SOURCES OF

PRODUCTIVITY GROWTH

IN THE

AMERICAN COAL INDUSTRY

A. Denny Ellerman, Thomas M. Stoker, and Ernst R. Berndt[1]

Massachusetts Institute of Technology

[1] Ellerman is Executive Director, Center for Energy and Environmental Policy Research, and Senior Lecturer; Stoker is the Gordon Y Billard Professor of Applied Economics; and Berndt is the Louis B. Seley Professor of Applied Economics, all at the MIT Sloan School of Management. This paper was prepared for and initially presented at the Conference on Research in Income and Wealth convened by the National Bureau of Economic Research in Silver Spring, Maryland, on March 20-21, 1998.

ACKNOWLEDGMENTS

This work has been made possible by the dedicated efforts of a succession of research assistants who have worked on the database underlying the research. We are particularly indebted to Chiaming Liu, the most recent of these assistants and a graduate student at the Sloan School of Management, who has proven himself particularly adept at manipulating the Access and Stata databases and running innumerable regressions as the analysis proceeded. His work and this paper would not have been possible, however, without the earlier contributions of Frank Felder, Babu Bangaru, Kevin Wellinius, and Narasimha Rao, all former MIT graduate students to whom we are also greatly indebted.

Personnel at the Mine Safety and Health Administration in Denver, Colorado, the source of our data, have been extremely helpful in clarifying definitional and procedural issues concerning the data collection. Special thanks are due Alice Brown, Chief of Statistics, and Rhys Llewellyn, head of the Data Division.

This research has been funded chiefly by the Center for Energy and Environmental Policy Research, through grants from a number of corporate sponsors supporting M.I.T. research in energy and environmental economics. Early funding for this project was also provided by the Office of Coal, Uranium, and Renewable Fuels Analysis at the Energy Information Administration in the U.S. Department of Energy. To all, we are appropriately grateful.

This research has benefited from comments and insights provided by a number of persons in the U.S. coal industry. Particular gratitude is due William Bruno of Consolidation Coal Company, and the senior management of both Cyprus Amax Coal Company and the Pittsburg and Midway Coal Mining Company, all of whom reviewed and commented on earlier versions of our research results.

1. INTRODUCTION

Aggregate productivity statistics succinctly and conveniently measure the efficiency with which resources are being used in a country or industry, but problems of measurement and aggregation require that these statistics be used carefully. . Furthermore, problems of measurement and aggregation can lead to very misleading results. There are two major sources of concern. First, a number of factors influencing productivity cannot be easily observed—for instance, learning. Second, the statistics are aggregates. Interpretation is greatly facilitated by assuming the constituent firms are more or less alike, but everyone understands that this is a simplifying assumption. There is usually no data that permits the analyst to study productivity trends at the level of the firm or to determine the extent to which heterogeneity affects observed aggregate trends.

This paper exploits an unusual database in order to address these concerns to explore the differences between productivity trends as they appear at the aggregate level and as they may be experienced at the firm level. The Mine Safety and Health Administration (MSHA), as part of its regulatory effort, has collected this labor input and coal output information for every mine in the United States since 1972 (our analysis considers data through 1995), along with site locations, operator identity, and mining techniques. Thus, we are able to observe labor productivity for this industry at the lowest practicable level and form a national aggregate, as well as any number of subaggregates, from the bottom up.

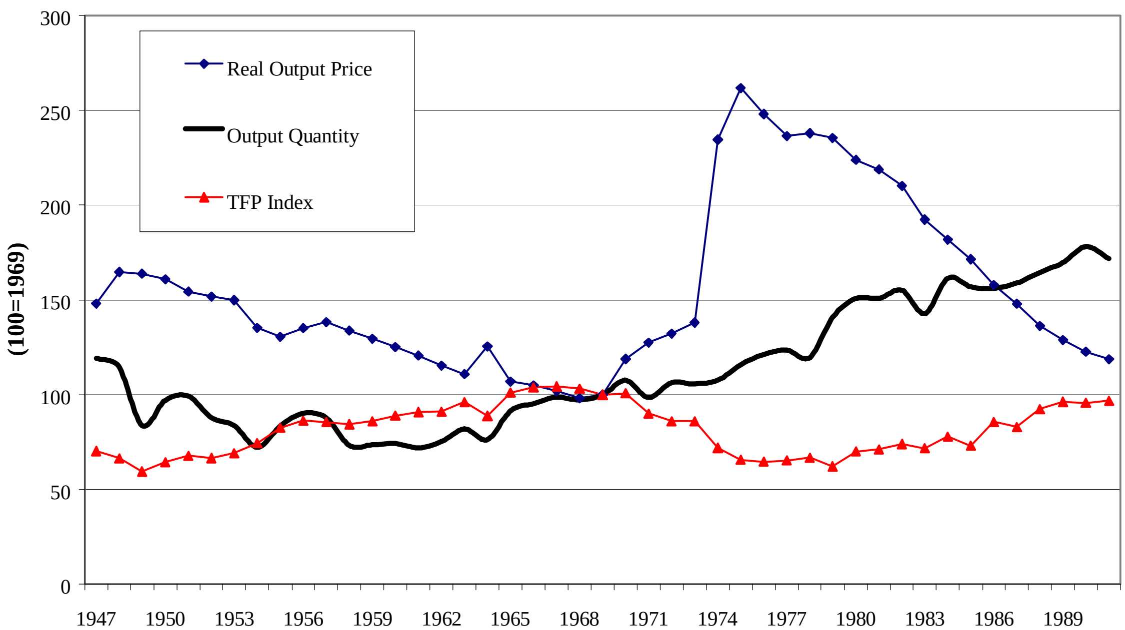
In the next section, we briefly comment on aggregate output, price, and productivity trends in the American coal industry, and then proceed to explain the causes for heterogeneity in the industry and to divide the industry into eleven relatively homogeneous subaggregates based on technology and location (the latter serving as a proxy for geology). Section 3 relates labor productivity to total-factor productivity, then discusses and develops several aggregate measures of productivity change based on our eleven subaggregates. Section 4 explains the data set, presenting first our model for estimating labor productivity at the subaggregate level, then the summary regression results. Section 5 describes and graphically presents what we identify as the four sources of productivity change based on the analysis in Section 4. Section 6 presents concluding remarks.

2. THE AMERICAN COAL INDUSTRY

Post-war Output, Price, and Productivity Trends

While our database limits this analysis to the years 1972–95, a longer view helps to place these years, and particularly the extraordinary decade of the 1970s, in perspective. **Figure 1** provides the essential aggregate statistics for the U.S. coal industry: the price and quantity of output and an index of total factor productivity (TFP) from the late 1940s until 1991. The year our microdata begins, 1972, is close to the year 1969 that, according to anecdote as well as statistics, marked a turning point for the industry.

Figure 1: Price, Quantity and TFP, U.S. Coal Industry



The Mine Safety and Health Act passed in 1969, signaling the beginning of what was to be a decade of increasing regulation to address issues associated with the health, safety, and environmental aspects of coal mining. Perhaps not coincidentally, 1969 also marked the end of a long period of declining real price and moderately increasing productivity. The 1970s were to be characterized by sharply rising nominal and real prices for output and significant declines in coal-mining productivity. Then, in the 1980s and continuing to the present, the former trend of declining real price and rising productivity resumed, at an accelerated pace.

During these periods of alternating productivity and output-price trends was one notable constant: coal output has increased steadily since 1960, despite considerable additional regulatory burdens placed on the industry beginning in 1969. While many factors contributed to the surprising growth in output, the most important were the seemingly inexorable increase in demand for electricity and the always-higher prices of petroleum products and natural gas, coal's chief competitors for electricity generation. Remarkably, when the highly unfavorable productivity and price trends of the 1970s set in for coal, prices of competing fuels rose more, for completely independent reasons. Even more remarkably, when competing fuels' prices collapsed in the 1980s, coal-mining productivity had improved and coal prices had declined so much that coal's share of the electricity market was impacted little.

The aggregate price and productivity trends in Figure 1 make it clear that, at least for the post-war period for which we have adequate data, the 1970s were an exceptional decade. The more recent experience of improving productivity and falling real prices in the 1980s and 1990s reflects the resumption of longer-term trends. A full explanation of the technological regress of the 1970s and the subsequent resumption of technological progress is beyond the scope of this paper. There is undoubtedly more to the story than the conventional explanation: the internalization of various social costs imposed by mine health and safety and surface reclamation legislation, and the effects of disruptions in oil and natural gas supply. We do not attempt to provide a complete explanation here, but our analysis does provide additional insight into the likely causes of falling labor productivity in the 1970s.

Elements of Heterogeneity in the Industry

There are a number of reasons for approaching aggregate coal productivity statistics with caution. Coal is produced in many locations in the United States, from the Great Western Basin to the Appalachian Mountains. Furthermore, labor productivity differs among coal-producing regions, and regional shares of output have changed significantly over the past 25 years. In particular, the Powder River Basin (PRB, in the northeastern corner of Wyoming and adjacent parts of Montana) increased from less than 1% of national production in 1970 to 25% in the mid-1990s. Although the PRB is located far from most coal markets, unusually favorable geology enables the area's operations easily to produce 20 to 30 tons of coal per hour of labor input. In contrast, 8 to 10 tons per hour is as much as the best mines in the Midwest or Appalachia can reasonably hope to achieve. Thus, even if there were no change in productivity within any region, the increasing PRB share would cause the national aggregate to increase.

A second way in which the coal industry exhibits heterogeneity concerns output. Quantity of output is conventionally measured in tons of production, but the ultimate service sought by nearly all coal purchasers is heat content (measured in British thermal units, or Btu), and the Btu content of coal varies considerably. Again, the PRB requires special consideration: the Btu content of each ton of coal produced there is a third to a quarter less than the heat content of Midwestern or Appalachian coals. Thus, although the increase in PRB coal production has been great, however production is measured, statistics based on tons overstate the importance of the PRB and growth in aggregate national labor productivity. The same arguments apply for lignite (an even lower rank of coal than that produced in the PRB),[2] for which the share of national output has also increased, though not as spectacularly as for Powder River Basin coal.

Third, the technology by which coal is produced is not uniform. In fact, mining techniques differ markedly. Productivity levels associated with different techniques not only vary within the same geographic region, but also appear to change at non-uniform rates.

Traditionally, coal mining has been an underground operation in which a shaft is sunk or tunnels are extended into the seam, from which coal is removed and transported to the surface. Underground mining techniques are further divided into two basic types: continuous and longwall mining. Continuous mines have machines with giant bits mounted in front that advance into a seam to remove coal from the face and pass it back to an elaborate conveyer belt or shuttle car system that takes the coal to the shaft for removal to the surface. Such systems require tunnels, and a portion of the coal must be left in place as pillars to support the roof. Longwall mining involves an elaborate shearing device that operates along an extended face (hence the term "longwall"), an attached shield that supports the roof, and a conveyor belt to take the coal to the surface. The distinctive feature of longwall mining is that the whole device—shearer, roof shield, and conveyor system—advances into the face as the coal is removed. The strata above the coal seam are then allowed to subside into the cavity created by the advancing longwall.[3] As a result, a higher percentage of the reserve can be removed than would be the case for continuous mining. The longwall shearer also separates a greater volume of coal from the seam per unit of time than does the continuous miner.

Coal lying close to the surface is mined by techniques in which the overburden is stripped away to expose the coal seam, after which the overburden is put back in place and the original surface condition restored. Bulldozers, steam shovels, draglines, and trucks are employed in essentially a giant earth-moving operation more akin to road-building and sand-and-gravel pits than to the underground mining that conjures the traditional image of black-faced miners tunneling through the bowels of the earth.

All three production techniques compete in most coal-producing regions, although some areas, such as the Powder River Basin and the lignite-producing areas of Texas and North Dakota, are mined exclusively by surface methods. Where the three coal-producing techniques co-exist, their respective shares may reflect

---

[2] Coal is conventionally classified by rank as anthracite, bituminous, sub-bituminous, and lignite (from highest to lowest quality). Rank is determined by a number of characteristics, among which is Btu content. Most coal produced in the U.S. is of bituminous rank, which ranges from 21 to 28 million Btu (mmBtu) per short ton. Sub-bituminous coals, including that produced in the PRB, range from 16 to 23 mmBtu per ton, and lignites have a heat content from 12 to 17 mmBtu/ton. Production of anthracite coal is insignificant and can be ignored for all practical purposes after the Second World War. For a more complete discussion of coal classifications, see DOE/EIA-0584(94), Coal Industry Annual 1994, Table C1.

geological conditions, the effect of factor price trends on differing factor proportions, different regulatory conditions and requirements, and different rates of technological advancement.

Eleven Relatively Homogeneous Subaggregates

In order to account for such geographical, geological, and technological heterogeneities, we assigned every coal mine in the U.S. to one of eleven subaggregates or groups. Table 1 lists these and the average heat content we assume for coal produced by each.

