btu per short ton, high Btu coal is defined as coal with greater than 23 million Btu per short ton.)

The fact is that there is tremendous variability in numerous attributes of the nation's coal reserves -- depending on deep or surface mining, eastern or western location, thin or thick seams, low or high heating value, and low or high sulfur content. Even today, the coal industry shows periodic strains in trying to accommodate itself to the varying demands of environmental and other policies, on the one hand, and the need to remain a player in the competitive marketplace, on the other. The point can be illustrated by referring to the way in which two desirable properties of coal -- low sulfur and high Btu value -- sort themselves out within the estimated recoverable reserve total. The nationwide distribution of coal reserves, broken down in Table 7-2 by sulfur content and heat value, provides a useful perspective on this point. As noted, numerous other factors -- distance from consuming centers, richness of seams, overburden in surface mines, depths in underground mines -- obviously enter into production decisions. Nonetheless, for the long-term future, Btu and sulfur content can be viewed as particularly important, with the possibility of tightened pollution controls making low sulfur content an even more critical factor than today. Yet if the combination of high- and medium-sulfur with low-Btu were deemed to have secondary appeal, it would apply to 69.8 billion tons of reserves, roughly a quarter of the U.S. total. Conversely, the “ideal” combination of low-sulfur and high-Btu coal -- concentrated in the Southern Appalachians -- amounts to only 6 percent of the U.S. total.

These observations do not undermine the proposition that it is in the extraction of coal from given reserves to which analysis of productivity in coal mining is most appropriately directed. At the same time, one needs to appreciate that an undifferentiated aggregate of 274 billion tons of coal reserves masks features -- including distributional issues, in the case of communities losing their coal mining base -- that can be quite crucial in the light of particular economic and policy circumstances. But even when estimated reserves are scaled back to “remove” portions least or less desirable, including those producible only at increasing real cost,[16] the remaining magnitudes are still substantial enough to suggest that constraints other than the magnitude of reserves of a particular type of coal are not likely to be decisive for coal’s status in the decades to come.

8. **COALBED METHANE**

Relevance to this Project

The companion study on productivity in the petroleum sector addressed issues associated with reserve additions to and recovery of *conventional* natural gas resources. Potentially large quantities of *unconventional* natural gas -- from tight sands, geopressured brines, devonian shales, and coal-seam derived methane -- have all remained largely untapped, owing to severe technological and/or cost barriers. Even in the case of shale-based gas, whose magnitude is estimated at nearly 50 percent more than proved reserves of conventional natural gas, numerous active wells in the Appalachian Basin produce gas at such slow flow rates as to deter meaningful investment. Whether extraction of coalbed methane is poised for a decisive take-off remains debatable, though developments in recent years appear to have made that prospect somewhat more favorable. For two reasons, the topic deserves at least some attention within the present project. First, the presence -- and, hence, the prospect of exploitability -- of coal mine methane is related to mine safety conditions and regulations and thereby to productivity. Second, while (as argued in the preceding section) the ample magnitude of recoverable coal reserves may make the creation of new coal reserves a low-priority issue, the much more limited extent of conventional U.S. gas reserves makes the challenge of obtaining supplementary methane supplies from coal mines and the cost of doing so matters of considerable interest.

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[16] Notwithstanding the definitional presumption of producibility at *today*’s cost and technology.

Quantitative Dimensions

A quantitative profile of coalbed methane is contained in several reports from EIA and the Gas Research Institute. (See EIA 1996C; FEI 1993; and GRI 1995.) GRI gives the "total U.S. coalbed methane resource" at about 400 trillion cubic feet, but EIA reports a proved, recoverable estimate of 10.5 tcf or somewhat over 6 percent of the 165 tcf in estimated conventional proved recoverable natural gas reserves. (See Table 8-1.) An assessment with greater emphasis on economic analysis comes from two USGS experts. (See Attanasi and Rice 1995.) Their report estimates that, while there are more than 700 tcf of coalbed gas in place in the continental U.S., of which some 50 tcf are deemed "technically recoverable," economic analysis suggests that around 5 tcf can be commercially found and produced at $1.50 per thousand cubic feet (mcf), with 21 tcf being commercially producible at $3.00 per mcf.

Table 8-1. 1995 U.S. Coal Bed Methane Production and Proved Reserves

	Production (Bcf)	Reserves (Bcf)
Alabama	109	972
Colorado	226	3,461
New Mexico	574	4,299
Others[a]	47	1,767

[a] Others Include Kansas, Oklahoma, Pennsylvania, Utah, Virginia, West Virginia and Wyoming.

Source*:* EIA 1996C.

