Impact of Technological Change and Productivity on the Coal Market

by
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The strong pace of improvement in coal industry labor productivity has been a major reason for the decline in coal minemouth prices that has taken place since 1979. The Annual Energy Outlook 2000 *(*AEO2000*) forecast projects that labor productivity on a national basis will improve on average at a rate of 2.3 percent per year between 1998 and 2020, declining from an annual rate of 6.1 percent achieved over the 1988 to 1997 period. This paper examines the components of past gains in productivity, including regional shifts, the exit of less productive producers, and technological progress. Future prospects for continuing productivity gains at sustained, but lower, rates of improvement are discussed.*

Background

Between 1979 and 1997, real (inflation-adjusted) U.S. coal minemouth prices declined by more than 60 percent.[1] The *Annual Energy Outlook 2000* (*AEO2000*) forecast, prepared by the Energy Information Administration (EIA), projects further declines in coal prices over the next 20 years, primarily attributable to continued improvements in labor productivity and strong competitive pressures within the industry. Future productivity gains will depend on additional penetration of more efficient production methods and technologies that are already available and the development and application of new technology. Projecting the pace at which new mining equipment and production methods will be introduced and the upper limits for their performance are sources of uncertainty in the coal forecast.

The *AEO* estimates of future productivity in coal are based on historical trends. The trends reflect the composite effect of three underlying components: marked shifts in coal production to regions with high levels of productivity, the exit of less productive mines, and productivity improvements in each region resulting from improved technology, better planning and management, and improved labor relations.

This paper discusses the relative impacts that these components have on aggregate productivity and assesses the ability of the industry to continue its strong rate of performance in this area. It examines the impacts that shifts in regional production and the closing or idling of less productive mines have had on aggregate productivity and discusses how technology has affected growth in productivity and the link between capital investment and the application of new technology.

Coal Price Projections in the Coal Market Module of the National Energy Modeling System

The Coal Market Module (CMM) provides annual forecasts of coal prices, production, and exports for the National Energy Modeling System (NEMS), an energy-economy modeling system of U.S. energy markets. The CMM uses an econometric model to forecast coal prices at the minemouth. The econometric methodology relates minemouth prices for specific coal-producing regions and mine types to a set of independent variables that include labor productivity, coal production, wages, fuel costs, and the costs of capital equipment. Labor productivity regression coefficients are estimated for each region and mine type.

In general, projections of the explanatory variables are based on macroeconomic forecasts, a review of historic trends (in the case of wage rates), and inputs from other NEMS modules. Regional productivity levels that are used in the price forecasting model are derived either by separate econometric equations or by offline trend analysis.[2] The demand for coal in each year is determined in

[1]Energy Information Administration, *Annual Energy Review 1998*, DOE/EIA-0384(98) (Washington, DC, July 1999), Table 7.6.

[2]Details of the econometric specification for coal minemouth pricing are presented in the documentation report, *Coal Market Module of the National Energy Modeling System*, DOE/EIA-M060(2000) (Washington, DC, January 2000).

an iterative process within NEMS that computes a least cost solution that is consistent with the energy requirements of each demand sector (including the world coal trade market), capital and operating costs of new energy-using equipment, environmental constraints, and the delivered prices of competing fuels. Coal distribution patterns, from supply regions to demand sectors, are based on coal quality requirements, and delivered prices, which incorporate minemouth and transportation costs.

Coal Prices and Competition

Strong competitive forces are driving coal markets and coal prices. The principal market for coal is the electricity generation sector, accounting for approximately 90 percent of domestic sales. Although coal has been and continues to be the primary fuel for electricity generation in the United States, electricity producers are increasingly turning to natural gas as the fuel source for new generating capacity, and some older plants may need to retrofit existing coal-burning units with scrubbers and low nitrogen oxide burner technology and/or switch to lower sulfur coals to maintain their position in the dispatch order, given existing environmental restrictions. The U.S. Environmental Protection Agency has proposed revisions to existing air quality criteria for fine particulates and ozone that could tighten requirements and necessitate additional control measures to reduce emissions from fossil-fired generating plants.

In the international arena, other coal-producing countries, including Australia, South Africa, Colombia, and Venezuela, have increased production and by aggressive pricing, coupled with favorable currency exchange rates, have achieved a growing share of traditional U.S. export markets and gained footholds within the United States. These factors have tended to cap the expansion of markets for U.S. coal and placed strong competitive pressures among domestic producers to keep coal prices low relative to other fuels, in order to maintain existing sales quantities and market share. Concerns related to the ultimate impacts of the Kyoto Protocol and subsequent measures regarding greenhouse gases also loom over future decisions that will affect coal use. Although EIA's *AEO2000* reference case forecast is neutral with respect to prospects for ratification of the Kyoto Protocol or similar measures, the potential for some form of controls on greenhouse gas emissions is likely to influence future decisions on capital investment related to coal.