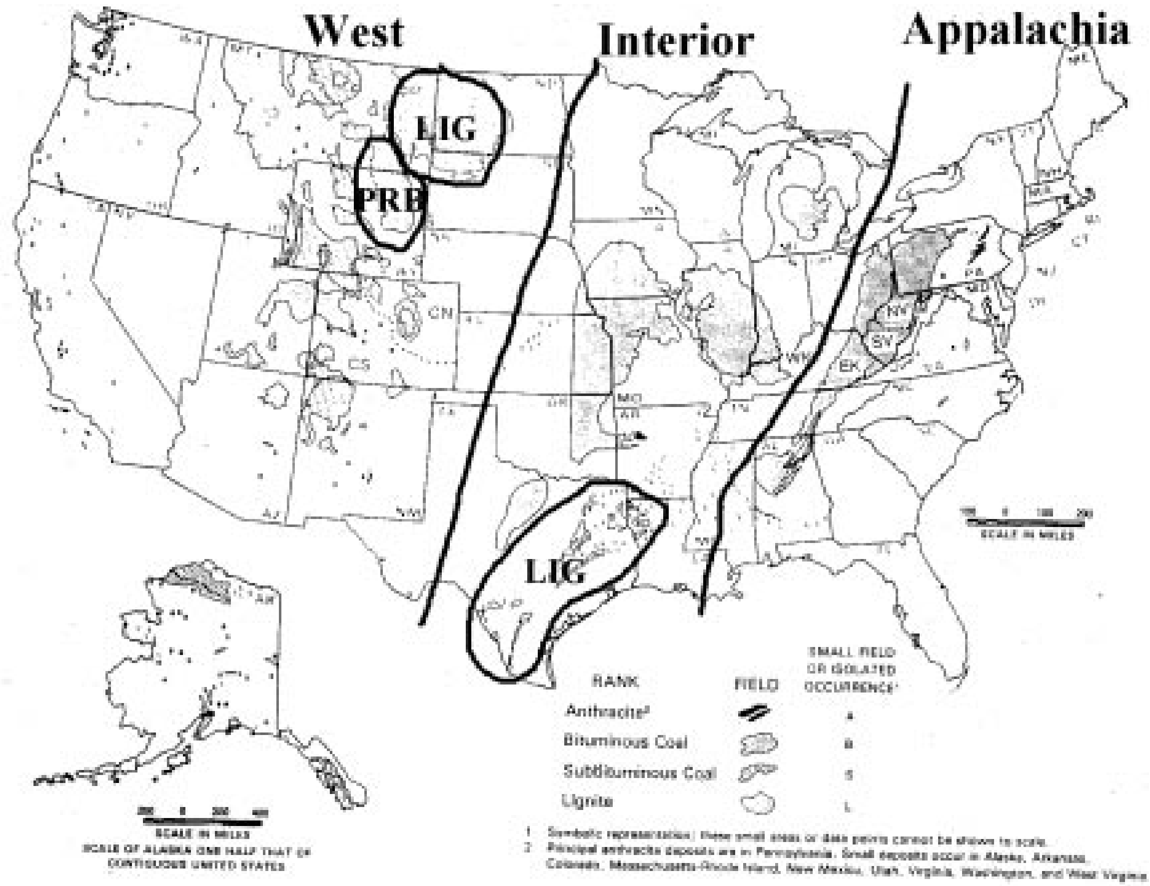
Table 1. Characteristics of the Eleven Subaggregates

Geographic Region	Production Technology	Heat Content
		(million Btu/ton)
Appalachia	Underground/Continuous	23
	Underground/Longwall	23
	Surface	23
Interior	Underground/Continuous	21
	Underground/Longwall	21
	Surface	21
Western	Underground/Continuous	22
	Underground/Longwall	22
	Powder River Basin	17
	Lignite	13
	Other surface	20

These regions are indicated in **Figure 2**'s map of coal reserves. In general, the line dividing the Appalachian and Interior regions represents the Appalachian Mountains' western foothills; the Great Plains (not the Mississippi River) separate the Western and Interior regions. As indicated by the average heat content assignations in Table 1, coal quality generally diminishes westward from Appalachia. Our classification differentiates Western surface production to call out both the aforementioned Powder River Basin, which is sufficiently unique to be considered separately, and lignite, which is produced only in North Dakota, Texas, and Louisiana—the only coal surface-mined in these states. All other western surface production is extremely heterogeneous, comprising relatively high-rank coals in Utah and western Colorado, near sub-bituminous coals in southern Wyoming and the San Juan Basin of New Mexico, and other small coal patches in such disparate locations as Washington state and Arizona. Classifying ("decomposing") western surface production more finely than we have done, to distinguish more than lignite and PRB coal, would offer little benefit since the many disparate Western surface "mines," or pieces, are individually and even collectively not very important in the national aggregate. Although

[3] The roof is supported in the conventional manner for a passage to provide entry and egress at one end of the advancing longwall face.

Figure 2: Coal Producing Regions



Western underground coal includes all underground coal produced west of the Great Plains, this subaggregate is much more homogeneous than Western surface mining; nearly all of it is produced in Utah, Colorado, and the Raton Basin of New Mexico.

Labor productivity varies widely among the eleven subaggregates; **Figure 3** graphs the absolute levels of labor productivity for each group and the national aggregate from 1972 through 1995.[4] The PRB is in a category by itself; the two other Western surface regions exceed all others, though by the end of the period, Western longwall production had reached equal levels. In general, labor productivity declined through the late 1970s or early 1980s, and improved thereafter for all the subaggregates. The national aggregate declined from 45 to 37 mmBtu/hour (1.8 to 1.5 standard tons) from 1972 to 1978 and thereafter increased steadily to a value of 112 mmBtu/hour (4.5 standard tons) as of 1995. Furthermore, as if to make up for the tendency of coal quality to decline from east to west, there is a compensating tendency for the absolute level of labor productivity to improve from east to west.

[4] Many people are unfamiliar with the unit of denomination in Figure 3, million Btu per hour. A standard (eastern) short ton of coal is equivalent to 25 million Btu.

Figure 3: Observed Labor Productivity by Group

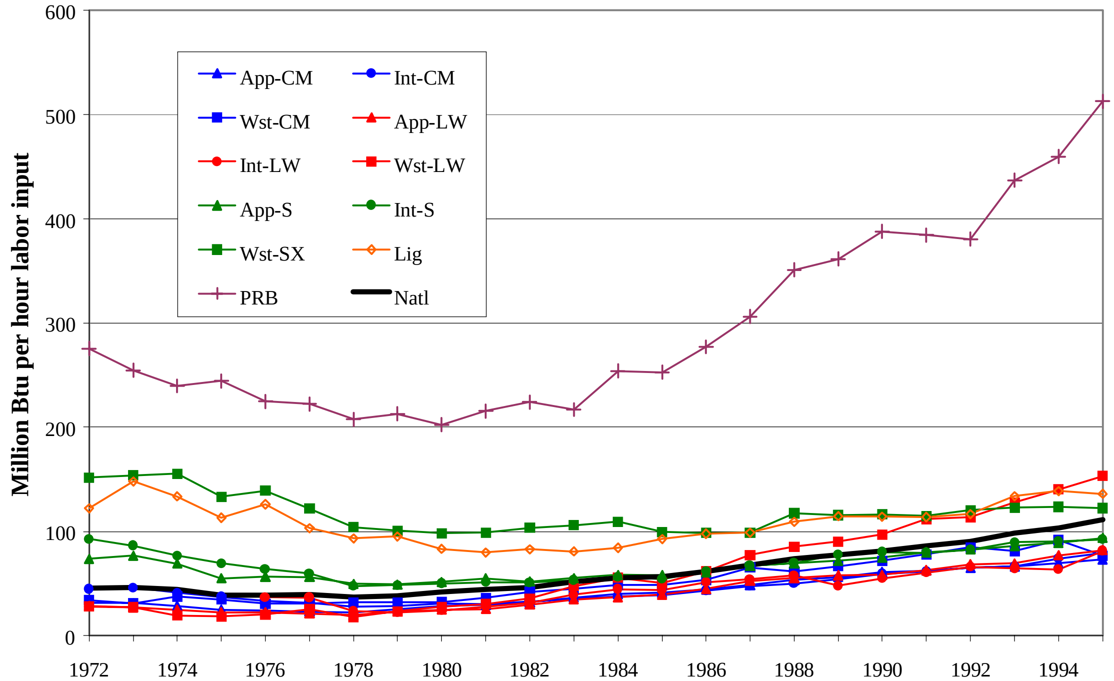
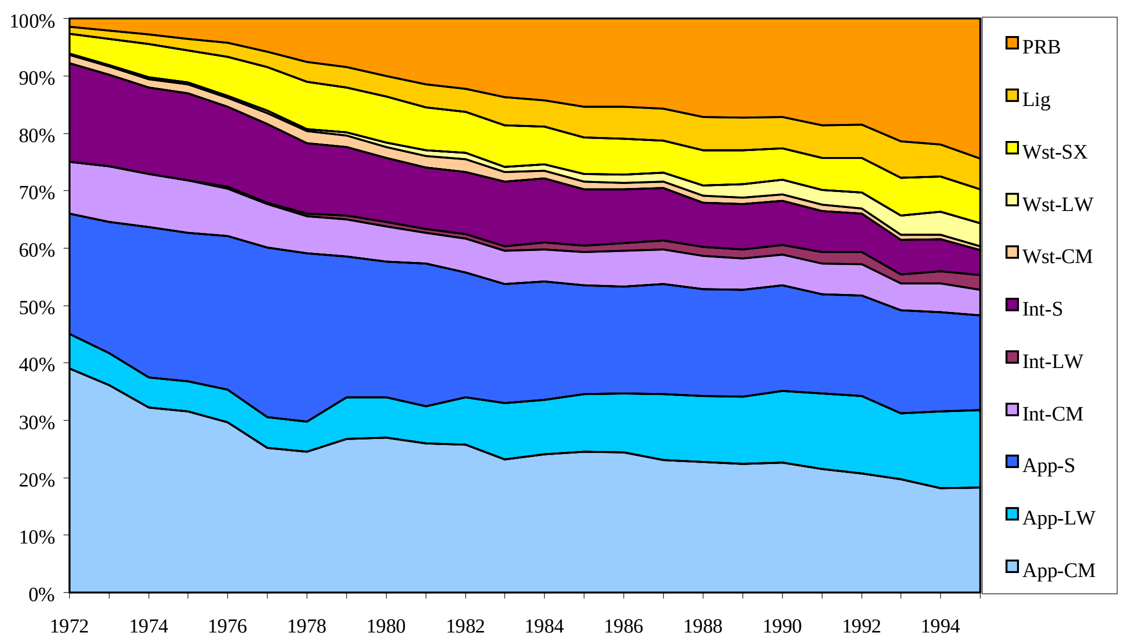


Figure 4: Btu Output Shares by Component, 1972-95



The relative shares of these eleven regions in terms of Btu output are given in **Figure 4**. The three Appalachian regions are the bottom three bands, representing continuous, longwall, and surface production, respectively, followed by the three Interior regions, with the five western regions at the top of the graph. Two points are notable. First, the contribution of Western coal has increased tremendously, from slightly less than 8% of coal Btu output in 1972 to 40% in 1995. In particular, the PRB has risen from 1.5% to 24% of the U.S. coal industry's Btu output. Second, despite a decline in share from 66% to 48% between 1972 and 1995, Appalachia remains the largest producer of Btus from coal.

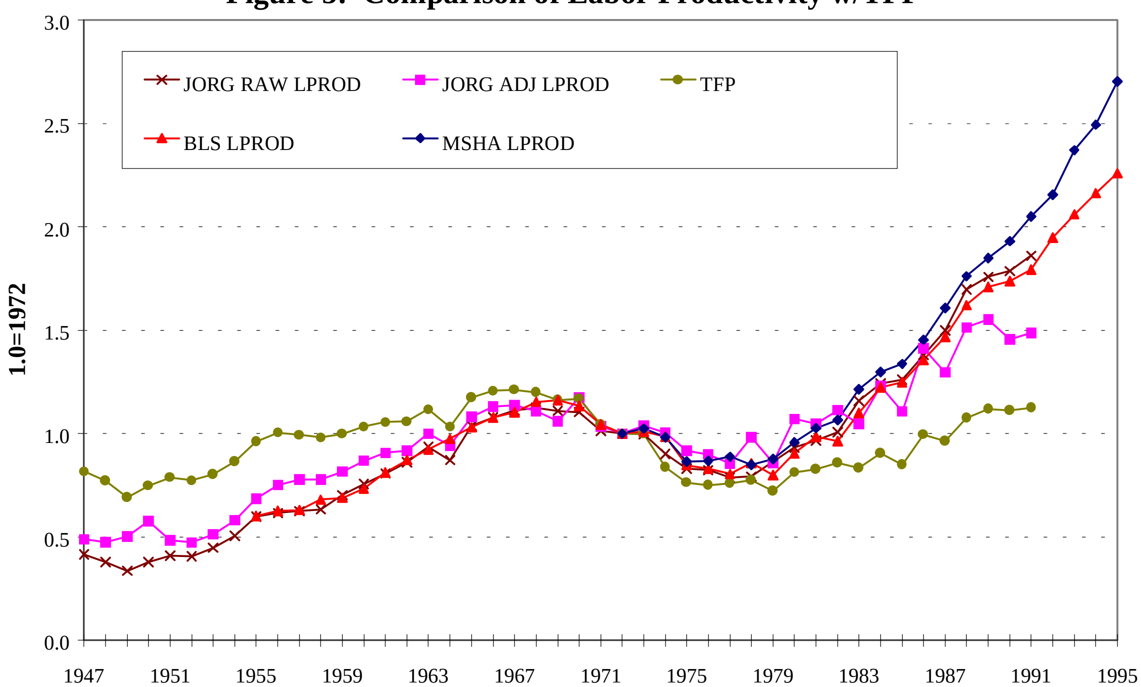
Appendix 1 tabulates total tons (1A), hours of labor input (1B), aggregate labor productivity (1C), and number of mines (1D) for the national aggregate and each of the eleven subaggregates.

3. AGGREGATE MEASURES OF PRODUCTIVITY CHANGE

Labor and Total Factor Productivity

Though our purpose here is not to address the difference between aggregate TFP and labor productivity growth, the two are closely related. **Figure 5** compares the total factor productivity index, first introduced here in Figure 1, with various labor productivity indices.

Figure 5: Comparison of Labor Productivity w/TFP



Five indices are shown, all normalized to the 1972 value. Three indices, spanning the years 1947 through 1991, draw upon aggregate coal industry statistics developed by Dale Jorgenson and associates:[5] output

[5] The development of these aggregate statistics is described in Jorgenson, Gollop, and Fraumeni (1987) and Jorgenson (1990). Dale Jorgenson and Kevin Stiroh kindly provided updated series through 1991.

quantity divided by raw labor hours (Jorg Raw Lprod), labor productivity when labor hours are adjusted for quality differences (Jorg Adj Lprod),[6] and total factor productivity (TFP). The fourth index, ranging from 1955 through 1995, is the Bureau of Labor Statistics' (BLS) measure of labor productivity, which practically coincides with Jorgenson's non-quality adjusted labor productivity index. The last index, which runs only from 1972 through 1995, is formed from the Mine Safety and Health Administration (MSHA) data by summing each year's production across all mines and dividing by the comparable sum for labor hours.

The close correspondence between the MSHA, BLS and Jorgenson non-quality adjusted labor productivity indices indicate that the same underlying phenomenon, undifferentiated labor input hours, is being measured. Moreover, labor productivity and TFP move together, albeit at different rates. During the progressive periods, labor productivity improved at a rate greater than that for TFP; during the one period of regress, labor productivity did not fall as sharply as did TFP. Earlier econometric work using Jorgenson's industry-level statistics suggests the coal industry has a strong laborsaving bias to technical change.[7] This bias explains most of the difference between the rates of TFP and aggregate labor productivity improvement that can be observed in Figure 5. It also suggests that a more or less constant relation exists between rates of change in labor productivity and TFP.

Finally, labor constitutes the largest input value share in output for the coal industry. Approximate shares during the years 1947–91 from Jorgenson's aggregate statistics are labor, 40%; materials 30%; and capital and energy about 15% each, although there has been a slight tendency for the labor share to decline and the materials value share to increase. All of this suggests that observed changes in labor productivity can, with appropriate adjustment, be used as an indicator of change in total factor productivity and output price.

Further support for viewing labor productivity as a proxy for total factor productivity can be found in the relationship between output prices and labor productivity in different coal-producing regions. If factor proportions are more or less constant across regions, then we might expect output prices to reflect, inversely, differences in labor productivity. Coal produced in the extraordinarily productive Powder River Basin currently sells for $4–5 per ton at the mine, while lower-productivity coal produced in the Midwest sells for $18–23 per ton, and still lower-productivity Appalachian coal sells for $22–28 per ton.[8] These price relationships are roughly the inverse of average 1995 productivity levels in these regions.