Annual U.S. coalbed methane production started from virtually nothing in the early 1980s and reached a level of 956 billion cubic feet (bcf), (an increase of 12 percent from 1994), or over 5 percent of conventional gas production, in 1995. Recent output has originated predominantly in the San Juan basin of western New Mexico and Colorado; and the Black Warrior basin of Alabama-Mississippi. These two regions also hold major deposits, although very large resources are located as well in the Northern Appalachian, Powder River, Piceance, and a number of other areas.

Factors Behind Recent Trends in Coalbed Methane Output

Three factors appear to have played important roles in bringing about the output surge in coalbed methane during the last several decades: government subsidies, health and safety statutes, and technological advances. A word on each.

Initially to control buildup of dangerous methane levels in the mines but then to promote production of coalbed methane (and several other sources of unconventional natural gas), a federal tax credit was awarded to producers between 1978-92 (and continues for those producing in 1992). The credit ranged between 50 cents and 95 cents per mcf after 1985. Even though a subsidy of that size must be viewed as generous (in the context of a natural gas market price of around $2/mcf in the early nineties), GRI states that “technology was simply not advanced enough even as recently as the mid-1980s to support economic production of coalbed methane in meaningful amounts, even with a tax credit” (GRI 1993). Trends in methane production commencing after the 1992 expiration of the tax credit and over the next few years (which may see higher gas prices) should offer more credible evidence on the economic incentive issue. It should be kept in mind that aside from the economics of producing methane, there is also the matter of marketing it: a coal mine far from gathering and branch pipelines could face barriers in feeding the gas into the nation’s gas distribution network. However, utilizing the gas for small-scale mine-mouth electricity generation -- both for on-site needs and delivery to the grid -- could skirt that constraint.

As required under the Federal Coal Mine Health and Safety Act of 1969, the U.S. Mine Safety and Health Administration specifies maximum methane concentrations in different sections of a mine (depending, in part, on the location of personnel), requires monitoring to ensure compliance with these standards, and compels evacuation when tolerances are exceeded. With excess methane having to be vented in any case, safety statutes encourage productive use of methane above levels that would otherwise exist.

Technological developments have reinforced the economic and safety spurs to harnessing coal mine methane as a productive resource. In its review of advances in drilling and completion technologies, GRI summarizes some of the learning-curve experience that has boosted production results and raised expectations as to the level of well completions and output in the years ahead. Included in this maturation process has been a growing sophistication in understanding differences in the geological structure of various coal-mining regions and the implication of such differences for the most appropriate gas recovery approaches to be used. There has also been improved understanding of the properties of coal-seam reservoirs compared to those of conventional natural gas fields -- e.g. with respect to the way the pressure of water causes methane to be absorbed onto the coal’s internal surfaces.

Coalbed Methane as a Productivity Issue

As we have seen, production of coalbed methane has begun to represent a more than trivial addition to the nation’s conventional natural gas output. But information that would facilitate a robust, generic economic assessment of the resource, with its geographically scattered operations and highly variable characteristics, remains spotty. Judgments about labor or total factor productivity in coalbed methane extraction are correspondingly ad hoc. The problems revolve around (a) interpretation of production cost estimates; (b) the jointness of coal and gas operations; and (c) the treatment of environmental effects.

(a) A limited number of studies have tried to simulate, or otherwise model, the economics of coalbed gas production, absent any government tax credit. We have mentioned the Attanasi-Rice USGS effort, suggesting a floor price of $1.50/mcf for any consequential production. Another analysis, centered on the Black Warrior Basin in Alabama, concludes that, at the market prices prevailing in the early nineties, coalbed methane production would be a loser (Hobbs and others 1992). A somewhat more upbeat stance on profitability comes from EPA, whose interest -- not surprisingly -- is strongly governed by the extent to which coalbed methane use could contribute to reduced greenhouse gas emissions. (See EPA 1995.) (EPA's cautiously optimistic conclusions were based on the economics of injecting coalbed methane into the pipeline network or using it to replace purchased electricity; no "credit" was assigned to reduced methane emissions to the atmosphere.) In very general terms, a large gassy mine could compete in a natural gas market with prices of no less than $1.50/mcf. Even a small mine with modest gas potential could generate its own electricity given its purchased electricity costing around 5.5 cents/kwh.

But this broad recap doesn't capture the detailed economic and technical content of the EPA and the other cited reports. Overall, these studies do not converge to a central outcome, but they do seem to suggest that, erring in a conservative direction, anything much under a $2/mcf natural gas price would render most operations uneconomical. With recent conventional gas wellhead prices hovering around that level, conditions for coal mine gas do not -- for now at least -- seem particularly promising, except for particularly prolific and technologically well established operations.

With exploitation of coalbed methane in a borderline zone of profitability, one can surmise that labor productivity could be quite high but total factor productivity -- the more meaningful clue for total cost -- quite low. This can be crudely inferred from EPA's analysis which shows, for each of its hypothetical cases, a very high degree of capital intensity -- irrespective of whether the product is pipeline-quality gas or electricity. In contrast, the labor component of overall annual operating plus capital costs is estimated to be conspicuously low -- ranging from 15 to 20 percent across the three cases.