Relationship of Labor Productivity to Prices

Coal labor productivity (measured as output in tons per miner per hour) is a key determinant of mining costs and prices in a competitive market.[3] EIA publishes detailed annual data on by region, mine type, mine size, and other measures that provide a disaggregation of trends in coal industry labor productivity. The product of hourly wage rates for labor (after adjustment for benefits, bonuses, insurance, and other items paid by the employer) and the reciprocal of labor productivity, expressed in miner-hours per ton, provides a measure of the labor cost per ton of production. Bureau of Labor Statistics data indicate that earnings of coal mining production workers averaged $19.34 per hour in 1999.[4]

Detailed studies of the components of aggregate total productivity indicate that labor constituted the largest input value share in the coal industry over the period 1947-1991, on the order of 40 percent, and that a close relation has existed between rates of change in labor productivity and total factor productivity, which measures changes in output to changes in a composite of all inputs used in production, including capital, labor, energy, and other inputs.[5] As such , trends in labor productivity constitute a reasonable proxy for trends in total factor productivity.

Certain factor input costs, such as capital costs for new equipment and the price of electricity or diesel fuel used in the production process, tend to vary only slightly across coal producers within a given region. However, because of differences in coal geology, mine characteristics, in-place capital equipment, and other local conditions, there is sufficient variation of productivity levels within and across regions and mine types to result in significant differences in the costs of production.

[3]Labor productivity is calculated by dividing total coal production by the total direct hours worked by all employees engaged in production, preparation, processing, development, maintenance, repair, and shop or yard work at mining operations, but excluding office workers. For 1997 and prior years, as well as the *AEO2000* forecast years, the measure also includes hours for all technical and engineering personnel. Increased productivity may be related in part to reducing staff other than miners. For 1998 and future years, EIA will obtain coal production and employment data through a data-sharing agreement with the Mine Safety and Health Administration (MSHA). MSHA has a separate category for office workers, which includes both professional and clerical employees. Employee hours in this category will not be included in the productivity statistic, beginning in 1998. The coal forecasts appearing in *AEO2001* and in subsequent reports will be based on the productivity definition used by MSHA and published by EIA in its *Coal Industry Annual*.

[4]Bureau of Labor Statistics, web site http://stats.bls.gov/ceshome.htm. Earnings include premium pay for overtime, but exclude irregular bonuses, various welfare benefits, and payroll taxes paid by employers.

[5]A.D. Ellerman, T.M. Stoker, and E.R. Berndt, *Sources of Productivity Growth in the American Coal Industry*, MIT-CEEPR 98-004 WP (Cambridge, MA: Massachusetts Institute of Technology, March 1998).

Overview of Trends in National Productivity

National productivity rates are determined by calculating a production-weighted average of the productivity levels of individual producers. Strong year-to-year gains have been achieved in most regions in both surface and underground mines, with an overall rate of improvement averaging 6.7 percent per year between 1978 and 1998. Three primary factors have contributed to the improvement in productivity:

- The regional shift to western, thick-seam, surface-mined coal, which in some areas of the West is produced at productivity rates that are more than six times the U.S. average productivity rate.
- Strong interfuel and intrafuel competition, coupled with excess production capacity for some coal types, which has led to the exit of less efficient (and generally smaller) producers.
- Technological change throughout the coal industry, which has more than offset resource depletion effects.

Projections of future productivity gains must consider the expected rate of change for the individual components that determine aggregate productivity improvement. Changes in each component—regional shifts in production levels, entry / exit of producers, and productivity gains at individual mines—take place at different rates over time. Determining and monitoring the relative impact of changes in the components and developing better methodologies for forecasting their path should result in an improved ability to project aggregate productivity improvement over the mid-term forecast period.

Productivity Measurement

The Bureau of Labor Statistics (BLS) regularly publishes data concerning labor productivity changes in various industries. The BLS estimates that output per hour in the bituminous coal and lignite mining industry increased at an annual rate of 5.9 percent over the period 1987-1998. The BLS index uses an output measure based on the value of coal production, whereas the EIA output measure is based on tons of production, with no adjustment for price. The BLS and EIA labor productivity measures track each other closely.[6] Unit labor costs (calculated as the ratio of current dollar labor compensation to constant dollar output), which measure the cost of labor input required to produce one unit of output, decreased at an annual rate of 2.9 percent per year. Productivity growth rate increases for coal mining were among the highest reported for all sectors.