---

[6] Output is treated as homogeneous, although there are some notable differences in the quality of coal produced by different mines and regions. We address this issue in what follows.

[7] See Berndt and Ellerman (1996).

[8] See any current issue of a number of coal-industry trade weeklies. Prices quoted here are taken from the Jan 19 and Jan 26, 1998, issues of Fieldston Publications' *Coal Markets* .

Aggregation and Substitution

There is an economic aspect to the interpretation of aggregate measures of productivity change. The aggregate provides an appropriate measure of productivity change when the components of a heterogeneous aggregate compete with one another. Competition between two coal-producing regions is no different than that between two mines within the same area. When a more productive mine displaces one less productive, productivity increases even if productivity did not change at either mine. By analogy, when a higher-productivity component of the national aggregate gains share at the expense of a lower-productivity component, the appropriate measure is one that allows for such competition, namely, the ratio of the sums of output and input across the components. However, when the components do not compete, the ratio of summed input and output does not provide an appropriate measure of productivity change. For example, higher productivity, Western coal production has grown rapidly during the 1970s and 1980s, not so much because it is displacing Appalachian or Midwestern production, but because of the movement of population and economic activity to the Southwest and West and the significant shift to coal away from oil and natural gas for the generation of electricity in those regions. The greater growth of these higher productivity components leads to an overstatement of the rate of productivity growth. The appropriate aggregate measure would be one that treats growth in the components as independent, namely an output-weighted average of the productivity change observed in the non-competing components.

The extent to which the eleven subaggregates for the US coal industry compete is neither uniform nor constant over time. Some are completely competitive one with another—for instance, longwall, continuous, and surface mining in Appalachia or the Interior. Others do not compete at all; for instance, lignite and Appalachian production. Furthermore, the extent to which geographically disparate regions compete has varied over the years. For instance, in the early 1970s, there was less competition than now exists between coal production from the Western and Interior regions. Lower rail rates have made Western coals more competitive in the Midwest and even extended that competition to Appalachian coals in the Southeast and upper Ohio River Valley. Accordingly, it would be very difficult to devise a single index to provide an appropriate aggregate measure of productivity change in the U.S. coal industry over the long term.

For the purpose of this analysis, we assume that mines within the same subaggregate region are competitive, although this is not strictly true for all regions. Where regional coal markets are well developed, as in Appalachia, individual mines directly compete; competition becomes less direct, however, as distance increases and other features of the all-important transportation system intrude. For instance, some coals produced in Northern Appalachia may compete more with Interior coals than with coal produced in Southern Appalachia. Where markets are even more disjointed, as in the West, competition within components as here defined is even less. For instance, coals produced in Washington and Arizona most certainly do not compete, though some other subsets within the Western region do.

Decomposition of the National Aggregate

The national aggregate for coal-labor productivity is the sum of output across components (subaggregates) divided by the analogous sum for labor input. As shown in Equation 1, this aggregate is equivalent to an input-weighted average of labor productivity in each component.

$$\frac{Q}{L} = \frac{\sum_i Q_i}{\sum_i L_i} = \sum_i \frac{L_i}{\sum_i L_i} \frac{Q_i}{L_i} \qquad [1]$$

In this equation, Q represents output, L labor hours, and subscripts denote components of the aggregate. With some manipulation, this aggregate can be decomposed into the sum of changes in input shares and in productivity Q/L for each component, weighted by output:

$$\frac{d\left(Q/L\right)}{Q/L} = \sum_i \frac{Q_i}{Q} \frac{d\left(Q_i/L_i\right)}{Q_i/L_i} + \sum_i \frac{Q_i}{Q} \frac{d\left(L_i/L\right)}{L_i/L} \qquad [2]$$

The absence of a subscript indicates the aggregate for the respective variable. The first term on the right-hand side can be used to form an index that would indicate average *output*-weighted productivity improvement. The second, right-hand-side term is a similarly weighted index of the change in *input* shares, which indicates the extent to which aggregate productivity is affected by reallocation of labor input. This reallocation is caused both by shifts in the geographical distribution of the demand for coal and by differing rates of productivity improvement among the subaggregates. The easiest interpretation of this second term is that it indicates the extent to which a completely aggregated index of labor productivity (*i.e.*, the left-hand term) differs from an index that reflects the output-weighted average of changes in labor productivity for the components of the aggregate (*i.e.*, the first right-hand-side term).[9]

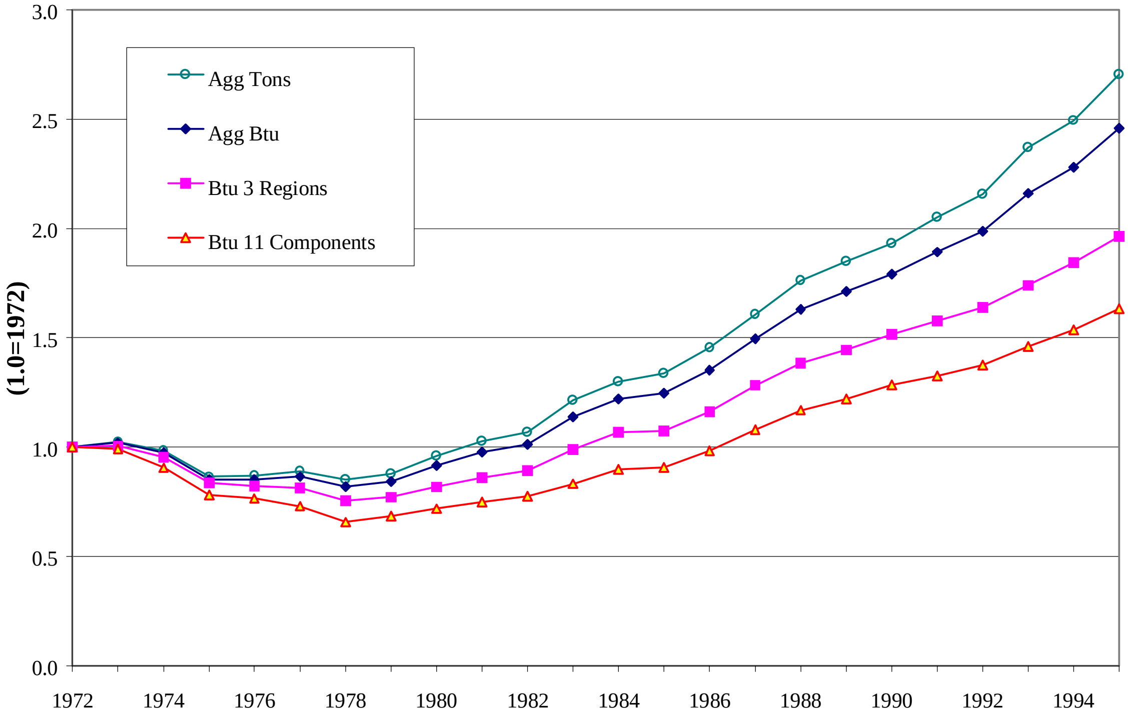
Figure 6 and **Table 2** provide several aggregate measures of productivity change in the U.S. coal industry.

The top line in Figure 6 represents the conventional measure of aggregate labor productivity, where the numerator, output, is stated in tons of coal. The second line is the Btu-corrected expression of the same index, using the heat content assumptions listed in Table 1. Comparing these two upper plots indicates that treating all tons as if they were equal leads to a slight overstatement of productivity: about a third of a percentage point in annual growth. The lower two lines represent Btu output-weighted indices for labor-productivity improvement, using two different decompositions.[10] The bottom line treats each of the eleven subaggregates as independent—obviously, a lower bound. A more nearly correct estimate is provided by

[9] The second term in the second equation would sum to zero only if 1) productivity change were uniform across components and output shares were unchanged, or 2) output is increasing at the same rate as productivity for each component. Although not impossible, it is unlikely that either condition would occur.

[10] In constructing these indices, we use the Tornquist approximation of the Divisia index in which the weights are the average of the beginning and ending shares for each discrete, annual change.

Figure 6: Aggregate Measures of U.S. Coal Labor Productivity



the 3-region index, in which the implicit assumptions are that coal produced by continuous, longwall, and surface techniques competes within the Appalachian, Interior, and Western regions, but there is no competition among these regions.

Table 2 displays values at the key turning points for these indices and the intervening annual rates of change.

TABLE 2. ALTERNATE MEASURES OF PRODUCTIVITY CHANGE

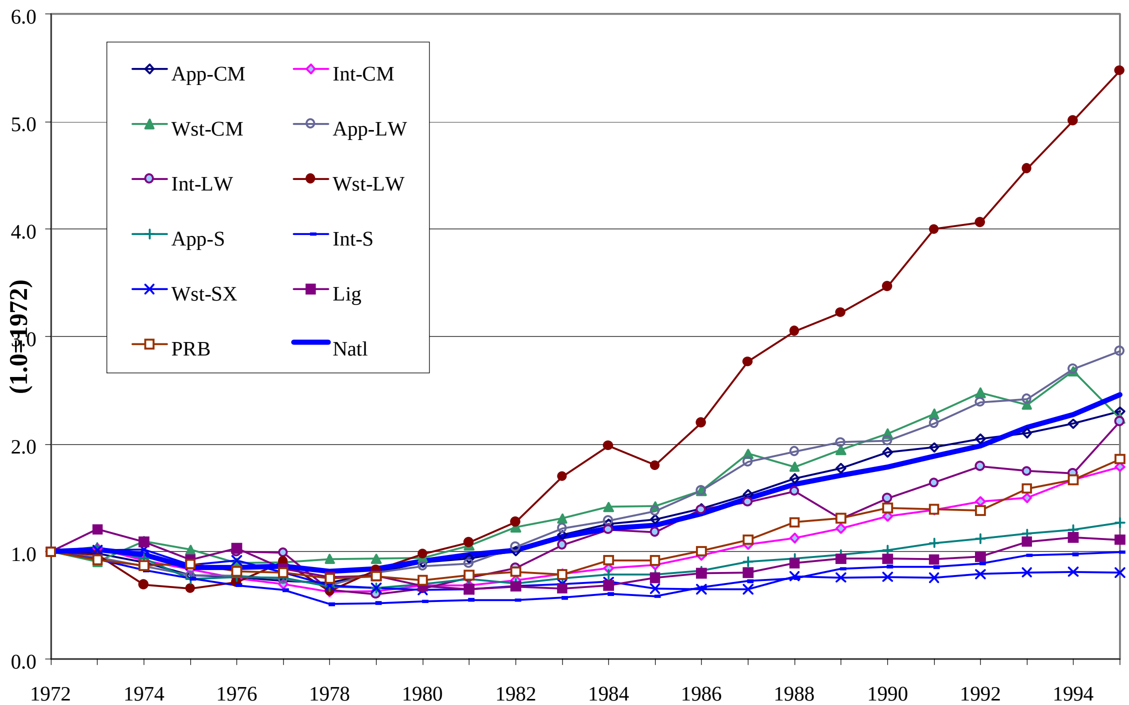
	1972	1978	1995	72 –78	78–95	72–95
Index tons	1.00	.850	2.704	–2.71%	+6.81%	+4.32%
Index Btu	1.00	.819	2.458	–3.33%	+6.47%	+3.90%
Index 3 regions	1.00	.756	1.963	–4.55%	+5.77%	+2.98%
Index 11 components	1.00	.657	1.634	–7.00%	+5.36%	+2.14%

In both the 1970s and 1980s, the national aggregate provides a misleading picture of productivity change in the coal industry. Productivity declined during the 1970s, but the severity of the decline in the subaggregates is masked in the national aggregate by the increasing share of the higher-productivity Western regions. The national aggregate measure for coal Btu output suggests that labor productivity declined at a rate of about 3.3% per annum from 1972 through 1978, while the disaggregated index indicates that labor productivity was falling on average by more than twice that rate, or 7.0% per annum. During the subsequent period of rising productivity, the misstatement of the national aggregate is not as severe, but still present: The national aggregate indicates a rate of improvement from 1978 to 1995 of about 6.5% per annum, while the production-weighted average improvement of labor productivity in the constituent groups for these years is around 5.5% per annum.

Differing Trends among the Subaggregates

So far we have noted only the differences in absolute levels of labor productivity among the eleven subaggregates, and the changes of share among them. An equally, and perhaps more interesting, aspect is the very different rates of productivity improvement to be observed among them, as shown by **Figure 7**, which normalizes the index of labor productivity for each component and the national average to the initial 1972 value. One subaggregate stands clearly apart from the rest: Western longwall mining's labor productivity in 1995 was more than five times its 1972 level and that improvement is twice that of the subaggregate experiencing the next most improvement in labor productivity.

Figure 7: Indices of Labor Productivity, 1972-95



Along with great diversity in their rates of change, the different components show interesting commonalities. Surface and underground techniques show quite a clear separation, for example. Four of the five surface-mining subaggregates cluster at the bottom, with labor-productivity levels in 1995 very little different than in 1972, although better than in the late 1970s. The fifth surface-mining region, the PRB, experienced more labor-productivity improvement, but only as much as the least progressive underground-mining subaggregates. The Western longwall index is only the most outstanding of what is generally impressive productivity improvement for all underground mining. Another regularity observed is that for each of the three main regions, longwall mining is experiencing greater rates of productivity improvement than are continuous mines. Finally, there is a clear regional ordering in rates of productivity improvement for each coal mining technology: Western first, then Appalachia, and finally the Interior region.

4. DATA AND METHODOLOGY

Database Description

The Mine Safety and Health Act of 1969 requires every coal mine in the United States to report quarterly to the Mine Safety and Health Administration (MSHA) on accidents and incidents, as well as tons produced, employees, and hours worked. Each mine is issued a unique mine identification number that is retained as long as the mine is active. In addition to accident data, the quarterly reports contain the following information:

1) current name of the mine and reporting address
2) location of the mine, by county and state
3) tons of coal produced for the quarter being reported
4) number of employees and employee-hours associated with the mine
5) whether the coal is mined by underground or surface techniques[11]

Our study has summed the quarterly data to obtain annual observations, of which there are some 86,000, on 19,098 individual mines that reported production from 1972 through the end of 1995.

Our database consists only of mines reporting production during the year of observation. In any given year, a number of mines report labor hours but no production. Such reports usually concern shops, preparation plants, temporarily idled mines, or mines being prepared for production. Although such labor is usually included in national aggregates, we excluded all such observations since our purpose is to analyze productivity at the mine level, and there is no obvious way to associate those hours with coal production at a particular mine in a given year. Nevertheless, when a mine was idled for less than a calendar year, it was included in our sample. Also included are all labor hours associated with a producing mine,—labor in preparation plants, shops, and offices in addition to labor directly employed at the face or in the pits. Finally, some mines report coal produced by both underground and surface techniques. We applied a 90% rule to these mines: If 90% or more of production was underground or surface, on average, over the years reported, it was so classified, and all coal produced so reported. In fact, nearly all mines reporting both underground and surface production fell easily into one or the other category under this rule. The few that did not were deleted from the database.