(b) Ideally, the factor inputs to produce both coal and gas (or electricity) should be separated; and BLS does combine the labor component of coalbed methane production with the labor requirements of all natural gas. (It isn't clear whether the same is done for the production of methane-based electricity.) Yet one cannot be sure whether there are significant joint factors -- labor, capital, other resources -- that serve the *combined* output of coal and methane. We have found no data to indicate how much of a distortion -- if any -- such combined treatment introduces.

(c) Section 4 of this monograph discussed health-safety-environmental aspects of coal production and the bearing that these may have had on productivity performance and measurement. The further back in time we go, the greater the incidence of injuries, fatalities, and damage resulting from inadequately controlled methane in coal mining. Whether, in those years, this exposure and its consequences represented a "non-market" externality which, by some indeterminate amount, overstated productivity by understating the degradation of the mine environment, or was internalized -- say, by a wage premium -- is unclear. Over time -- particularly following enactment of the Coal Mine Health and Safety Act -- greater or lesser amounts of whatever external costs may previously have existed have become internalized by virtue of resources having to be devoted to methane management, so that measured and "true" productivity have tended to converge. To the extent that, other things equal, this signifies lower productivity levels or slower productivity growth than would otherwise be the case, rather than seeing a deceleration of productivity growth, we are seeing a more faithful way of recording it. And even though, as we have shown, experience has so far been fairly limited, where control of coalbed methane prompted by safety considerations can be successfully coupled to economic use of the gas, part of that productivity penalty can be recouped.

9. INDUSTRY STRUCTURE AND PRODUCTIVITY

Structural changes in the American coal industry over the past several decades have been conducive to rising productivity. The main driving force in that process has been growth in the size both of mines and of firms -- without, in the latter case, evidence of anticompetitive results. Average mine size can rise both because the productive capacity of existing mines is expanded --as Denny Ellerman and his MIT associates have determined to be the case in the Powder River Basin -- and because newly opened surface and underground mines have tended to be larger than existing ones -- further evidence attesting to resource adequacy. Size factors apart, lesser, though probably not inconsequential, contributions to enhanced productivity, stem from a number of managerial and work-rule changes that have been introduced.

The correlation of mine size with productivity, as illustrated in Table 9-1, arises for several reasons. Large mine size allows for the use of machinery and technologies, such as draglines in surface mining and longwall equipment in underground mining, that would be uneconomical in small-scale operations. Deployment of such large capital inputs is, in turn, facilitated by firms large enough to mobilize the needed investment funds. Increasing the average output of a mine provides opportunities for economies of scale -- for example, in more efficiently cutting, processing and transporting coal to the mine mouth or in economizing in the number of miners needed to perform maintenance and repair work.

Table 9-1. Coal Mine Productivity By Mine Production Range, 1995
(short tons per miner hour)

Mine Production Range (1000 short tons per year)	Productivity Underground	Productivity Surface
10-50	2.03	2.77
50-100	2.36	3.08
100-200	2.72	3.64
200-500	3.45	4.18
500-1000	3.67	4.86
1000 and over	4.11	13.21

Source: EIA, *Coal Industry Annual 1995*, Oct. 1996, p. 85.

The record of growth in the size of mines and firms is a striking one. In 1976, the average coal mine produced 105 thousand tons per year; by 1995. output had reached 490 thousand tons. Growth in the number of major coal producers -- those with annual output of more than three million tons -- paralleled this trend. In 1976, 34 firms produced 57 percent of total coal production. By 1995, the number of major coal producers had reached 44, accounting for 80 percent of total production (EIA 1993 and EIA, *Coal Industry Annual 1995,* Oct. 1996). At the same time, the industry fails to meet criteria commonly invoked to gauge anti-competitive threats: in terms of output shares accounted for by both the top four and top eight producers, the percentages of recent years (approximately 22 and 33 percent respectively) represent a significant drop from shares that prevailed two decades earlier and do not typify what one would view as an unusual degree of economic concentration (EIA 1992, pp. 22-23). All in all, coal mining remains a highly competitive industry with a substantial number of firms and relatively easy entry. (The concentration of output in the largest number of *mines* has, however, risen markedly.)