In comparison, output per hour in the crude petroleum and natural gas industry increased at a rate of 2.3 percent per year, and unit labor costs increased at rate of 2.9 percent annually.[7] Labor productivity in the overall manufacturing sector rose by 3.0 percent on average per year over the period 1988-1997, while unit labor costs rose by 0.4 percent.[8] The BLS measure of compensation includes payroll expenses (wages, bonuses, vacations, etc.), as well as supplemental payments for legally required and voluntary employer expenditures. BLS noted the following regarding the relationship between output from an industry and the labor time involved in its production: "Although these measures relate output to hours of employees or all persons engaged in an industry, they do not measure the specific contribution of labor, capital, or any other factor of production. Rather, they reflect the joint effects of many influences, including changes in technology; capital investment; level of output; utilization of capacity, energy, and materials; the organization of production; managerial skill; and the characteristics and effort of the workforce."[9]

Econometric Study of Productivity Change, 1972-1995

Researchers at the Massachusetts Institute of Technology have published a detailed econometric analysis of coal industry productivity growth using 11 regional and production technology subaggregates. The study identifies four sources of productivity growth: scale effects, fixed effects, price effects, and residual time effects. While the effects vary substantially across subaggregates, the study finds that "the effect of scale on labor productivity, and presumably on unit cost, is pervasive" and concludes that there appears to be no tendency for the mean productivity of a given vintage to rise over time; rising fixed effects are due to higher labor productivity that is associated with successive vintages, particularly in the later years of the time period examined.

[6]U.S. Department of Labor, Bureau of Labor Statistics, *Productivity and Costs: Service-Producing and Mining Industries, 1987-98*, web site ftp: / / 146.142.4.23 / pub / news.release / prin.txt. The BLS productivity measure, expressed in output per employee hour, uses a chained output index based on the production tonnages of four ranks of coal (bituminous, subbituminous, lignite, and anthracite) that are weighted by their corresponding minemouth prices.

[7]U.S. Department of Labor, Bureau of Labor Statistics, *Productivity and Costs: Service-Producing and Mining Industries, 1987-98*, web site ftp: / / 146.142.4.23 / pub / news.release / prin.txt.

[8]U.S. Department of Labor, Bureau of Labor Statistics, *Productivity and Costs: Manufacturing Industries, 1987-97*, web site ftp: / / 146.142.4.23 / pub / news.release / prin2.txt. Note that the end year is 1997 for Manufacturing Industries, compared with 1998 for Service-Producing and Mining Industries.

[9]U.S. Department of Labor, Bureau of Labor Statistics, *Productivity and Costs: Service-Producing and Mining Industries, 1987-98*, web site ftp: / / 146.142.4.23 / pub / news.release / prin.txt.

The analysis also indicates that when output prices fall relative to wage rates, attempts will be made to improve labor productivity. They note that in the mid to late 1970s, when coal prices increased more rapidly than wages, labor productivity declined as companies opened mines that were not only smaller but also apparently less favorable geologically. The authors also note that many of those mines closed within several years when relative coal prices fell.[10]

Regional Shifts in Production Levels and Productivity

Historical Trends

Changes in national productivity are the composite result of changes in the basic level of productivity for a region and mine type and shifts in regional production levels. A change in the quantity of coal that is produced in a given region can affect the national average productivity, even if productivity rates in all regions are unchanged. Since 1970, mines located west of the Mississippi River have made significant gains in both production levels and market share. The regional shift in production shares, coupled with high productivity rates from thick-seam surface mines in the Powder River Basin (PRB) in Wyoming and Montana, has led to strong national rates of productivity improvements.

The shifts in regional production volumes are the result of market growth in coal-using sectors, interfuel competition, and relative regional coal prices (coal-on-coal competition). The integrated regional structure of NEMS supports analysis of future regional shifts in production by projecting regional demands by sector and the costs of alternative feasible sources of supply and then applying an algorithm that minimizes the overall delivered cost of the coal in each forecast year.

Strong interfuel competition, especially from natural gas, in the electricity generation sector and the difficulty of financing large-scale baseload generating units under electricity restructuring are expected to limit new coal-fired generation builds and reduce the market share held by coal. The shift in regional production volumes to meet the demand for coal is determined by price competition among coal-supplying regions, after factoring in the costs of meeting environmental requirements. Over the period 1988-1997, regional coal production levels changed significantly (Table 1).

Because of improvements in productivity and the shift of production share to the West, a U.S. production increase of 1.5 percent was achieved despite a 5.5-percent annual decline in the average number of miners.[11] Productivity increases in the Western Region (5.4 percent) equaled those in the Interior and were somewhat higher than those in the Appalachian Region (4.9 percent) (Table 2). As a result of the strong gain in the share of production held by the Western Region, there was a 6.1-percent increase in U.S. productivity, greater than the rate in any of the regions individually.