Production is measured in "clean" tons produced. A clean ton is a ton that has been screened and washed to remove rock and dirt, ready for shipment to the customer. Although the raw ton that comes from the mine is not clean, the factor to convert raw, run-of-mine coal to clean coal is well known and is applied prospectively for MSHA reporting purposes. This factor tends to be mine-specific, reflecting the geology of the mine, and will not necessarily be constant over time

In order to identify longwall production, we had to add data to the MSHA database. The industry magazine *Coal Age* (now *Coal*) has conducted an annual longwall survey since the late 1970s. This survey lists every longwall mine for the given year and indicates among other things when the longwall panel was first installed. We used the name, location, and other information from the longwall survey to match each reported longwall mine with an underground MSHA mine identification number. Unless the industry survey indicates that a longwall has been removed, we consider all production since the installation of the longwall at such a mine as longwall production.[12] Most of the identifications could be made relatively easily. Where questions arose, we resorted to such other coal-industry publications as the *Keystone Coal Industry Manual* to help resolve the matter, and in many cases, we simply called the mine or company to determine the status of a particular mine. In a few cases, we could make no satisfactory match. Since we consider all underground mines that we have not identified as longwall mines to be continuous mines, there is the possibility that a few of the latter are in fact longwall mines.

We also created indices of the price of output relative to the wage rate for the auxiliary regressions described below. Since output price varies considerably by location, we created relative price indices for Appalachia, Interior, Western, Lignite, and PRB production to correspond to the subaggregates. The Energy Information Administration of the U.S. Department of Energy collects and publishes nominal mine-mouth coal prices by state on an annual basis.[13] For the Appalachian, Interior, and Western regions, the prices reported for each coal producing state are weighted by that state's share of coal production for the respective region, as contained in the MSHA database, and summed to form a regional index of nominal coal prices. In calculating the shares, production by longwall, continuous, and surface mining is combined for each state. For Kentucky, where production in the eastern counties is part of Appalachia and production in the western counties is part of the Interior province, separate price data is reported. We associate the reported price with the appropriate region and weight it by the amount of state production falling in the

---

[11] We defined "surface techniques" to include the small amounts of coal produced by augers, dredging, and from culm banks.

[12] In fact, continuous miners, which are used to create the longwall panels and ancillary passageways, account for some of the production.

[13] See USDOE/EIA, *Coal Industry Annual (*previously *Coal Production Annual*) for various years since the 1970s. Prior to the formation of the U.S. Department of Energy and the Energy Information Administration in the 1970s, this data was collected by the Bureau of Mines and published in the *Minerals Yearbook.*

respective region. Also, in some states, prices are not reported because of the small number of mines. In these cases, we formed the index using only the states for which prices were available and adjusted the weights so that the shares of the states reporting prices summed to unity.

The nominal price index for lignite is formed from the prices reported for Montana, North Dakota, and Texas weighted by the production reported as lignite. Since North Dakota and Texas produce no other sort of coal, these states' averages do not appear in any other index. The PRB index is formed from prices reported for the states of Wyoming and Montana, weighted by the amount of state production falling in counties that define the Powder River Basin. Price data for these states is also included in the Western index corresponding to the amount of production outside the PRB in Wyoming, and for Montana, production not classified as PRB or lignite).

The relative price indices for these five regions are formed by dividing the five geographically specific nominal coal price indices by a proxy for the nominal national coal wage rate: average hourly earnings for production workers in SIC 12 (Coal Mining), as reported in the *Employment, Hours, and Earnings* series published by the Bureau of Labor Statistics.

Specification of the Model for Estimating Labor Productivity

The principal aim of our empirical analysis is to succinctly describe how labor productivity varies over individual mines in order to better describe aggregate coal productivity trends. As in most micro-level analyses of production, a huge number of possible factors affecting productivity can vary across individual production facilities and over time.

For coal mines, numerous geological features are essentially unique to each mine location and remain more or less constant over time. These might include, for instance, for underground mines, seam height; roof conditions; width, length, and slope of the seam; and surface structures relevant to accessibility of various parts of the seam. Important issues arise from the state of depletion of a given mine, or the quantity of coal remaining in a seam after years of production. Mines also differ in their configuration of production facilities; for instance, some mine locations are associated with a preparation plant or maintenance shop, whereas others are not. The labor employed in these associated facilities is part of producing a "clean" ton of coal, so where it is found, such labor is included, obviously affecting labor productivity across mines.

Other important features tend to change over time but affect all mines more or less equally in a given year. As we have noted, labor-productivity declines were common in the face of environmental regulations in the 1970's, with apparently different regulatory impacts on surface and underground mines, at least after

1972.[14] New advances in coal-mining technology tend to diffuse quickly across mines and raise labor productivity, but the precise impact on a given mine still varies with the ability of that particular mine to benefit from the particular advance in technology. Finally, although mine-mouth prices vary according to netback considerations involving location and coal-delivery systems, those prices tend to move together from year to year within any given coal-producing region, moderated by long-term contract terms where present.

We observed annual output Q_{it} and labor (man-hours) input L_{it} for each mine i for every year t that the mine was producing; $t = T_{1i}, \ldots, T_{2i}$ where "producing" is defined as having positive observed output. Again, mines were classified into the eleven groups indicated in Table 1: three broad geographic regions (Appalachia, Interior, and Western); two unique producing regions (Lignite and the PRB); and three distinct mining technologies (surface, continuous, and longwall). We also observed a few characteristics of individual mines, such as seam height and the presence of a preparation plant, but in no way could we completely take into account geological or technical conditions for each mine for each year.

Given this available data, we adopted a panel data modeling approach to deal with the potentially vast heterogeneity of individual mine geology and technology. For mines within each of the eleven group classifications, our basic model takes the form:

$$\ln\left(\frac{Q_{it}}{L_{it}}\right) = \tau_t + \alpha_i + F(\ln Q_{it}) + \varepsilon_{it} \qquad [3]$$

where $i = 1, \ldots, N_{group}$ and $t = T_{1i}, \ldots, T_{2i}$. The parameters τ_t, $F(\cdot)$ and α_i vary by group classification in our analysis, although we have omitted the group distinction from the notation for simplicity.

The mine-specific fixed effect α_i serves to capture all mine-specific geology and technical attributes specific to the mine location by establishing a base level of (log) labor productivity for each mine. The time effect τ_t represents the common impact of all year-specific changes, such as common technological advances, input price effects, and regulations for each classified group of mines. The disturbance ε_{it} is

[14] The Mine Safety and Health Act of 1969 primarily affected underground mines; a perceptible decline in labor productivity occurred between 1969 and 1972 (*cf.* Figures 1 and 5). The federal Surface Mining Control and Reclamation Act came later, in 1977, though many states had enacted similar reclamation requirements earlier. It appears that underground mining productivity was affected by regulation in the early 1970s, while the effect on surface mining occurred more in the late 1970s and early 1980s. Our detailed mine-level data shows the latter but not the former, phenomenon, perhaps because much of the effect of underground regulation had been internalized by 1972.

assumed to capture all other idiosyncratic features of productivity for each mine, and is assumed to be normally distributed with mean zero and constant variance, uncorrelated across mines and time periods.[15]

Of particular interest is the way labor productivity varies with scale of operation, which is represented by the unknown function $F(\cdot)$ of (log) output Q_{it}. We began our empirical analysis by setting

$$F(\ln Q_{it}) = \beta \ln Q_{it} \quad [4]$$

— a constant-scale elasticity specification, so that estimates of the scale effect β could be compared across groups of mines.

Further empirical analysis indicated significant nonlinearities in the log productivity–log output pattern. While the function $F(\cdot)$ is a natural candidate for nonparametric estimation, we adopted fairly flexible parametric models in order to facilitate statistical simplification and comparisons of the scale effect across groups. In particular, we found that the output patterns are adequately captured by a cubic polynomial in log output:

$$F(\ln Q_{it}) = \beta_1 \ln Q_{it} + \beta_2 (\ln Q_{it})^2 + \beta_3 (\ln Q_{it})^3 \quad [5]$$

which allows log-linear as well as log S-shaped scale patterns.

In the panel data format, time effects τ_t capture the impacts of all variables that are time-varying but equal across mines during any given time period, such as common regulations, common technical advances, and prices of coal, labor, and other inputs to coal production. In order to examine the relationship between coal productivity and prices, we further structured the time effects as

$$\tau_t = \kappa + \gamma \ln \frac{p_t}{w_t} + \eta_t \quad [6]$$

where $\ln {}^{p_t}\!/_{w_t}$ is the log ratio of coal price to wage rate. Here γ gives the impact of relative price/wage effects on common productivity levels (the elasticity of labor productivity with respect to real output price),

[15] We did not observe much detailed information on mine features that vary across mines and time other than output and labor input. Seam height is reported; however, close inspection of this data showed that, aside from some patently unrealistic values, the values given were almost always constant over time, and thus part of the fixed effect for each mine.

and η_t gives the common log productivity level net of price and wage effects. This specification assumes that the log real coal price and the log real wage have equal coefficients (but opposite signs) in the time-effect equation. We will verify this empirically by noting the insignificance of the coefficient γ^* in estimates of

$$\tau_t = \kappa + \gamma \ln \frac{p_t}{w_t} + \gamma^* \ln w_t + \eta_t \,. \qquad [7]$$

There are several important features to note from our structuring of the time effects. First, without additional assumptions, the price effects are not identified, and Equation [6] places no restriction on the panel model [3]. Because our approach is empirical and descriptive, we do not want to bias the basic panel estimates of the time effects by inappropriately specifying time, price, and remaining productivity effects. Consequently, we adopt a two-stage approach to estimation. The first stage is to estimate model [3] by ordinary least squares (OLS), with fixed time and mine effects, giving a series of estimated time effects $\hat{\tau}_t, \quad t = 1, \ldots, T$. The second stage is to estimate Equation [6] using OLS with the estimated time effects $\hat{\tau}_t$ as dependent variables. This gives estimates of the price and wage elasticities, and we take the estimated residuals from [6], $\hat{\eta}_t$, as representing the remaining time effects after taking price effects (what we later term "residual time effects") into account. This is consistent with an assumption that the residual time effects are stochastic with zero mean, and with

$$Cov(\ln p_t, \eta_t) = 0; \quad Cov(\ln w_t, \eta_t) = 0 \qquad [8]$$

where covariance is taken over time periods. However, we do not impose the structure of [6] and [8] on [3] for the initial estimation, because of our interest in the overall level of time effects.

One way to view our procedure is that we are assuming [3]–[6][8] but using an inefficient two-stage estimation procedure. Another way to view our procedure is that we are not assuming [8], but are using OLS to define the split between price effects and residual time effects in [6] (imposing the empirical analogue of [6]). In any case, we will report the overall time effects as well as the residual time effects as part of our analysis below. Further, we perform statistical testing to simplify the scale relationship, where possible. We will also test whether the pattern of overall common time effects and the scale relationship varies across the different mine groups.

The panel data approach gives quite a flexible empirical model for accounting for mine heterogeneity. Some issues of interest are difficult to study because of this flexibility. For instance, suppose we were interested in measuring linear depletion (or mine-specific learning) effects by including the age of the mine as a regressor in the model. A problem arises because age is perfectly collinear with a linear combination of mine effects and time effects. A model with the linear age effect has the same fitted values as the model without such an effect, with the estimated age effect not necessarily representative of the aging process (separate from the mine and time effects). If a specific nonlinear aging profile were deemed appropriate for representing depletion at all mines, then an effect could be measured; however we have no *a priori* reason for choosing one kind of depletion profile over another.

Before proceeding with the discussion of empirical results, we comment briefly on the interpretation of our methodology. While our approach for studying labor productivity is very flexible, it serves primarily as a method for describing mine-level changes in productivity over the past two decades. Our approach is clearly reduced form in nature, in that we have not yet determined what particular innovations give rise to improvements in productivity with scale, and how those innovations differentially impact regions and mine types. Our work is best viewed as a cohesive description of general patterns of changes in coal mine productivity. Improving upon this would require a more detailed accounting of other factors involved in coal production.

A natural behavioral setting for coal mining starts with an assumption of price and cost-taking behavior at the mine, with optimal output levels chosen either when marginal profits are zero or when output reaches the physical maximum capacity of existing production facilities. That is, given the price of coal (net of transportation costs) and prices of all associated inputs, current output is chosen, and labor productivity results from the existing technology at the chosen output. The existing facilities and type of technology are chosen via a medium-to-long-term planning process, based on the geological features of the mine site and expectations of future prices.

With this view, the choice of technology—for example, a longwall versus continuous process for an underground mine—and scale of operations are determined endogenously, as is the resulting labor productivity. As such, the "scale effects" estimated from our model refer to the empirical pattern of labor productivity and scale, a relationship which might have been different had the past two decades seen a different pattern of coal, transportation, and input prices. The problem one faces is how to estimate basic production possibilities at a site, because the combination of geological characteristics and all prices are "exogenous" to the choice of technology, the output decision, and the resulting labor productivity. The term "exogenous" is in quotation marks because one can take a further step backwards, and note that since sites are chosen to be mined, even the observed package of geological features depends in part on prices and the current set of available technologies for mining.[16]

This issue is mitigated somewhat in our data by specific features of scale decisions for coal mines. In particular, because long- and medium-term coal contracts are often written with neighboring (location-specific) mines, for much of our sample, the scale of operations can be viewed as exogenous. For such mines, it is reasonable to assume that operators strive toward efficiency and higher labor productivity, conditional on scale. To the extent that this characterization of scale applies broadly, our estimates avoid the sorts of spurious correlation that can arise from jointly endogenous scale-and-technology choice decisions.

One feature of endogeneity that we will study directly as part of future research involves the ongoing decision of whether to keep a mine in operation or not. The rate of coal-mine turnover is quite pronounced, and one might conjecture that our labor productivity equations may be subject to selection biases, since they are based only on mines currently producing. For a severe example, if labor productivity is comparable for all mines in any given year, but only larger- and larger-scale mines survive over time, one could detect a relationship between labor productivity and scale due solely to the fact that smaller mines are leaving the sample. We have carried out some control of the sample composition by using average mine (fixed) effects as part of our decomposition, but the issue is whether the composition itself is connected in important ways to individual mine scale.

Part of our analysis examined labor productivity equations estimated with many different sub-samples of mines that varied with regard to exit decisions (*e.g.*, the sub-sample of mines still in operation in the final sample year, versus mines that were not) and found no substantial differences in the estimates. While our initial view is that selection issues from entry and exit do not materially affect labor productivity relationships in this industry, we plan to estimate models of entry and exit in order to understand whether our observable variables are associated with features of those decisions.

Regression Results

Full sets of estimates of the panel model [3] are attached as Appendix 2. The graphs in the following section provide the most interpretable depiction of our results' operational features, namely, the association of labor productivity with scale, price, time and fixed mine-specific effects. Here we highlight a few features of the basic estimation, and present some results from testing the model's basic structure.