In the initial part of the period surveyed here, the industry trend was actually *away* from greater concentration. The trigger for that was the oil-market disruptions and energy price run-ups of the 1970s. Higher oil prices, the expectation of booming demand for coal, and the prospective economic feasibility of converting coal into liquids and gases gave oil companies both the financial wherewithal and the incentive to diversify into coal mining -- a move which, at first, involved acquisition of smaller mines and, along with the re-opening of many marginal mines, meant a substantial increase in the number of mines without anything like a commensurate increase in output. Oil companies weren't the only new entrants into the coal mine industry. In an attempt to ensure a dependable source of energy, many electric utilities started moving toward coal and away from oil and gas fired units. A number of these utilities had, even some years earlier, begun acquiring coal mines or negotiating long-term purchase contracts in order to secure a supply of the desired quality coal for the lifetime of their plants. (Some steel and coke plants followed a similar course of action.) In a detailed historical analysis, Gordon attributes this development "primarily to concern over the logistics of supplying the ever larger plants that the electric power industry was installing. Companies wanted assurance of the availability of the required amounts of coal" (Gordon 1975, p. 63). Exploiting the transportation efficiency offered by the unit train as an increasingly attractive coal delivery mode reinforced these emerging supplying patterns.

The mirror image of the 1970s, when most new entrants into coal mining opened relatively small mines, occurred in the 1980s and 1990s when the combined effect of declining coal prices and recourse to powerful new technologies impelled the departure of many of the small and inefficient mines attracted into the industry a decade earlier. Moreover, once the price of coal started to decline, many petroleum companies decided to leave the coal business -- recognizing the illusion of a viable synthetic fuels industry, selling their coal assets, and, under circumstances where a concurrent fall in world oil prices threatened the profitability of their core business, pursuing cost-reducing technological advances in petroleum exploration and development. (Key developments are summarized in EIA 1993; the petroleum story is told in Bohi's 1997 companion monograph.)

The financial impetus for that relinquishment becomes clearer when one compares profit rates for major energy companies on a consolidated basis with their coal properties only. During the period 1977-95, while the gap between the two narrowed, returns to the coal component pretty consistently fell below the petroleum components' performance. For the entire period, the Federal Reporting System, a database of 36 major energy companies monitored by the Energy Information Administration, shows the latter to have achieved an average return 10.0 percent (based on net income relative to net investment in place), the former, one of 4.8 percent (EIA, *Performance Profiles of Major Energy Producers*, Appendix B6, various years). However, some care needs to be taken when analyzing these figures; firms that report to the Financial Reporting System account for over 50 percent of domestic petroleum production, but only account for 10 to 15 percent of domestic coal production.

Propelled, in part, by growing constraints on combustion of much higher sulfur Appalachian coal and facilitated by the use of ever larger truck shovels and draglines, the development of large and thick-seamed open-pit Western coal reserves played a major role in increasing average mine size. And similarly to the financial requirements of opening a large surface mine, in both the East and the West, the adoption and increased use of longwall and continuous mining equipment in underground mining required the assurance of large amounts of output in order to cover the capital costs associated with those technologies.

From the mergers and acquisitions that took place during the 1970s and the subsequent shake-out of the 1980s, we might expect to see some change in the competitive structure of the coal industry -- conceivably with negative consequences for productivity, as a more oligopolistic industry relaxed its zeal for optimal efficiency. However, as we observed earlier in citing declining and only modest coal industry concentration ratios, there is no evidence supporting such a scenario. It appears that the new entrants of the 1970s were unable to gain significant market strength, while the selling of assets in the 1980s was generally from small firms, electric utilities and petroleum companies to medium-sized independent coal firms.

Somewhat separate from factors relating to scale, technology, and capital requirements, there have been a number of managerial developments and changes in work practices with arguably positive effects on worker productivity. An example is provided by the large surface lignite Freedom Mine in North Dakota. In order to try and overcome lags in labor productivity advance, the facility in 1992 changed shifts from three 8-hour shifts, five days per week, to two 12-hour shifts, six days per week. This led to a decrease in the amount of down time associated with shift changes. By working fewer but longer shifts the amount of time spent moving crews to and from the coal face was decreased, resulting in improved productivity. (Additional discussion of labor conditions and issues appears in Section 5.) A mobile equipment shift change also proved productive. This eliminated shift change times and allowed for a period of refueling and preventive maintenance to be scheduled without decreasing the time spent extracting coal. The estimated one-time increase in productivity brought about by shift changes alone ranges from four to twelve percent (Pippenger 1995, p. 336).

To the extent that this example can be generalized to the national level, it suggests that at least some portion of productivity growth in recent years can be attributed to changing worker schedules, which show a 1986-95 increase in shift length of from 8.2 to 8.6 hours for underground mines and one of from 8.6 to 9.1 hours in surface mining. (Data for 1993 to 1995 from EIA, *Coal Industry Annual*; earlier data from *Coal Production.*) From the graph accompanying the Box in Section 1, we saw that from 1960 to 1979, changing the measurement of input variables had little effect on the measured estimates of productivity change. However, from 1979 to 1995, the average annual growth rate in tons per miner hour was 7.1 percent, while, on a per employee basis, it was 7.8 percent. This seems to be roughly consistent with the proposition that lengthened shifts have contributed to productivity advance.