Table 1. Coal Production by Region, 1988 and 1997

Coal-Producing Region	1988		1997		Average Annual Percent Change in Production
	Production (Million Short Tons)	Percent of National Total	Production (Million Short Tons)	Percent of National Total	
Appalachian	449.4	47.3	467.8	42.9	0.4
Interior	193.0	20.3	170.8	15.7	-1.3
Western	307.9	32.4	451.2	41.4	4.3
U.S. Total	**950.3**	**100.0**	**1,089.9**	**100.0**	**1.5**

Source: Energy Information Administration, *Coal Industry Annual 1997*, DOE/EIA-0548(97) (Washington, DC, December 1998), Table 1.

Table 2. Regional Coal Productivity, 1988 and 1997
(Short Tons of Coal Produced per Miner per Hour)

Coal-Producing Region	1988	1997	Average Annual Percent Change
Appalachian	2.44	3.76	4.9
Interior	3.45	5.54	5.4
Western	11.01	17.75	5.4
U.S. Total	**3.55**	**6.04**	**6.1**

Source: Energy Information Administration, *Coal Industry Annual 1997*, DOE/EIA-0548(97) (Washington, DC, December 1998), Table 48.

[10] A.D. Ellerman, T.M. Stoker, and E.R. Berndt, *Sources of Productivity Growth in the American Coal Industry*, MIT-CEEPR 98-004 WP (Cambridge, MA: Massachusetts Institute of Technology, March 1998).

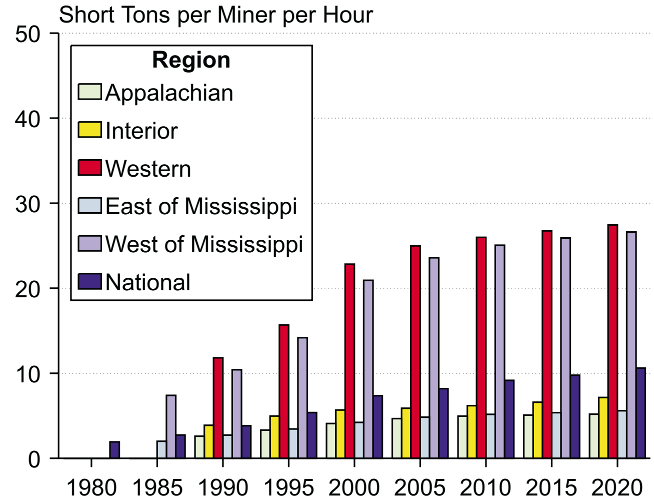
[11] Energy Information Administration, *Coal Industry Annual 1997*, DOE/EIA-0548(97) (Washington, DC, December 1998), Table 40.

AEO2000 *Projections*

In the *AEO2000* forecast (Table 3),[12] western coal production gains continue, reflecting both low costs of production and increased demand for low-sulfur coal to meet environmental requirements.[13]

AEO2000 projects that national aggregate labor productivity will increase from 6.47 to 10.61 tons per miner hour between 1998 and 2020. Regional productivity gains are projected to continue but decline from recent historical rates over the 2000-2010 period and then drop more sharply over the 2010-2020 period. This pattern initially tracks recent productivity trends in each region, but growth rates decline in later years to reflect analyst judgment that future productivity gains will be tempered by low coal prices and a slower rate of introduction of labor-saving technology (Figure 1). Because production is expected to increase at the fastest rate in the already highly productive Western Region, aggregate U.S. productivity is projected to increase more quickly (2.3 percent annually over the 1998-2020 period) than productivity in any major component region (Table 4).[14]

Figure 1. National and Regional Coal Productivity Levels, 1980-2020



Source: AEO2000 National Energy Modeling System, run AEO2K.D100199A.

Table 3. Projected Coal Production by Region, 1998 and 2020

Coal-Producing Region	1998 Production (Million Short Tons)	1998 Percent of National Total	2020 Production (Million Short Tons)	2020 Percent of National Total	Average Annual Percent Change
Appalachian	469.9	41.7	384.8	29.2	-0.9
Interior	168.4	14.9	154.8	11.8	-0.4
Western	489.3	43.4	776.0	59.0	2.1
U.S. Total	**1,127.6**	**100.0**	**1,315.6**	**100.0**	**0.7**

Source: AEO2000 National Energy Modeling System, run AEO2K.D100199A.

Table 4. Projected Regional Coal Productivity, 1998 and 2020
(Short Tons of Coal Produced per Miner per Hour)

Coal-Producing Region	1998	2020	Average Annual Percent Change
Appalachian	3.91	5.19	1.3
Interior	5.59	7.15	1.1
Western	19.58	27.42	1.5
U.S. Total	**6.47**	**10.61**	**2.3**

Source: AEO2000 National Energy Modeling System, run AEO2K.D100199A.