[16] Longwall technology, developed in Europe prior to the 1970s, was available and used in the United States throughout our entire data sample, though early longwalls had very low productivity relative to later ones.

Table 3: Cubic Scale Coefficients: Underground Mines

	Underground Continuous Mines			Underground Longwall Mines		
	Appalachia	Interior	Western	Appalachia	Interior	Western
$\ln Q$	1.784	5.223	2.192	0.264	-44.98	9.212
	(35.9)	(11.3)	(6.86)	(.214)	(-2.22)	(2.97)
$(\ln Q)^2$	-0.158	-0.411	-0.165	0.031	3.24	-0.731
	(-28.7)	(-10.0)	(-4.81)	(.755)	(2.21)	(-2.863)
$(\ln Q)^3$	0.00519	0.0113	0.00467	-0.001	-0.077	0.0199
	(26.0)	(9.40)	(3.95)	(.448)	(-2.18)	(2.863)
Number of Mine:	8339	173	128	111	14	29
Sample Size	38100	1295	902	1216	106	224
R-sq Within Min	0.335	0.634	0.556	0.775	0.93	0.573
R-sq Overall	0.265	0.439	0.609	0.743	0.87	0.797

(t statistics in parentheses)

Table 4: Cubic Scale Coefficients: Surface Mines

	Surface Mines				
	Appalachia	Interior	Western	Lignite	PRB
$\ln Q$	1.686	1.502	1.458	0.966	1.273
	(24.6)	(7.93)	(5.90)	(3.06)	(2.306)
$(\ln Q)^2$	-0.128	-0.114	-0.0572	-0.000831	0.0000852
	(-17.2)	(-6.12)	(-2.34)	(.027)	(.002)
$(\ln Q)^3$	0.0037	0.00348	0.000832	-0.000658	-0.00121
	(14.0)	(5.802)	(1.066)	(-.70)	(.981)
Number of Mine	9019	1260	87	40	30
Sample Size	37161	5219	789	506	450
R-sq Within Min	0.302	0.391	0.673	0.767	0.828
R-sq Overall	0.177	0.179	0.619	0.531	0.607

(t statistics in parentheses)

The scale–labor productivity relationship in Equation [3] is modeled as a cubic polynomial (Equation [5]. Estimates of these scale effects are presented in **Table 3** for underground mines and in **Table 4** for surface mines. Actual magnitudes of the coefficients are difficult to assess (because they are embedded in the model with firm and time effects); nonetheless, some common patterns can be seen.

Underground continuous mines are characterized by clear estimated nonlinear patterns of log labor productivity increasing with scale. For underground longwall mines, the scale effects are very imprecisely estimated. Only Western longwall mines have an estimated structure with the same shape as that for underground continuous mines. Appalachian longwall mines exhibit a basically linear scale pattern, and Interior longwall mines have counterintuitive, very poorly estimated effects. These patterns, as well as the high goodness-of-fit statistics, suggest that scale effects are very difficult to separate from time effects in these two groups, and could also reflect the fact that most longwall mines are "large scale" relative to continuous mines in the same regions.

The imprecision in these estimates suggests various kinds of simplifying tests. For instance, we began by testing whether longwall and continuous mines share the same scale structure; namely, whether the log cubic polynomial coefficients are the same for each type of technology. This hypothesis is decidedly rejected by F-tests for each of the three regions. We could further proceed to test whether the scale structure can be simplified for certain regions—for example, whether a log linear scale effect suffices for Appalachian longwall mines. We have not carried out such a detailed simplifying analysis, preferring at this stage to simply report the raw scale patterns as estimated. This likely does not make much difference to most of the analysis of the next section, such as when we compute a "scale effect" index by evaluating the micro-scale structure at average output for each region.

The scale structure for Appalachian and Interior surface mines is estimated to be quite similar to that for underground continuous mines: namely, productivity increases with scale. Strong scale effects are also evidenced for Lignite and Powder River Basin (PRB) mines, although little evidence suggests nonlinearity in the log-productivity–log-output relationship. Western surface mines have a more precisely estimated scale structure than that of Lignite and PRB mines, but it is essentially similar. Again, we proceed by presenting the raw patterns as estimated, without further statistical refinement.

Table 5 summarizes the results of regressing the time effects estimated with model [3] on the log ratio of coal price to labor wage rate. We expect the coefficients to be negative, as higher prices or lower wage rates support less productive mines. All estimates are negative, except for that of Appalachian surface mines, where log-relative prices are essentially uncorrelated with time effects. In fact, the degree of correlation between time effects and log-relative price is quite high, overall. Surface mines display somewhat lower fit, and one could conjecture that regulatory changes might have played a much larger role here than did price effects in labor productivity.

Table 5: Relative Price Effects

Each Category: 24 Time periods

Underground Continuous Mines	Constant	Log Relative Price Effect	R sq	Log Price = Log Wage Effect t Test Statistic
Appalachia	-6.509	-0.406	0.831	-1.853
	(-199.4)	(-10.44)		
Interior	-22.406	-0.613	0.637	-1.893
	(-405.2)	(-6.21)		
Western	-9.701	-1.042	0.601	-0.419
	(-158.6)	(-5.75)		
Underground Longwall Mines				
Appalachia	-5.391	-0.849	0.795	-1.075
	(-67.7)	(-8.94)		
Interior	206.659	-1.424	0.899	-1.046
	(-3102.6)	(-12.66)		
Western	-39.222	-0.793	0.160	-0.333
	(-299.8)	(-2.05)		
Surface Mines				
Appalachia	-6.950	0.045	0.011	-0.938
	(-89.7)	(.49)		
Interior	-6.252	-0.472	0.459	0.362
	(-102.0)	(-4.32)		
Western	-9.298	-0.643	0.239	-0.177
	(-112.5)	(-2.63)		
Lignite	-9.789	-0.641	0.766	-4.73
	(-225.6)	(-8.50)		
PRB	-12.478	-0.522	0.613	0.787
	(-283.9)	(-5.90)		

(t statistics in parentheses)

When separate effects of real coal price and real wages are estimated, the log real wage coefficients are by-and-large small and very imprecise. To check our restriction of whether wage effects have the same value as, but opposite sign to, output price effects, we considered the *t*-statistic values for coefficient γ^* in

Equation [7], listed in Table 5. These offer minimal evidence for a difference in the effect, so we maintained the basic model [6]. Lignite provided an exception: the unrestricted estimate implied a very negative effect of higher wages on labor productivity, a result sufficiently counterintuitive that we retained model [6] in this case, as well.

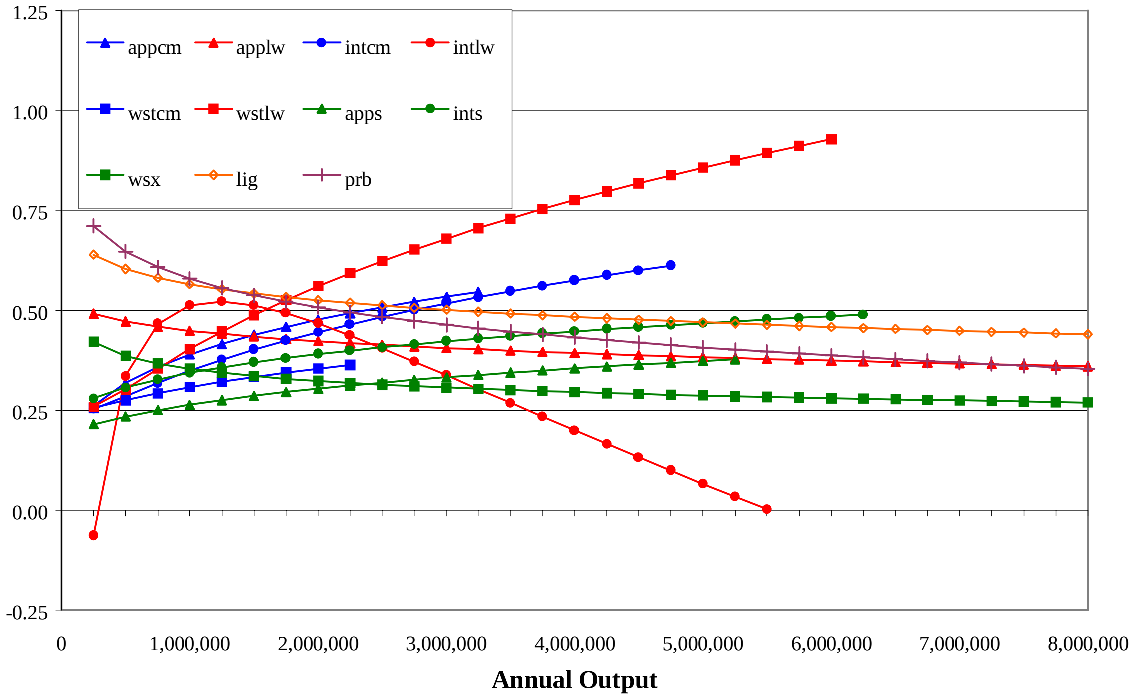
5. FOUR SOURCES OF PRODUCTIVITY CHANGE

Our study of the decomposition of an aggregate measure of productivity change has consisted of two parts. The first can be characterized simply as getting the numbers right for a very heterogeneous industry in which the conventional measure of output is not entirely appropriate. The second part of our dissection attempts to determine sources of productivity change within relatively homogeneous subaggregates by modeling labor productivity at the level of the individual mine. Four sources of labor-productivity growth can be identified from this second part of the analysis. First, the level of annual output is an important determinant of labor productivity at the mine level regardless of mining technique, geographic location, or specification. Second, our model identifies the fixed effect of time-invariant, mine-specific differences in labor productivity; the annual means of these fixed effects vary over time as mines enter and exit. The basic regression leaves us with what we term an undifferentiated time effect—namely, the extent to which productivity changes across all mines from year to year after scale and fixed effects have been taken into account. The effects of changing output and input prices on labor productivity would be included in this undifferentiated time effect. Accordingly, we run an auxiliary regression to identify the third and fourth sources of observed productivity change: price effects and residual time effects.

Scale Effects

Scale effects are the product of the elasticity of labor productivity with respect to annual output—what we term “scale elasticity”—and the observed change in scale. **Figure 8** plots the indicated scale elasticities for all eleven regions up to a scale of 8 million tons of annual output. The elasticities are positive, implying economies of scale, except for some extreme values for one subaggregate. Elasticities are projected only through the maximum observed mine size for those subaggregates with maximum annual mine output less than 8 million tons. For the three Western surface-mining subaggregates, maximum observed mine size is considerably larger: 10 million tons for Western surface mining other than Lignite and PRB, 16 million tons for Lignite, and 36 million tons for the PRB. Although not shown in Figure 8, these elasticities continue to fall modestly, and in the case of PRB, scale elasticity is ~0.20 for annual tonnage of 30 million tons.

Figure 8: Scale Elasticities



The values of these scale elasticities are remarkably uniform. With the exception of Interior longwall mining, all take positive values lower than unity.[17] For Interior longwall, values near zero, implying no economies (or diseconomies) to scale, are observed at the extremes of observed mine output, but in the range of output observed for most Interior longwall mines, elasticities fall between 0.20 and 0.55. Even though the cubic specification permits great flexibility, we find surprisingly that the scale elasticities either rise or fall steadily over the observed range of annual output, with the exception of Interior longwall mining, where we observe rising and then falling elasticities. Furthermore, a tendency can be observed toward uniformity by mining technique. The three Western surface-mining components all show declining elasticities with scale, and in the case of Lignite and PRB coal, elasticities are virtually the same. Appalachian and Interior surface mining also show very similar and rising elasticities over the ranges observed. The same can be said for continuous mining in all three geographic regions. The exception to this tendency to uniformity by mining technique is longwall mining. The idiosyncrasy of Interior longwall mining has already been noted. Although the scale elasticities are roughly the same for longwall mining in all regions at levels of output from 1 to ~3 million tons annually, longwall scale elasticities diverge radically thereafter. The value for Western longwall mining rises almost linearly, while the comparable value for Appalachian longwall mining declines modestly, and that for Interior longwall mining falls sharply.

---

[17] Unity is a limiting value for the elasticity of labor productivity since it implies that labor has become a non-essential input. A value of one for this elasticity corresponds to a zero value for the elasticity of labor demand with respect to output.

The extent to which these scale elasticities matter depends upon the increase in average mine size, which varies greatly among components. Average mine size is not a perfect statistic to use with scale elasticities because it includes both changes over time at continuing mines and changes in the size composition of mines over time, while in a fixed-effects estimation, scale elasticity is based only on the former change. To the extent that size distribution changes over time and thus contributes to variations in average mine size, and that cross-sectional elasticity differs from the longitudinal value, this measure will err. Nevertheless, to gain some sense of the importance of scale effects, we use average mine size as an acceptable statistic. **Figures 9** and **10** show the evolution of average mine size and the scale-effect index for each of the eleven subaggregates.