In addition to changing worker shift lengths, management at some firms has decided to switch from a flat rate of payment to a performance and bonus payment system. Mine foremen and some individual miners are paid performance bonuses based on output, improved attendance and improved safety records. (Whatever one's judgment about whether the safety burden was or was not historically an externality, the last of these three factors implies *internalization*, as the company is willing to pay to promote it; see additional remarks in Section 5.) But there is no evidence that such changes have perceptibly boosted productivity.

Certain other management decisions probably had a more simulative impact on productivity. In order to improve the quality of their drilling equipment, some companies have begun signing contracts with equipment suppliers based on a guaranteed number of working hours, enabling mines to effectively shift risk away from themselves and onto the equipment supplier. The effective result of this sort of contract has been to decrease equipment downtime and to increase the amount of available time of equipment at the coal face (Wiebmer 1994). For A.T. Massey, a major Appalachian coal producer, about 50 percent of all repairs are contracted out in this sort of fashion, the rest (routine maintenance and simple repairs) being performed in house.[17] The earlier practice, at most mines, of retaining their own repair capacity evidently proved economically inefficient and, it seems, created unnecessary losses in available equipment time. The potential for realizing economies of scale and scope by contracting with specialized firms for major equipment repair and maintenance is part of an out-sourcing trend that appears to be growing across a variety of industries. Perhaps, as in coal mining, the increased sophistication and complexity of equipment, instrumentation, and information-system technology are common elements fueling that momentum.

10. INTERNATIONAL COMPETITIVENESS

With its volume of production exceeded only by China, the United States, along with Australia, ranks as a major world exporter of both steam and metallurgical coal. As seen in

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[17] Outsourcing of tasks formerly performed by mine personnel could mean some overstatement of labor productivity increases, though not of multifactor productivity increases.

the table below (expressed in Btu's, owing to sharply differences in heat content among countries), lesser, though still important, exporters in the 1990s include South

1994 Coal Production and Exports for Selected Countries (trillions of Btu)

Country	Production	Exports	Country	Production	Exports
China	25,352	590	Germany	3,091	61
United States	22,067	1,895	Ukraine	2,002	70
South Africa	5,574	1,148	Canada	1,804	844
Russia	5,011	582	Kazakhstan	1,450	696
Australia	4,403	2956	Great Britain	1,126	50
Poland	3,571	718	Colombia	644	505

Africa, Poland, Canada, Colombia, Russia, and Kazakhstan (EIA 1997). Mine-level labor or total factor productivity are not the sole factors entering into international competitiveness; advantages in transportation costs, for example, give Australia the edge in serving Japan's utility market, and enable some Canadian exports from the country's western provinces to compete in Pacific rim markets as well. But productivity is clearly a significant determinant of the ability to carve out a commanding share of coal export markets.

Now, since skills of workers and resources available to them differ across countries, even a high-wage country can compete internationally if its worker productivity remains high enough to hold unit labor costs, and thereby total costs and prices, in check. That situation prevailed, for example, during the period 1984-89 when a Bureau of Mines study found the U.S. coal mine labor productivity growth rate of 7.4 percent to have exceeded growth rates in Australia, Canada, and South Africa. Although Colombia achieved a still higher *rate of increase*, a surface mine comparison for the late 1980s shows the U.S. successfully competing with Colombia -- a low-wage country whose labor productivity *level* was estimated at well under half that of the U.S. (Bureau of Mines 1993). The converse, of course, is that some countries can overcome their low-productivity disadvantage with wage rates low enough to remain competitive. Also, labor, while a key cost item -- averaging around 42 percent of total production cost in a large American longwall mine --is obviously not the only cost element to be considered. There are capital costs, non-labor mine operating costs (including various forms of regulatory compliance), land costs, and taxes. Finally, the significance of *point-in-time* comparisons of world coal trade patterns (and underlying competitive factors to which they contribute) must be validated by *trends* which can widen, sustain, or shrink the comparative advantage of major coal exporters. For example, the determination by the British and, it appears, German governments finally to eliminate or greatly scale back the subsidies that have long shielded producers from unrestricted foreign competition will give rise to efforts on the part of efficient exporters to exploit the resulting expansion of market opportunities.