[12]The values for production and productivity for 1998 shown in Tables 3 and 4 are forecasts, which are consistent with *AEO2000*. Final historical values for 1998 were published in June 2000 in EIA's *Coal Industry Annual 1998*, DOE/EIA-0584(98), after the December 1999 release of *AEO2000*. The historical values for regional production and productivity differ slightly from the forecast values for 1998 that appear in this paper.

[13]The forecast values for average annual percent change in coal production by region are based on coal tonnage. If the computation were based on the total energy content of the coal produced, slightly different growth rates would result. For example, the growth rate of U.S. coal production, based on energy content, is projected to increase at an annual rate of 0.6 percent over the period, compared to the 0.7-percent growth in coal tonnage.

[14]The values for production and productivity for 1998 shown in Tables 3 and 4 are forecasts, which are consistent with *AEO2000*. Final historical values for 1998 were published in June 2000 in EIA's *Coal Industry Annual 1998*, DOE/EIA-0584(98), after the December 1999 release of *AEO2000*. The historical values for regional production and productivity differ slightly from the forecast values for 1998 that appear in this paper.

Additional penetration of certain highly productive technologies, such as longwall mining, could be limited by surface subsidence concerns and by reduced availability of new sites with appropriate geologic characteristics and reserve blocks. New or more stringent regulations on coal mining could potentially increase reclamation costs. A significant share of recent surface mine development in the Appalachian region has been mountaintop removal (MTR) projects. Court actions pertaining to MTR have delayed further development and led to the shutdown of several existing mines and the downsizing of others. Pending adjustment to new regulations, it is possible that productivity growth will slow in this mine category. Other environmental regulations relating to the size of waste impoundments at preparation plants may also lead to somewhat lower productivity rates in the region.

Entry/Exit/Expansion

New mines and existing mines that have expanded capacity typically have higher productivity than those mines that have closed. Over time, this results in higher aggregate productivity. The number of coal mines in the United States dropped at an annual rate of 8.0 percent over the period 1988-1997, with declines occurring in all regions.[15] While many mines have closed during this period (particularly small mines), the large operations have been able to more than offset the loss in production that resulted from the closures. Production at the 208 mines producing at least 1 million tons per year accounted for 75.5 percent of U.S. production.[16]

The future impact of the entry, expansion, and exit of individual firms on aggregate productivity is dependent on the degree to which firms with higher productivity are able to displace less efficient firms (which may currently hold contracts at above-market prices) by offering lower prices. The *AEO* productivity forecast assumes that, as mines reach optimum scale within a region/mine type and advanced technology approaches upper limits of penetration, the performance differentials among remaining mines will narrow and the rate of exit of existing mines will slow.

Productivity Gains at the Mine Level

In addition to the effects of regional shifts in production levels and the entry, expansion of production, and exit of firms, national aggregate productivity has improved as a result of technological gains and operational changes at the individual mine level. The core rate of productivity improvement (productivity change excluding effects of regional production shifts and exit of producers) differs within and across regions and mine types, reflecting in large part the geologic characteristics at each producing site. The geologic factors, such as the nature of the terrain, seam thickness, and resource size, determine the economic feasibility of introducing new technology and improved production methods.

Technology Progress

The rate at which productivity will advance is dependent on the mix of relatively new technologies that are contributing to the gains, their individual significance in realizing productivity improvement, and their stage in the technology diffusion cycle. Federal Reserve Chairman Alan Greenspan, in remarks to the New York Association for Business Economists, recently noted that "What differentiates this period from other periods in our history is the extraordinary role played by information and communication technology . . . . Most of the gains in the level and growth rate of productivity in the United States since 1995 appear to have been structural, largely driven by irreversible advances in technology—irreversible in the sense that knowledge once gained is almost never lost."[17]

The impacts of information and communication technology on coal industry productivity are difficult to quantify, but they have enhanced production planning and scheduling and have led to improved mining operations and preventive maintenance of production equipment. Such measures have led to increased availability and utilization of capital equipment and minimized nonproductive work hours. Two uncertainties are whether the technological improvements and other advances that have led to productivity gains in the past two decades are one-time or repeatable, and whether they are approaching the maximum likely penetration in the coal industry. The potential for achieving major productivity gains from even larger material handling equipment could be limited, but other improvements contributing to higher output, such as advances in equipment electronics and control systems, are still likely. Additional uncertainty with respect to future productivity gains results from the difficulty in projecting the rate at which invention and innovation of new technologies will take place and the extent to which seemingly unrelated technologies may be adapted to new uses in coal production.

Technology can serve to expand coal markets as well as improve the costs and performance of coal production. To the extent that new technology can produce

[15]Energy Information Administration, *Coal Industry Annual 1997*, DOE/EIA-0548(97) (Washington, DC, December 1998), Table 2.