Figure 9: Average Mine Size

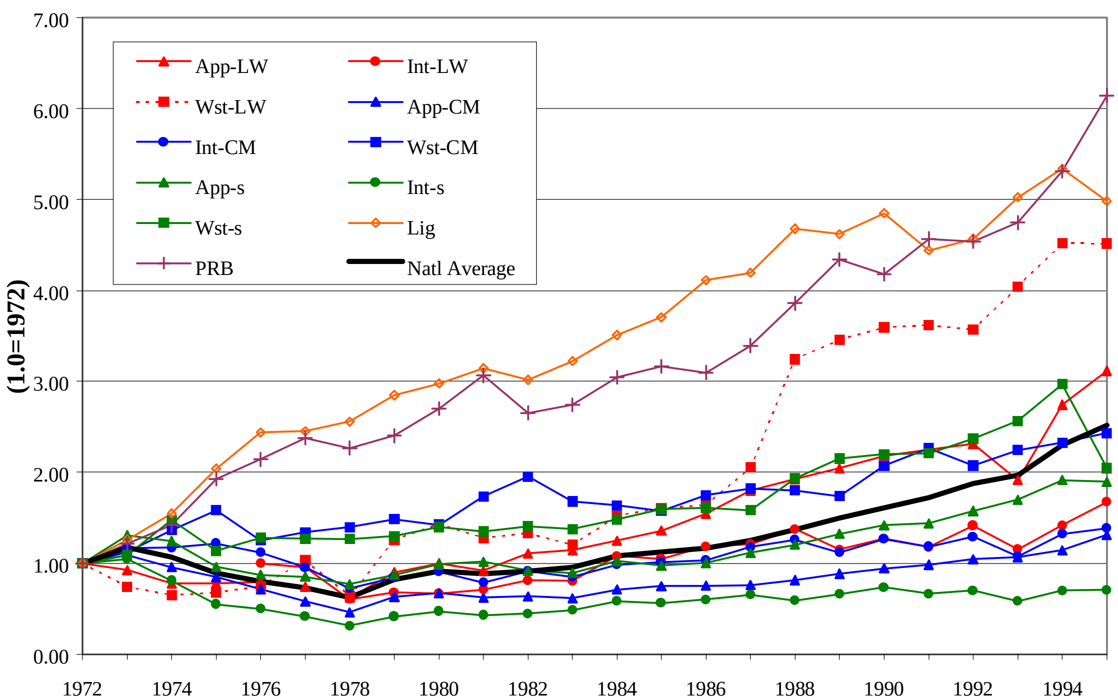
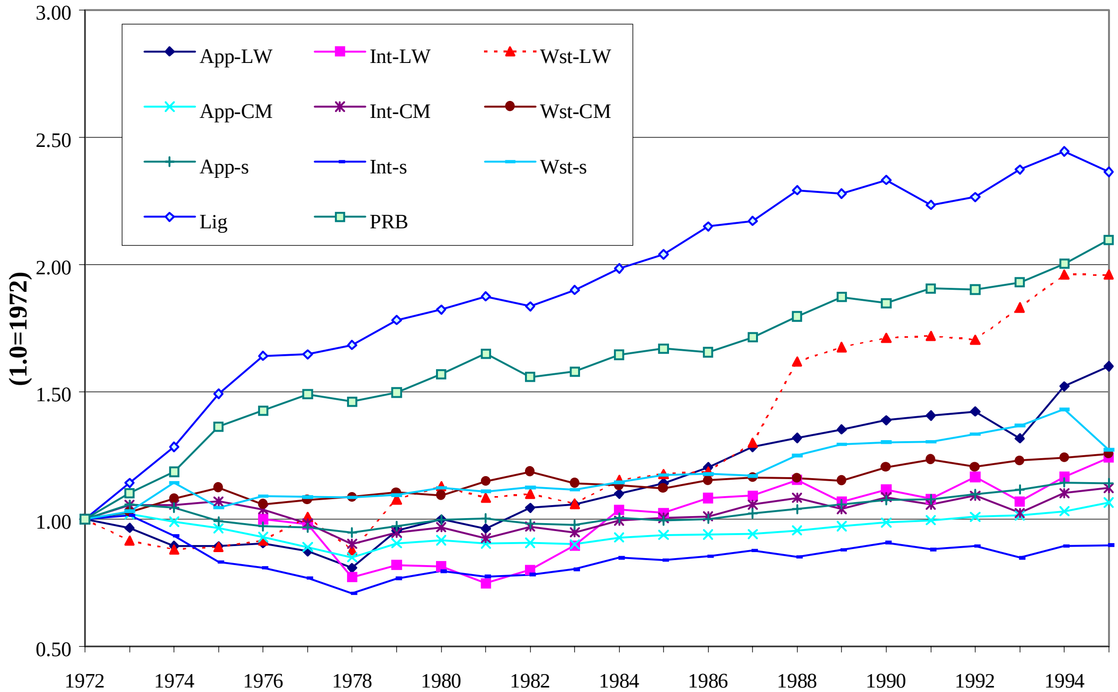


Figure 10: Scale Effect Indices by Component



National average mine size increased about two-and-a-half-fold between 1972 and 1995, but the components exhibit tremendous diversity. In general, Western components steadily increased in scale over the period; the three largest increases are registered by three Western subaggregates—PRB, Lignite, and Western longwall mining—where average mine size increased 4.5- to 6-fold over 1972 levels. The Interior and Appalachian components experienced a decline in average mine size during the 1970s, but have increased considerably since then, with one exception: Interior surface mining. The ratio of the average mine size in 1995 to that in 1972 for the other Appalachian and Interior subaggregates range from about a 30% increase for Appalachian continuous miners to a more than threefold increase for Appalachian longwall mining.

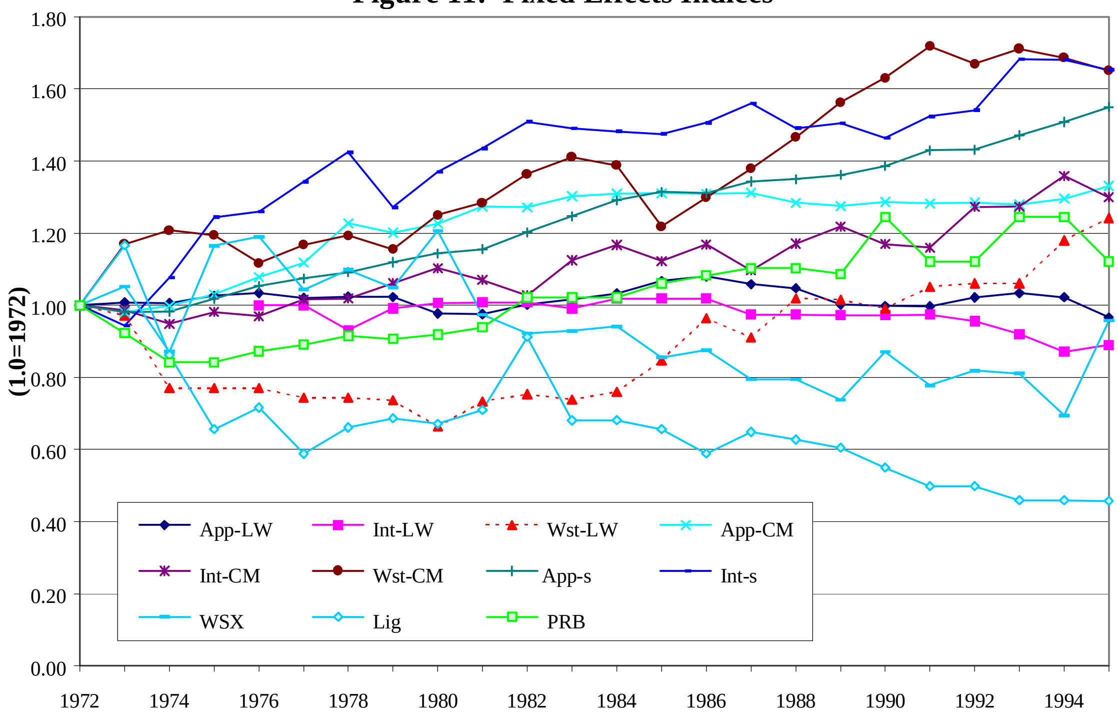
The same general pattern appears in Figure 10, where the combined effects of change in average mine size and scale elasticity on labor productivity are indicated by an index relative to 1972. The three regions with the greatest increase in average mine size would have experienced a 2.0–2.5-fold increase in labor productivity due to scale effects, if no other factors had been in play. With the exception of Appalachian longwall mining, which took an intermediate position in 1995, all components are grouped together with indices, indicating that 1995 labor productivity would have been from 0.90 to 1.27 times the 1972 level if all other influences were held constant.

In summary, at the micro level, the effect of scale on labor productivity, and presumably on unit cost, is pervasive.

Fixed Effects

Interpretation of the fixed-effects index is not obvious. The average of the fixed-effects coefficients for all mines over all time periods is zero, but for any given year within the sample, the mean of the fixed-effect coefficients would typically differ from zero and vary over time as individual mines entered and exited. In effect, this index reflects the effect of compositional changes within each of our subaggregates. As shown by **Figure 11**, no obvious pattern emerges.

Figure 11: Fixed Effects Indices



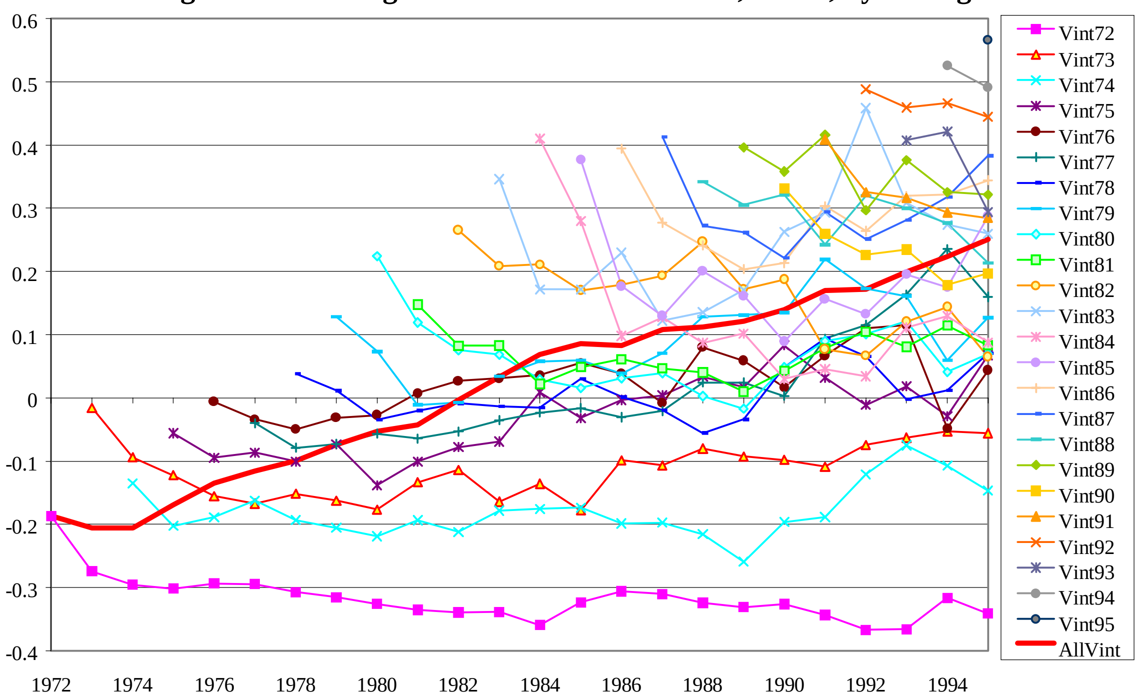
A rising fixed-effects index occurs for five of the subaggregates: all three continuous-mining components, and Appalachian and Interior surface mining. The remaining six regions show varying patterns. The index for Appalachian and Interior longwall mining hardly changes, although Interior longwall mining since the mid-1980s clearly declines. For the PRB and Western longwall mining, the index declines during the 1970s, and increases significantly thereafter. The index for Lignite mining experiences a similar decline in the 1970s but no recovery in the 1980s, and the mean of the fixed-effects coefficients declines even more in the 1990s.

Although it is tempting to try to read some meaning into these differences, a more important distinction in interpreting the evolution of the yearly mean of the fixed-effects coefficients may be the number of mines in each subaggregate. **Table 6** shows the maximum and minimum number of mines observed in any year for each subaggregate.

Table 6. Maximum and Minimum Number of Mines, by Subaggregate			
	Longwall Mines	Continuous Mines	Surface Mines
Appalachia	32 64	870 2,137	864 2,438
Interior	1 9	36 65	93 382
Western	2 15	16 58	20 47
Lignite	NA	NA	13 26
PRB	NA	NA	5 26

Only three subaggregates have a sufficiently large number of mines in all years that the yearly means would not be greatly affected by the entry or exit of a single mine. For the three shaded subaggregates in Table 6, the index rises as might be expected based on improving vintages and the disappearance of less productive mines within vintages. For the other eight subaggregates, the vintage means exhibit no particular pattern, and the subaggregate mean can also be erratic. Two subaggregates, the PRB and Western longwall mining, show a clear trend to successive vintages with higher labor productivity. The rest show no clear pattern for successive vintages, as there is none for successive years.

Figure 12: Average Fixed Effect Coefficients, APPS, by Vintage



For the subaggregates containing many mines, it is possible to separate the effect of successive vintages from that of successive years within each vintage. The emergent pattern is very clear, illustrated for Appalachian surface mining in Figures 12, 13, and 14. **Figure 12** plots the means of fixed-effects coefficients by year for each vintage; the heavy black line shows the average of all vintages for each year. **Figure 13** normalizes each index for the 24 vintages to the vintage's initial year, and shows two additional indices: the first year of each successive vintage relative to 1972 and the annual mean for all mines in the subaggregate.

Figure 13: Indices of Fixed Effects Means by Vintage, AppS

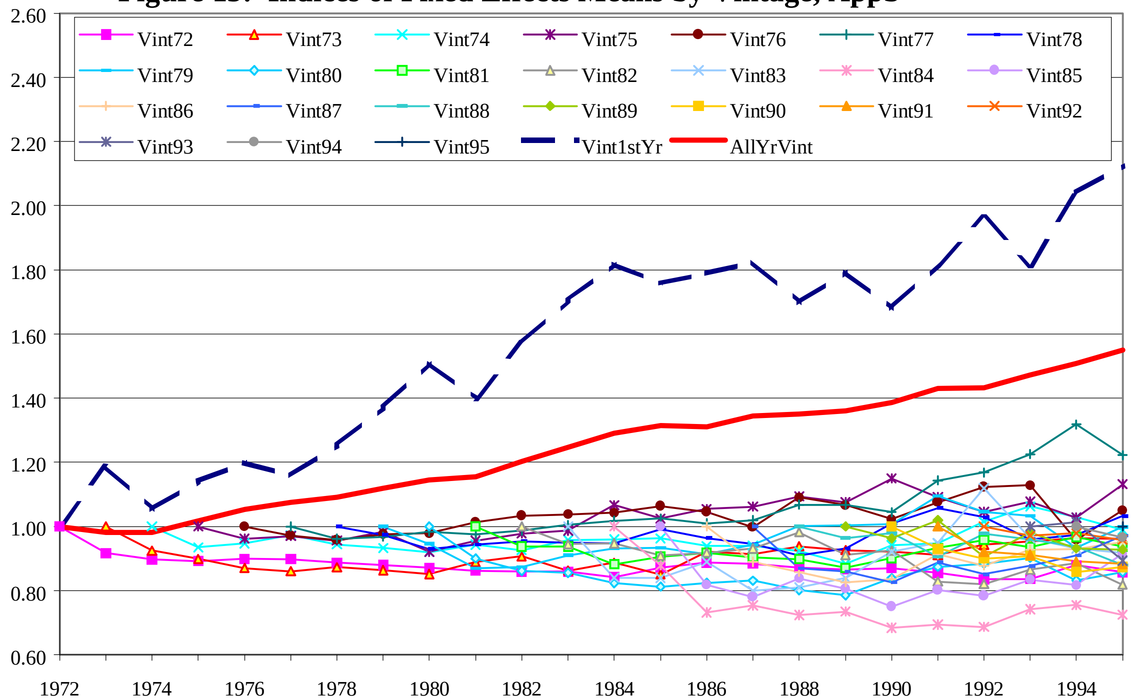
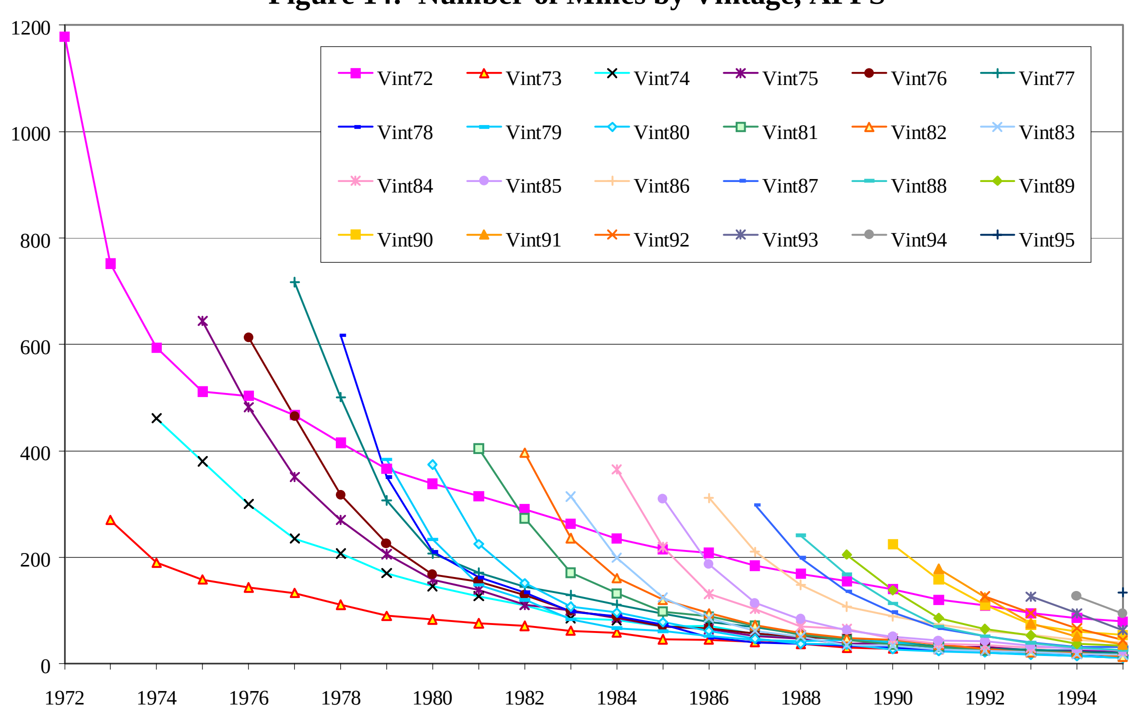