Table 10-1. Selected International Cost and Productivity Comparisons, Late 1980s
(all figures per short ton)

	U.S.	Australia	South Africa	Canada
Large longwall mines				
Labor productivity[a]	3.6-6.5	2.6-4.4	NA	NA
Total mining costs	$15.12-$23.15	$22.99-$36.12	NA	NA
Of which: labor	$6.57-$9.67	$6.60-$11.11	NA	NA
H-S-E	$2.19-$2.86	$1.72-$2.52	NA	NA
Surface mines				
Labor productivity[a]	14.3-21.0	2.7-24.5	3.6-5.2	11.3-19.6
Total mining costs	$5.52-$6.30	$9.05-$37.71	$3.56-$5.25	$4.78-$12.25
Of which: labor	$1.35-$1.72	$1.41-$4.69	$1.07-$1.47	$1.23-$2.22
H-S-E	$0.70-$1.14	$0.28-$0.36	$0.24-$0.44	$0.56-$1.59

[a]Per worker hour

Notes:
(1) The estimates are based on samples of mine visits during 1985-90. But the U.S. dollar costs shown in the table apply to January 1989.
(2) The capital component (not separately shown) of total costs assume a 15% discounted cash flow rate of return.
(3) H-S-E (health-safety-environment) costs for longwall mines are not additive to labor costs since the Bureau of Mines included under H-S-E an estimate of the productivity penalty (translated into unit labor costs). In other words, that penalty would appear in both the labor cost and H-S-E rows. The estimates in question are:

U.S.	Australia
$1.02 - $1.93	$1.32 - $1.93

To clarify: assume that the low-end-of-the-range $1.02 shown for the U.S. in the preceding line corresponds with the low-end labor and H-S-E costs of $6.57 and $2.19 respectively shown in the body of the table. Then $1.02 out of both the $6.57 and $2.19 represent labor costs attributable to compliance with health-safety-environmental regulations -- say, a worker having to accompany a federal safety inspector.
(4) All pairs of numbers in the table refer to minimum and maximum estimates.
(5) NA = not included in the Bureau of Mines study.

Source: Bureau of Mines 1993.

The Bureau of Mines estimates in Table 10-1, though by now somewhat dated, provides some insight into the United States' international competitive standing. Especially striking is the relatively strong showing vis-à-vis Australia, America's major rival (particularly in Asian markets) among world exporters. Not only does the U.S. show up favorably in labor productivity terms. That advantage is reinforced by lower labor costs and appears not to be negated by the costlier health-safety-environmental burden then faced by the U.S. While more recent data would probably capture some of the progress that has occurred in overcoming the historic fragmentation and strike-prone conditions of Australia's craft unions, with accompanying improvements in productivity, Australia's labor practices appear still to undermine worker efficiency with a variety of benefits that raise unit labor costs. For example, Australian coal miners earn an average of 200 hours in annual leave and a maximum of 120 hours in sick leave, compared to 76 and 40 hours, respectively, in the U.S. Overall, "lost time" -- through such leaves and other absences -- constitute a third of "potential annual work hours" in Australia compared to a fifth in the U.S. (Walker 1996, p. 66).

Still, while the U.S. has spearheaded labor productivity advances in recent years, Australia has maintained a sufficiently close pace to remain very much within the front rank of world exporters. Though possessing little more than one-fifth the volume of U.S. reserves, that magnitude and technological sophistication for exploiting its coal resources (involving, in part, direct investment by American firms) suggests that Australia is well positioned to sustain its important coal trading status.

While South Africa, Colombia, Canada, and several other countries are likely to remain important players in the coal trade, we have already alluded to the prospect of once-prominent coal producers -- notably Germany and Britain -- receding from major competitive contention. But it is also a fact -- and Britain is a case in point -- that mines which survive following closure of uneconomic and inefficient pits sheltered by subsidies compare favorably with technologically advanced operations elsewhere. The volume of production from such modern facilities doesn't add up to dramatic national totals, however.

A thorough analysis would evaluate the situation in and prospects of important producers like Russia and China. But those countries have yet to shed the legacy of their distorted pricing and incentive structure under Communism and therefore cannot easily be analyzed as to their viability under free-market circumstances. Even Poland, relatively far along towards economic reform among the former centrally-planned countries, is still in the process of closing uneconomic mines and transitioning to free markets.

Notwithstanding the retreat of Britain and Germany from major international significance -- the inexorable result of unfavorable geological conditions -- it is something of a paradox that numerous developments ensuring technologically advanced and safer mining practices among today's leading producers were, and, indeed, continue to be, innovated by these dominant coal powers of an earlier period. Longwall mining, for example, was beginning to replace room-and-pillar extraction methods in Britain during the early decades of the twentieth century -- a period during which it was practiced on only a small scale in the U.S. The emergence of longwall mining in Britain and elsewhere in Europe was dictated by gradual increases in working depths to levels where the large pillar requirements of room-and-pillar techniques became increasingly costly (Walker 1996, Chapter 3). Advances in face conveyor equipment developed by Germans after World War II was another important milestone for spurring longwall adoption in the U.S. Bucket wheel excavator technology developed for German lignite extraction is now employed in the Texas lignite industry. It has also been argued that Europe's concern with mine safety -- e.g. methane drainage -- preceded, and helped intensify, such concern in the U.S. Additionally, according to the GAO, as of the latter 1970s, "European miners are given considerably more safety and skill training in more facets of mining. This increases safety and reduces the disruptive effects of absenteeism. Similar levels of training for U.S. miners may be warranted on safety and productivity grounds" (GAO 1981, pp. vii-viii). Strides over the past several decades in health and safety practices in U.S. coal mining have, of course, been significant, as discussed earlier in Section 4. But in assigning credit for such improvements in health and safety as well as in technological progress, the foreign influence deserves to be kept in mind.