[16]Energy Information Administration, *The U.S. Coal Industry in the 1990's: Low Prices and Record Production*, DOE/EIA-0631(99) (Washington, DC, September 1999), Table 1.

[17]Alan Greenspan, U.S. Federal Reserve, web site www.federalreserve.gov/boarddocs/speeches/2000/20000613.htm.

cost-effective solutions to certain environmental problems, coal use could increase beyond current projections. More efficient and less expensive scrubbers, nitrogen oxide (NO_x) control measures, and fine particulate control technologies under development will improve the economics of installing and using emissions control equipment. Funding has been authorized for further research and development on advanced coal-burning units and carbon sequestration technologies that could greatly reduce concerns about emissions of sulfur dioxide (SO_2), NO_x, and greenhouse gases. The pace of development and degree of success that these new technologies achieve will be key determinants of the future position of coal relative to competing fuels.

Examples of Technology Improvements

The U.S. coal mining industry has developed or adopted a number of technological changes in each stage of production and achieved economies of scale that have contributed to overall productivity improvements. Examples include mining equipment and materials handling in underground mines, surface mining equipment and methods, equipment monitoring and automation, and mine planning.

Underground Mines: Mining and Materials Handling Equipment

Larger motors and improved designs of longwall shearers and continuous miners have contributed to greater output per hour. These improvements have led to increases in longwall production, despite a reduction in the number of longwall units. Face widths and panel lengths have increased, and the depth of the shearer's cut into the face now averages 37 inches, with some units capable of a 42-inch cut.[18] Although the number of U.S. longwall mines appears to have leveled off to the 60 to 65 currently in operation, gains in productivity and the closing of less productive conventional underground mines have resulted in longwall mines representing an increasing proportion of all underground production (Table 5). In 1997, longwall productivity averaged 4.62 tons per miner per hour, compared with 3.58 for continuous miners and 2.64 for conventional mining methods.[19]

Conveyor motors have improved and belt sizes have increased (from 48 to 60 inches), permitting higher delivery rates from the mine face to offloading points.

Surface Mines: Mining Equipment and Mining Methods

The capacity, size, and performance of draglines and power shovels have increased, contributing significantly to the growth of production in large-scale surface mines such as those in the Powder River Basin. Larger haul trucks with capacities of 240 tons are now in widespread use, and trucks that are capable of hauling payloads in excess of 320 tons have entered service at large surface mines. Their use, in combination with mining shovels capable of 100-ton payloads, improves cycle times and scheduling.[20,21] Blast casting, which applies improved methods of placing and detonating explosives at surface mines, has made it possible to remove overburden directionally from the coal seam so that subsequent removal requirements are less extensive.

Equipment Monitoring and Automation

Equipment maintenance and downtime inevitably entail higher production costs associated with repair personnel and disruptions to established work patterns. Improvements in equipment monitoring via special sensors and computerized diagnostics have resulted in longer service lives and fewer unscheduled maintenance activities. Computer-supported automation and the introduction of robotics have been applied to both surface and underground mines. More precise control of longwall shearers and shields in underground mines has expanded production rates in large underground mines. Satellite tracking of material handling equipment

Table 5. Longwall Mine Production Compared with Total Underground Production

Year	Longwall Production (Million Short Tons)	Total Underground Production (Million Short Tons)	Longwall Share of Underground Production (Percent)
1983.	79.6	298.3	26.7
1993.	109.7	350.4	31.3
1997.	194.8	420.7	46.3

Note: Production from longwall mines includes production from both longwall units and continuous miners operating at the same mine.

Sources: Energy Information Administration, *Longwall Mining*, DOE/EIA-0588 (Washington, DC, March 1995), Table 14; and Energy Information Administration, *Coal Industry Annual 1997*, DOE/EIA-0548(97) (Washington, DC, December 1998), Table 5.

[18]"U.S. Longwall Census '99," *Coal Age* (1999).
[19]Energy Information Administration, *Coal Industry Annual 1997*, DOE/EIA-0548(97) (Washington, DC, December 1998), Table 54.
[20]P&H Mining Equipment, web site www.phmining.com/products/index.html.
[21]"Ultra-Class Haul Trucks," *Coal Age*, web site www.coalage.com/feature1.html.

is now being employed at surface mines, improving equipment utilization and enhancing the return on capital investment in new machinery.

Mine Planning

Mine planning has been enhanced by the use of more sophisticated computer systems to schedule the sequence of mine development. Remote measurements by satellite have made possible more comprehensive and faster mapping of existing mines and potential resources and have accelerated the determination of optimum paths for mine expansion.