Figure 14: Number of Mines by Vintage, APPS



Curiously, the mean for nearly all vintages declines in the first few years, but each successive vintage attains a higher level of labor productivity, so the overall average rises. Since no new mines enter after the year that defines the vintage, the movement of the average fixed-effects coefficients for each vintage average reflects whether mines with higher or lower fixed-effects coefficients are dropping out.[18] The movement of the vintage means is an almost uniform decline during the initial years, followed by a leveling out. **Figure 14** shows that, for every vintage, a large number of mines cease production in the first few years. Evidently, these mines enjoy relatively high labor productivity during their short lives.[19]

What emerges from this analysis of the evolution of fixed-effects coefficients is that there is no tendency for the mean of a given vintage to rise over time. If anything, the contrary is the case. Where we observe a rising fixed-effects index, it is due almost entirely to higher labor productivity being associated with successive vintages. Such a trend can be observed for at least five of the subaggregates: Appalachian surface and continuous miners, Interior surface mining, Western longwall mining, and the PRB. These subaggregates account for a large part of national production— 66–79%, depending on the year. We presume that this trend reflects the introduction of improved technology in later years.

Price Effects

The auxiliary regression described earlier decomposes the undifferentiated time effect into two components: one reflecting the effects of changing output and labor prices, and the other, what we call residual time effects. **Figure 15** provides nominal prices for coals produced in Appalachia, the Interior, West, Lignite, and PRB, as well as the national coal wage rate and the consumer price index (CPI) for comparison, all normalized to 1982 values. The coal wage rate increased steadily, in nominal terms, while output prices rose during the 1970s but have either remained constant or declined since 1982. **Figure 16** depicts the regional price term for the auxiliary regressions (*i.e*., the output price for each region divided by the national wage rate). This figure readily shows that the price of coal relative to labor prices increased sharply during the 1970s for all regions, although the peaks for Appalachia and the West (1975) differ from those for the Interior, Lignite, and PRB (1981). Since 1981, the price of coal relative to labor prices has declined steadily in all regions, although at different rates.

The roughly inverse correlation of these prices' time pattern with observed changes in labor productivity suggests that the evolution of output and input prices has influenced labor productivity. A higher output price relative to the price for labor inputs would be expected to depress labor productivity as more labor is applied in response to the rising marginal revenue product of labor. Conversely, when output price falls relative to the wage rate, attempts will be made to improve labor productivity as the marginal revenue

[18] There are mines which exit and then re-enter a year to two later.

Figure 15: Nominal Coal Prices

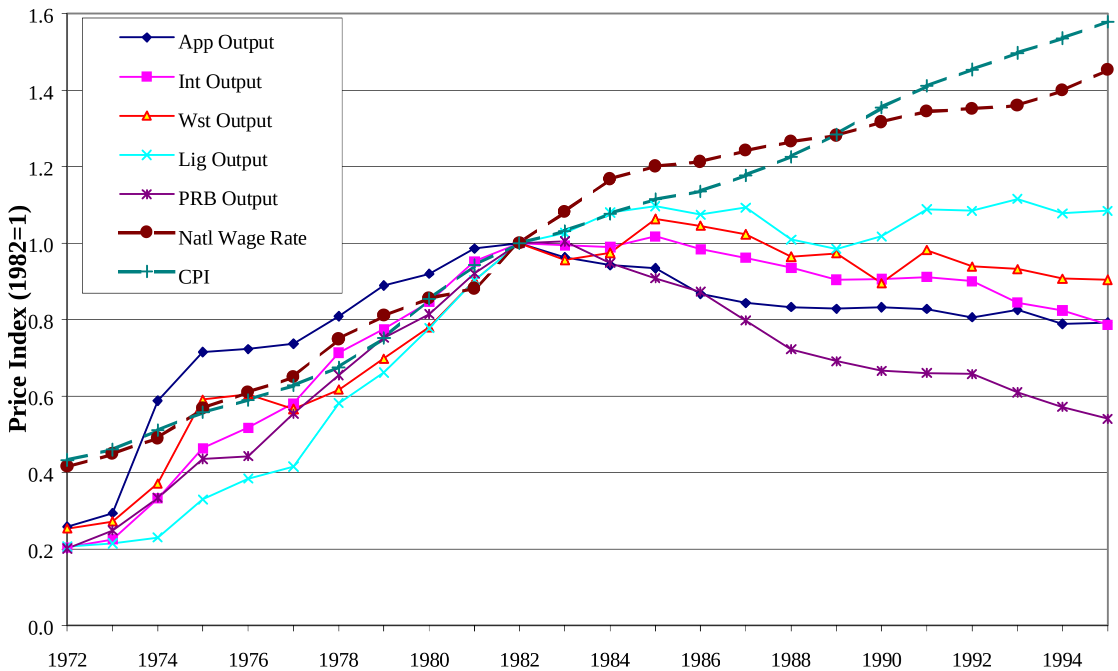
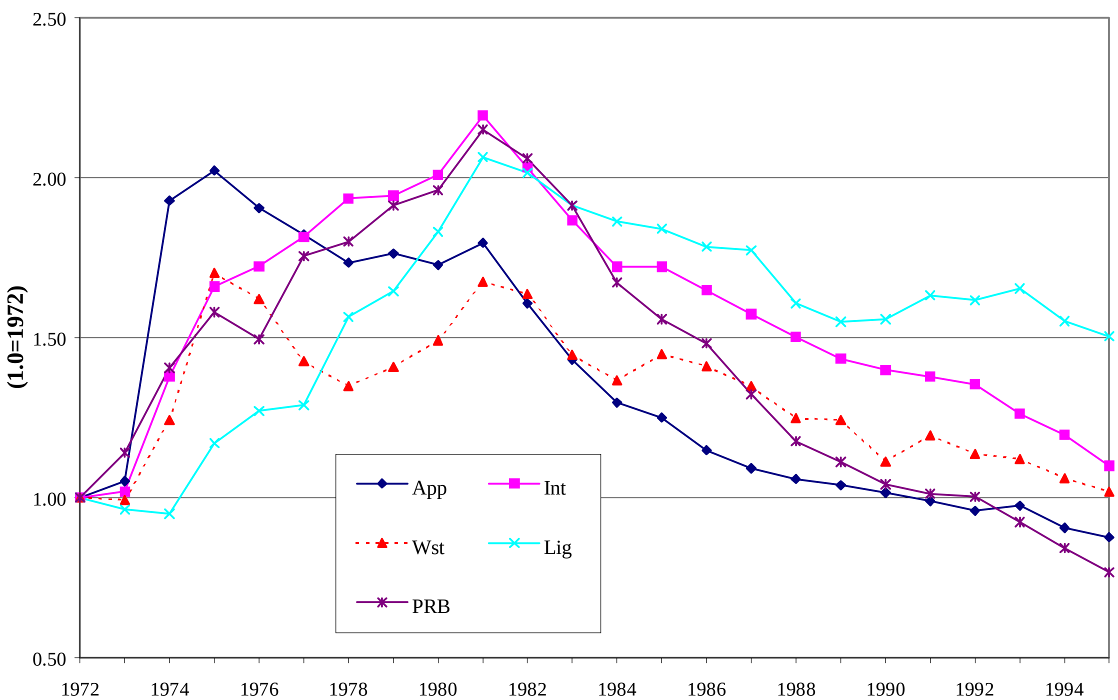


Figure 16: Indices of Output/Labor Price Ratio by Region



[19] Industry observers say this peculiar phenomenon is due to small mines (often the "corners and pockets" of larger reserve tracts) by-passed by larger mines to be exploited by smaller operators who benefit from a

Figure 17: Elasticity of Labor Productivity to Relative Price with Standard Deviations

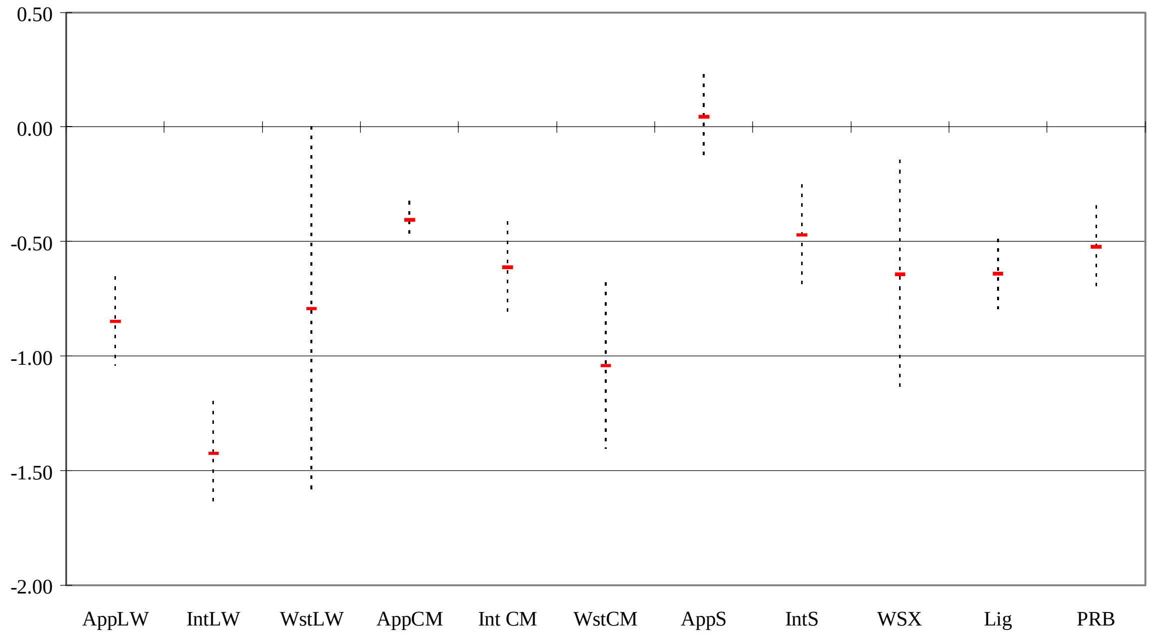
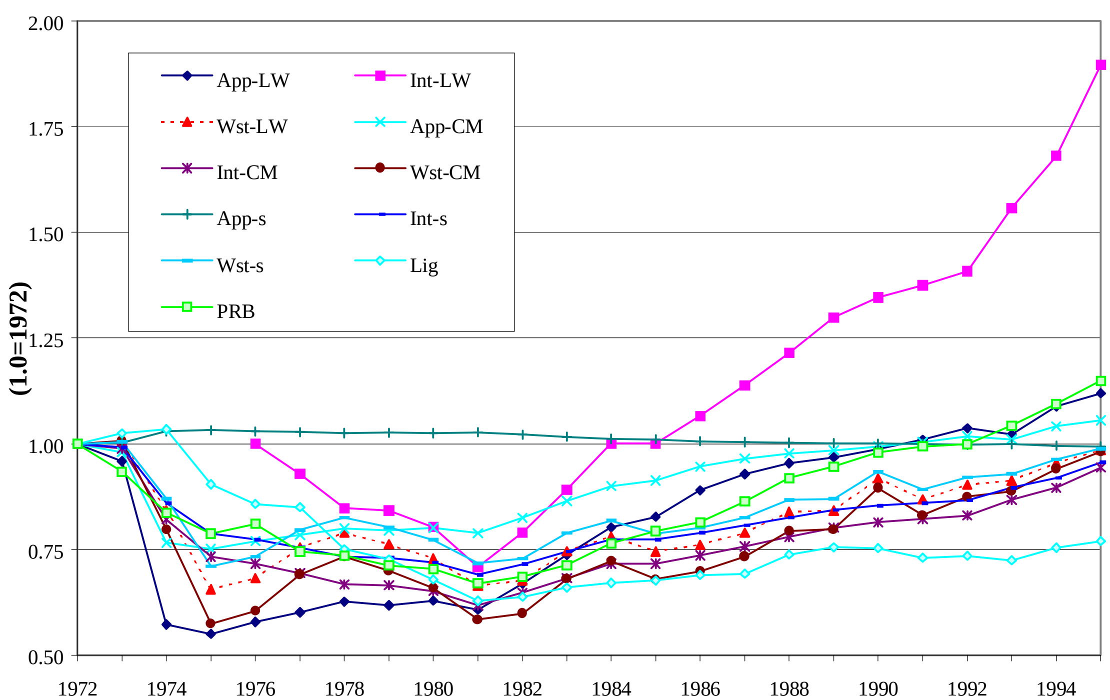


Figure 18: Price Effects Indices



---

de facto, differential application of mine, health, safety, and reclamation regulations.

product declines. In fact, we find a strong relationship between the undifferentiated time effects and the relative output/labor price for all subaggregates except Appalachian surface mining. **Figure 17** depicts the elasticity of labor productivity with respect to this relative price within the range of two standard errors. With the exception of Appalachian surface mining, the range of values is always negative, with mean values falling mostly between –0.5 and –1.0. **Figure 18** plots price effect indices for all eleven subaggregates.