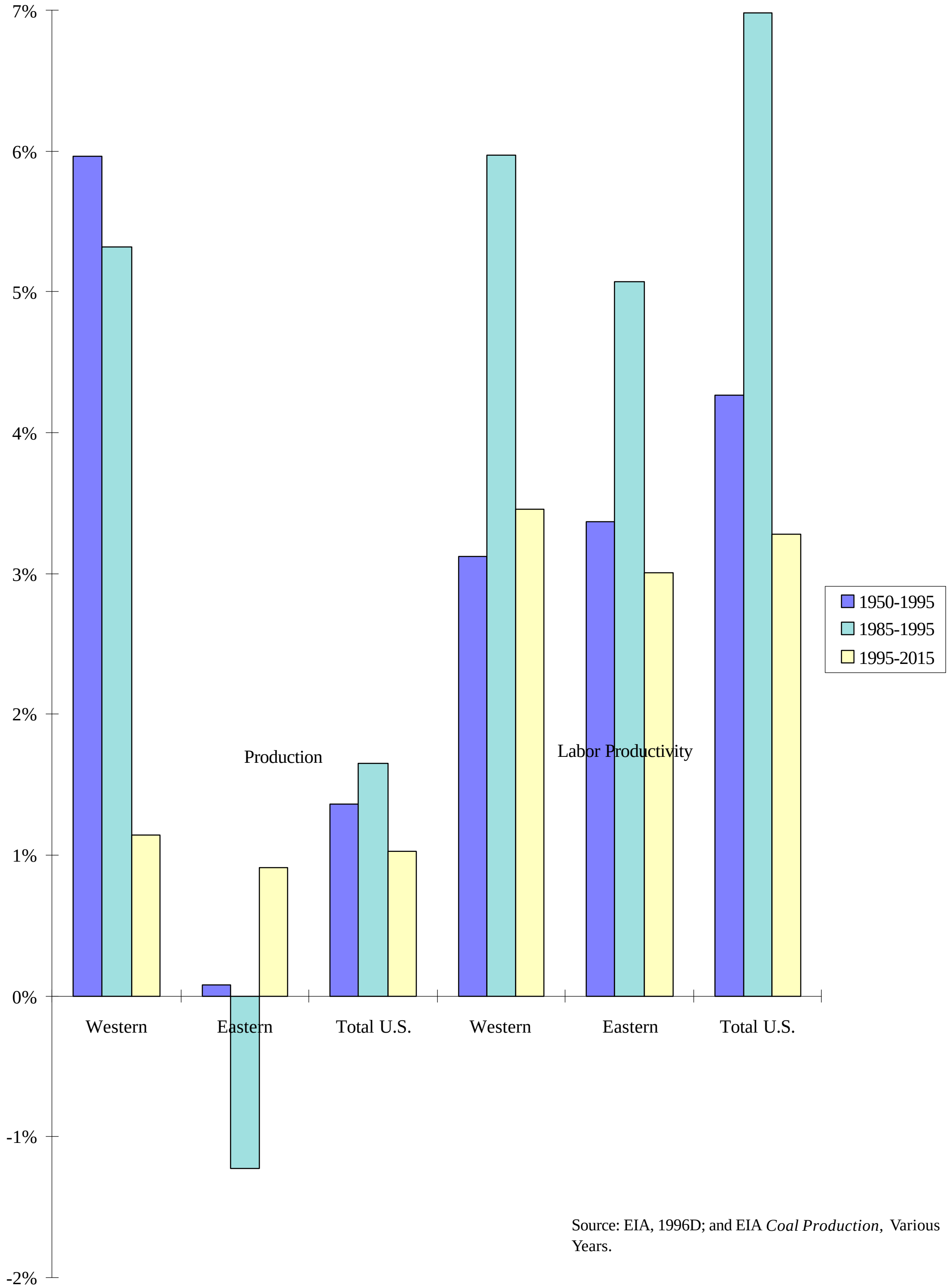
That said, the 1996 IEA Coal Research study concludes that, with respect to longwall extraction, all "the evidence clearly indicates that ... mines in the United States have gained a significant advantage over comparable operations elsewhere" (Walker 1996, p. 71). To be sure, U.S. coal achieves some of its comparative advantage from favorable geologic conditions. (In contrast, the progressive deterioration in the quality of U.S. copper ores puts all the more burden on advances in extractive technologies in that industry, as the RFF companion study clearly shows; see Tilton and Landsberg 1997.) But there is more to it than the good fortune of the U.S. possessing vast and prolific coal seams. Walker credits the U.S. with a twofold set of technological achievements: at a general level, impressive techniques of quality control and sophisticated management information systems; at a more specific level, efficient coal handling and conveyor systems capable of maintaining "sustained peak face output without [being] a bottleneck in the process, as has often occurred elsewhere in the past. As a result, longwall mines typically can achieve utilization factors [i.e. the proportion of available time that cutting and other machinery is actually operating] of over 60% compared to the maximum of 50-55% attained in Australia, and around 40% in the United Kingdom" (p. 72).