Feasibility of Funding Future Technology

Future introduction and application of new coal mining technology will depend on the expectation of potential benefits of further research and development and the prospects for achieving the requisite return on capital investment. Recent low prices for coal and the prospects for increased environmental restrictions have limited the introduction of new equipment. One equipment manufacturer notes in its annual report: "Our mining customers have deferred purchases of new machinery for several years in recognition of economic uncertainties. As a result, some equipment is aging beyond its economically useful life."[22] This view suggests that there is potential for further gains in productivity caused by capturing the pent-up opportunities for improved efficiency. Alternatively, if the pessimistic sentiment continues, it could dampen the rate of productivity gains obtained from the penetration of new technology.

Economic Census Data

The Economic Census—Mining (formerly conducted as the Census of Mineral Industries) is one of a series of 29 industry reports prepared by the U.S. Census Bureau to provide summary operating and financial data on various industries. The census is taken every fifth year, covering calendar years ending in 2 and 7. Four separate publications in the series have been released, for Bituminous Coal and Lignite Surface Mining, Bituminous Coal Underground Mining, Anthracite Mining, and Support Activities for Coal Mining. The data concerning the value of shipments and capital expenditures for each census year (Table 6) are of particular relevance regarding the pace of technology introduction.

The ratio of capital expenditures to the value of shipments (combined surface and underground) ranged from 6.4 percent to 8.6 percent over the three census years. The decline in the value of shipments between 1992 and 1997 is largely attributable to the 13.7 percent drop in nominal minemouth prices during that period.[23] It appears that underground mining entails a greater level of capital expenditure relative to the value of shipments. The data reported in each census year constitute a snapshot for that year and may, in fact, vary significantly on a year-to-year basis because of prevailing economic conditions or irregular investment levels

Table 6. Coal Industry Investment Data, 1987-1997

Mine Type and Census Year	Production (Million Short Tons)	Productivity (Short Tons per Miner per Hour)	Production, Development, and Exploration Worker Hours (Millions)	Shipment Value (Million 1996 Dollars)	Capital Expenditures (Million 1996 Dollars)	Ratio of Expenditures to Shipments
Bituminous and Lignite Surface						
1987	545.3	4.98	99.5	17,480.7	945.3	0.054
1992	590.3	6.59	90.9	15,075.7	982.8	0.065
1997	669.3	9.46	64.7	12,208.6	753.5	0.062
Bituminous Underground						
1987	372.9	2.20	149.9	15,056.9	1,126.7	0.075
1992	407.2	2.93	126.0	13,750.4	1,102.7	0.080
1997	420.7	3.83	91.6	10,603.1	1,203.1	0.113
Surface and Underground (Combined)						
1987	918.8	3.3	249.4	32,537.6	2,072.0	0.064
1992	997.5	4.4	216.9	28,826.1	2,085.5	0.072
1997	1,090.0	6.0	156.3	22,811.7	1,956.6	0.086

Sources: U.S. Census Bureau, *Bituminous Coal and Lignite Surface Mining 1997*, EC97N-21211A, and *Bituminous Coal Underground 1997*, EC97N-2121B (Washington, DC, October 1999); and U.S. Census Bureau, *1992 Census of Mineral Industries, Coal Mining*, MIC92-I-12A (Washington, DC, July 1995), and prior issues.

[22] Harnischfeger Industries, *1998 Annual Report*, p. 6.
[23] Energy Information Administration, *Annual Energy Review 1998*, DOE/EIA-0384(98) (Washington, DC, July 1999), Table 7.8.

resulting from several large expenditures. Accordingly, apparent differences between 5-year periods must be viewed with caution.

The Census Bureau also conducts the Annual Capital Expenditures Survey. In that survey, capital expenditures for coal mining averaged $2.2 billion (1996 dollars) over the 5-year period 1994-1998. Expenditures for equipment represented 77 percent of the total, with the balance allocated to structures. Over that time period, expenditures rose from $1.87 billion in 1994, peaked at $2.45 billion in 1995, and returned to $1.89 billion in 1998. In contrast, expenditures for all non-farm businesses, over the same period, rose in each year at an average rate of 10.6 percent. Expenditures for crude petroleum, natural gas, and natural gas liquids companies increased at a 12.1 percent annual rate.[24]

Company Financial Reports

The relatively complex financial structure of coal-producing organizations and the rapid pace of consolidation cause difficulties in obtaining a longitudinal view of the capital expenditures of major coal companies. However, the commentary provided in the "Management's Discussion and Analysis of Results of Operations and Financial Condition" sections in periodic financial reports provides useful insights into the factors that enter into mid-term planning decisions regarding future introduction of the technology necessary to improve productivity. As an example, the following comments appeared in the Management Discussion section of a recent CONSOL quarterly financial report:

"CONSOL Energy has implemented strategies to reduce costs. We have imposed spending limits on our mines, reducing supply costs. We have deferred capacity expansion projects, reducing planned capital expenditures . . . . CONSOL Energy has focused the Research and Development Department on only those activities that add value to the marketing effort or make a significant contribution to reducing mining costs . . . .[25] Similar comments appear in the reports of other coal producers and illustrate the current emphasis on controlling capital expenditure levels and the focus placed on productivity improvement.

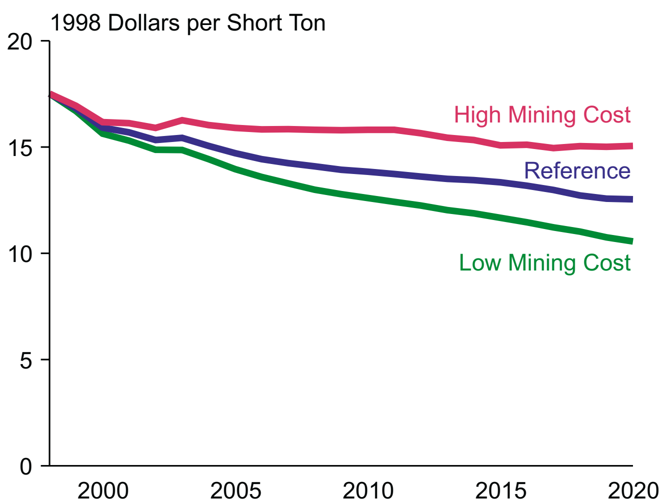
Industry Earnings and Capital Investments

Companies must generate sufficient revenues and earnings to fund investments in both new mines and more productive technology that will keep prices competitive with other producers. The investments must meet corporate targets for return on investment in an environment in which prices are projected to decline in real terms. Contracts that formerly were of long-term duration are being written for shorter time periods and incorporate provisions to renegotiate prices based on prices in the current market. As a result, it may become more difficult to justify or fund technology projects that potentially have a long payoff period. However, this trend toward shorter contracts could be slowed or reversed if customers anticipate that future coal prices will increase relative to current levels and, as a result, elect to lock in contracts for a more extended time period.

Outlook for the Future

AEO2000 projects that national average minemouth coal prices will continue to decline from current levels in real terms through 2020 to a level of $12.54 (1998 dollars) but increase in nominal terms, reaching $20.71 (nominal dollars) per ton in 2020.[26] The *AEO* presents two alternative mining cost cases to examine the impacts of different labor productivity and labor wage rate growth rates. In these cases, real minemouth prices in 2020 range between $10.56 and $15.05 per ton (Figure 2).[27] In the low and high mining cost cases, the *AEO2000* reference case productivity path in each region was adjusted by

Figure 2. Projected U.S. Minemouth Coal Prices in Three Cases, 1998-2020



Source: National Energy Modeling System, runs AEO2K.D100199A, LLCST2K.D100599C, and HLCST2K.D100599A.

[24]U.S. Bureau of Census, web site www.census.gov / prod / 2000pubs / ace-98.pdf, and prior versions.

[25]CONSOL Energy, *Securities and Exchange Commission Form 10-Q* (September 30, 1999).

[26]Energy Information Administration, *Annual Energy Outlook 2000*, DOE / EIA-0383(2000) (Washington, DC, December 1999), Table A16.

[27]Energy Information Administration, *Annual Energy Outlook 2000*, DOE / EIA-0383(2000) (Washington, DC, December 1999), pp. 221 and 241 and Table F16.

1 standard deviation.[28] The resulting national average productivities in 2020 (in short tons per miner per hour) were 14.01 in the low mining cost case and 7.86 in the high mining cost case, compared with 10.61 in the reference case.

In the reference case, labor wage rates for coal mine production workers were assumed to remain constant in real terms over the forecast period. In the alternative low and high mining cost cases, wages were assumed to decline and increase by 0.5 percent per year in real terms, respectively. The two alternative cases are intended to capture the potential for different paths of mining costs. With the exception of the electricity generation sector, the mining cost cases were run without allowing the demands to shift in response to changing prices.

Further penetration of western subbituminous coal into eastern markets and the growth in aggregate productivity associated with this regional shift in production is projected to continue but slow gradually as a result of the increasing distance of hauls and higher associated transportation costs that are necessary to reach new markets at price levels that are more favorable than the total cost of scrubbing nearby higher-Btu coal. The component of productivity improvement that has been produced by more productive firms gaining market share and the exit of less productive firms will moderate as the productivity differential among existing firms in the same region / mine type grouping narrows. As a result, *AEO2000* projects that aggregate productivity gains, due primarily to technological progress and shifts in regional production patterns, will continue over the next 20 years but gradually decline from current rates, averaging 2.3 percent annually between 1998 and 2020.

[28]This is the standard deviation of the moving average of year to year productivity growth rates over the period 1980-1995, calculated separately for surface and deep mines.