11. PRODUCTIVITY PROSPECTS AND ISSUES

Compared to the record over the period 1980-95, the projection of labor productivity to the year 2015 is, as EIA sees it in its recent energy forecasting exercise (EIA 1996D, pp. 67-71), in for a fairly sharp deceleration in the rate of growth -- particularly toward the end of the period and particularly in the case of eastern, low-sulfur mines facing the need to exploit progressively thinner and deeper coal seams.[18] Over the two decades as a whole, EIA projects national labor productivity to improve at an annual rate of 3.3 percent. While this is about half the rate achieved during 1980-95, it is not far off the productivity pace achieved in both Eastern and Western coal over the period 1950-95. Keep in mind, in this connection, that the latter period was one that included a decisive shift of coal production from East to West which -- given the West's much higher productivity *levels* -- yielded a *national* rate of productivity improvement exceeding that achieved by either of the two major producing regions. Although some shift from Eastern to Western production is expected to endure, it is projected to be much

[18] The implication that resource constraints (i.e. rising real costs) may start being felt in these regions illustrates how aggregate recoverable reserve estimates, such as those introduced in Section 7, have to be taken with a grain of salt, notwithstanding their definitional characterization as producible at today's prices and technological conditions.

Figure 11-1
Historic and Future Growth Rates for Coal Production and Productivity



Source: EIA, 1996D; and EIA *Coal Production,* Various Years.

less pronounced than in the past. In short, judged in a long-term context, rather than the experience since emergence from the dismal 1970s, a 3.3 percent rate of productivity improvement is not only respectable but healthy enough, in EIA's judgment, to sustain level, and even some decline in, real coal prices. (See Figure 11-1.)

EIA's "Reference Case" shows real coal prices not only retaining their competitive advantage relative to oil and gas, but for that advantage to increase with time. On a Btu basis, the U.S. minemouth coal price stood at 30% of the world oil price in 1995. By 2015, it is projected to fall to 20% percent (and still no higher than 30% in the event of a drastic fall in the price of oil). Of course, a decisive price edge is necessary, but far from a sufficient condition, for coal to enjoy significantly expanded markets. In that respect, EIA foresees a slightly declining share (though a modest absolute increase) in electricity generation and fairly robust growth in exports.

Given the prospective rate of improvement in coal mine labor productivity, accompanied by stable or declining coal prices, one can surmise that, implicitly, total factor productivity will continue to rise as well, though, as in the historical case, below rates of labor productivity improvement. Reinforced by a continued decline in labor demand, inflation-adjusted wage rates remain basically flat.

Little is said by EIA on the extent to which technological and other factors that have supported productivity advance in the past, will remain equally significant driving forces in the future. For example, might diseconomies of scale emerge, dampening the contribution of longwalls and draglines to productivity growth? It is also worth asking whether the long-term market outlook for coal is certain enough to generate the requisite capital investments even if the outlook for such technologies remains promising. In this respect, environmental uncertainties may be the biggest factor clouding the investment picture. Although minemouth coal prices are, as noted, likely to compete favorably with petroleum, pollution control requirements may justify, on the basis of capital and nonfuel operating cost considerations, utility decisions to opt for gas- rather than coal-fired generation. Judgments about the likelihood of CO_2 emission limitations will presumably enter into the industry's strategic planning, as will considerations about access to coal-bearing public lands. But there are no doubt targets of opportunity as well. For example, the need to begin replacing decommissioned nuclear capacity early in the twenty-first century, and the potential increase in coal-fired electric utility plants in a competitive electricity market, may strengthen coal's long-term market prospects.

Although health and safety statutes and practices have reduced coal mine injury and fatality rates in recent decades, health and safety conditions will undoubtedly be a source of enduring concern. In the past, even industry representatives credited the U.S. Bureau of Mines for research that contributed importantly to that improved record. It isn't clear what the Bureau's 1996 demise signifies for future health and safety research. While the final location of the remnants of the Bureau of Mines has not been determined, the expectation is that three of the pre-1996 research centers will be incorporated into the USGS or MSHA. The largest coal companies have the resources, and possibly the motivation, to pick up some of the slack. But, as an “information externality,” whose benefits are not easily appropriable, and an industry where there is very little inter-firm interaction to diversify risk, the presumption that such research will become a willing responsibility of the private sector may or may not be borne out.

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