Price effects account for a large part of the observed productivity reduction during the 1970s and the subsequent improvement. In particular, these price effects provide intriguing evidence to suggest that the decline in labor productivity in the 1970s reflected efforts to mine higher-cost and lower-quality geological formations.

Time Effects

Our analysis has produced two indices of time effects. Undifferentiated time effects are produced by the panel regression when the effects of scale and of mine-specific factors are separately identified. As shown in **Figure 19**, the undifferentiated time-effect indices generally decline throughout the 1970s, and rise thereafter for all regions; indices also definitely cluster according to technology. Longwall mining in all three geographic regions exhibits similar but much greater growth in labor productivity than does either continuous or surface mining. Continuous mining in Appalachia and the Interior occupies an intermediate position. Western continuous mining and all Western surface mining are the least progressive. In particular, what appears in Figure 7 to be a higher rate of labor productivity growth for the PRB than for the other surface groups is entirely accounted for by the sixfold increase in scale and the PRB’s relatively high-scale elasticity. Had there been no changes in scale or fixed effects, labor productivity for all surface-mining subaggregates would have been lower in 1995 than in 1972.

Accounting for price effects produces a second measure of the time effect. **Figure 20** plots indices of these residual time effects. There is no longer an apparent technical regress during the 1970s followed by increasing productivity for all subaggregates. Rather, we observe a decline in the labor productivity of surface mining during the 1970s, with subsequently little to no improvement. Underground techniques experience slight to significant increases over the period, with a general tendency for longwall techniques to show greater productivity growth than does continuous mining.

Figure 19: Undifferentiated Time Effects Indices

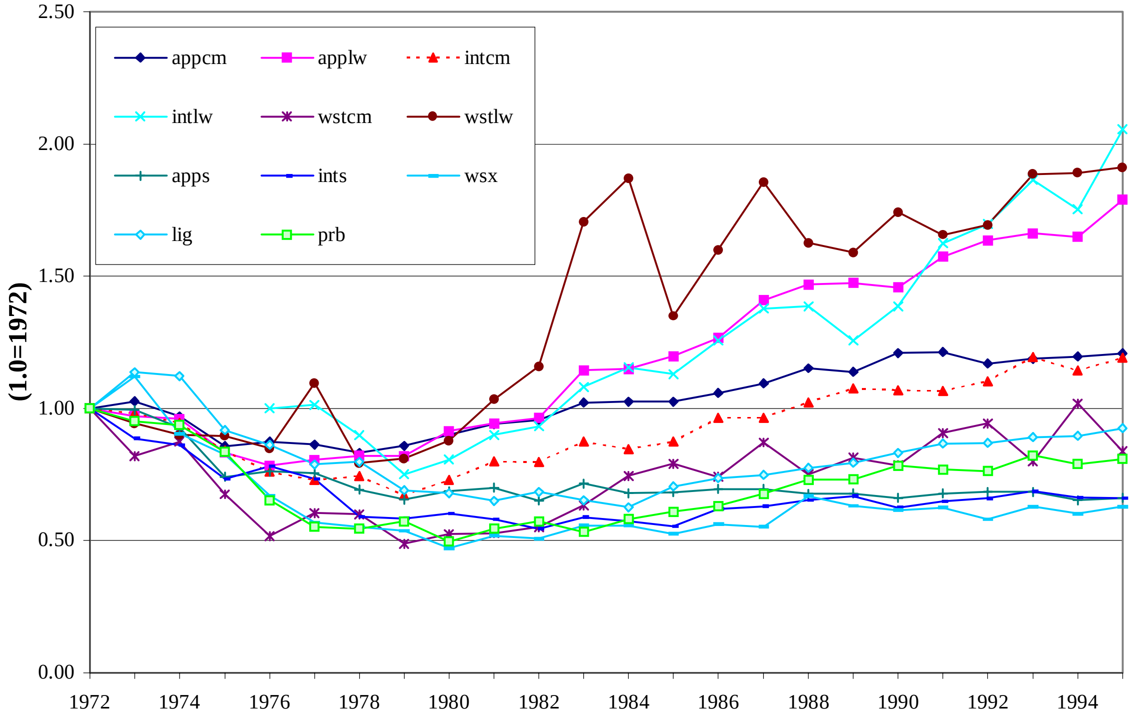
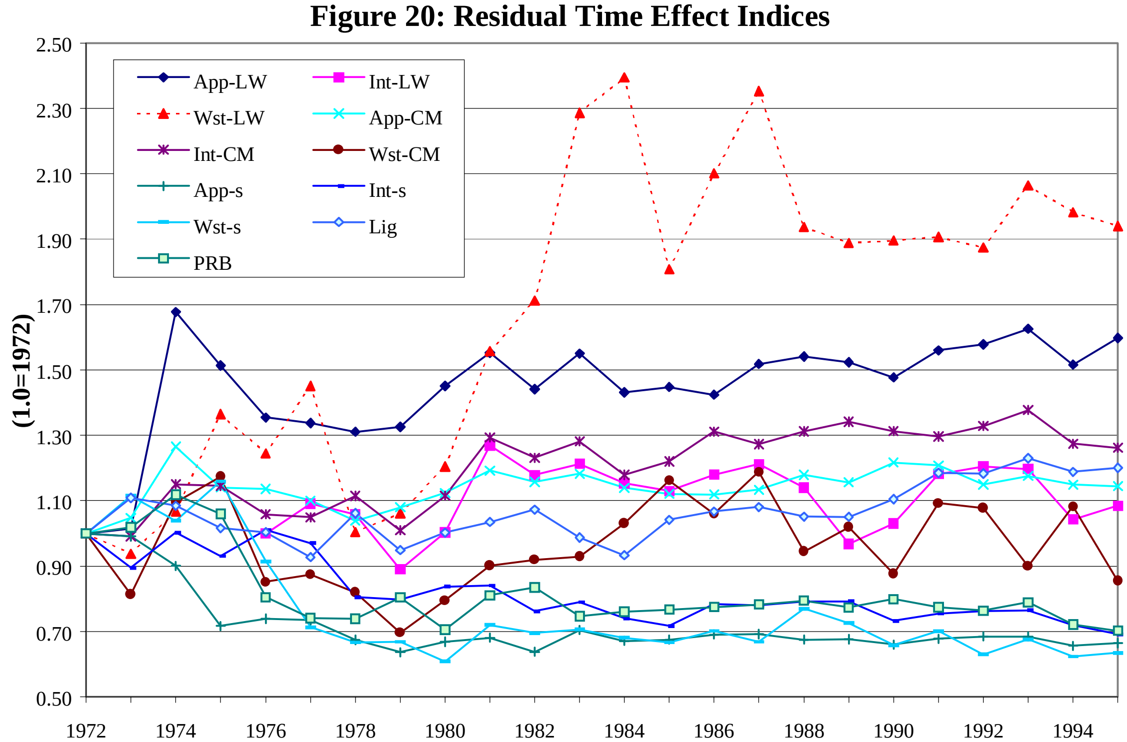


Figure 20: Residual Time Effect Indices



The highly suggestive separation of time effects by technology that is observed before price effects are taken into account is generally preserved, but not entirely. The two exceptions are Interior longwall mining and Lignite mining. Both are found in the residual time effects cluster for continuous mining, which is below the other longwall subaggregates and above the other surface-mining subaggregates. In both instances, there is reason to suspect that the auxiliary regression may be allocating too much of the undifferentiated time effect to price influences. In the case of Interior longwall mining, the auxiliary regression yielded a very high price elasticity. If the Interior longwall elasticity were similar to that obtained for longwall technology in Appalachia and the West (on the order of –0.8 instead of –1.4), the residual time effects would be more strongly progressive. This index would take a value in 1995 of about 1.40, slightly below the value of 1.59 for Appalachian longwall mining. In the case of Lignite, the suspicious element is not price elasticity, which is similar to the price elasticities for other surface-mining subaggregates, but the relatively small change in relative price compared to other surface-mining subaggregates. The necessary result from our partitioning of the undifferentiated time effect is a more progressive residual time effect that places it clearly above the other surface-mining components in Figure 20.

These differences in time effects by technology have plausible explanations. Longwall mining is a newer technology than is continuous mining, so not surprisingly, we observe stronger and more progressive residual time effects for longwall components of the national aggregate. Continuous-mining components show slightly positive rates of improvement of around 0.5% to 1.0% per annum, which might be taken as reasonable for a mature technology. What is surprising is the general lack of any secular improvement in surface mining after the effects of new regulatory requirements were absorbed in the early 1980s. Possibly the considerable difference between the technologies of surface mining (which we characterized before as earth moving) and those of underground mining are differentially impacted by new developments such as computerization. An alternative hypothesis for which we have found support in discussions with industry is that the effects of depletion offset what would otherwise appear as a slow progressive improvement of this technology. This argument rests on the observation that surface-mining reserves are inherently limited from below by underground reserves. The depth at which it is more economic to burrow into the earth than to try to move the earth always limits surface mining. While underground reserves are also ultimately limited, they are far more expansible below; as mining costs are reduced, greater depths become economically accessible.

Aggregating the Four Sources of Productivity Change

This analysis permits us to attribute the changes in mine-level labor productivity within each of the eleven relatively homogeneous subaggregates to four sources: scale, fixed, price, and residual time effects. An index can be formed to track the effect of each source of labor productivity change in each subaggregate. Indices for the effect of each source can be aggregated across each subaggregate, weighted by shares of national output, to provide an index of the contribution of each source to the change in labor productivity at the aggregate, national level. When multiplied, the combined effect of the aggregate indices for scale, fixed, price, and residual time effects should approximate the similarly weighted aggregate of observed change in labor productivity.

Figure 21 presents that aggregation and comparison. The heavy solid line is the output-weighted Divisia index of observed labor productivity for the eleven subaggregates, repeated from Figure 6 above. The dotted lines are similarly aggregated indices for each of the four sources of labor-productivity change. The heavy dashed line is the product of the four aggregate indices for each source of productivity change. The fit of this combined index, while not exact, is close. In general, the predicted aggregate shows less productivity decline in the 1970s and less productivity growth thereafter than that actually observed. We believe that the failure to exactly decompose the sources of labor productivity results from changes in the size composition of mines within some subaggregates (chiefly Appalachian continuous and surface mining), but we have not yet explored this issue. We do believe, however, that the relative roles of the four sources are approximately correct.

Figure 21: Contributions of Scale, Price, Fixed and Time Effects

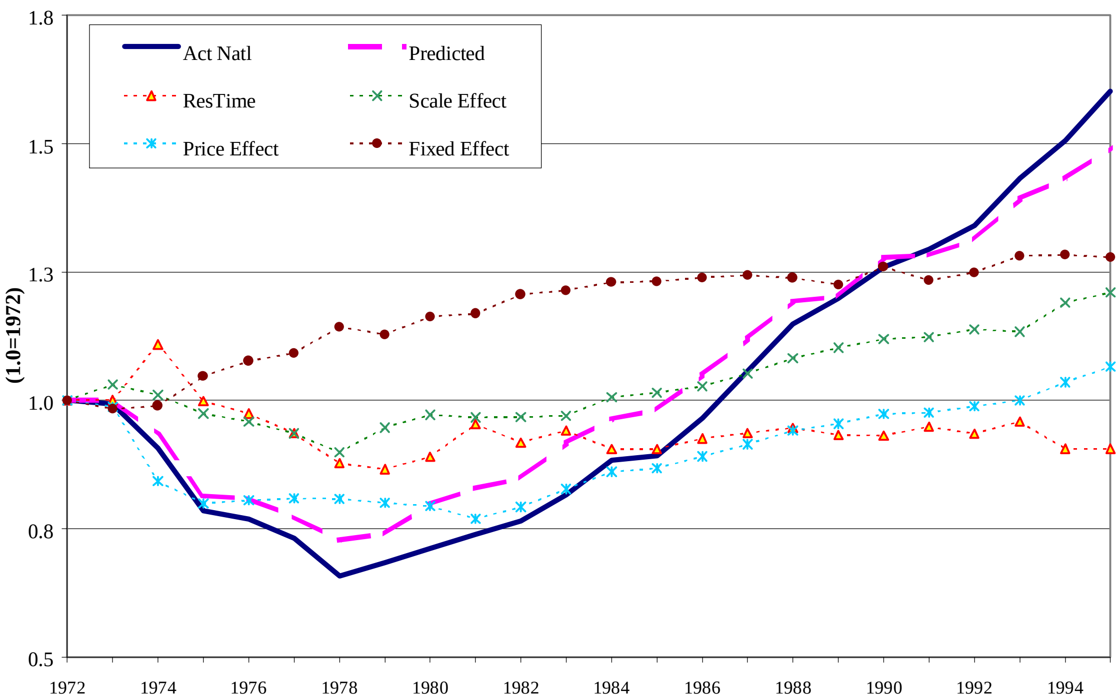


Table 7 displays annual rates of growth for observed and predicted labor productivity in the eleven-component aggregate during periods of falling and rising productivity and the entire period 1972–95. The predicted rates of change can be decomposed exactly into the four sources we identified.

Table 7. Sources of Labor Productivity Growth			
	1972–78	1978–95	1972–95
Observed	-7.00%	+5.24%	+2.05%
Predicted	-5.30%	+4.22%	+1.74%
Scale Effect	-1.79%	+1.75%	+0.83%
Fixed Effect	+2.22%	+0.66%	+1.07%
Price Effect	-3.55%	+1.63%	+0.28%
Residual Time Effect	-2.18%	+0.19%	-0.43%

The period of falling productivity results from a diminution in average mine size, the rising price of output relative to the wage rate, and a regressive residual time effect that is particularly pronounced among the surface-mining regions, probably reflecting the imposition of surface-mining reclamation requirements and enforcement during the 1970s. These negative influences were partially offset by the entrance of mines with higher fixed-effects coefficients in three subaggregates that accounted for about 75% of national production in these years: Appalachian continuous and Appalachian and Interior surface mining.

The period of rising labor productivity during the 1980s and 1990s is largely explained by increasing mine size and the declining price of output relative to the coal wage rate. Contributions from fixed effects and residual time effects during these years were relatively small. The rate of improvement in the fixed-effects index diminished considerably, mostly because the average fixed-effects coefficient stopped rising for one large subaggregate (Appalachian continuous mining) and because the fixed-effects index for two Western regions, Lignite and Western surface mining, began declining for reasons as yet unclear. What would at first appear to have been considerable technical progress, judging from the undifferentiated time effects, becomes much less once price effects are taken into account.

This decomposition is indicative, but not definitive. The analysis demonstrates that the evolution of annual output at an individual mine is an important determinant of labor productivity that cannot be ignored in explanations of productivity trends in the U.S. coal industry. Our regression approach permits us to track over time the evolution of mine-specific productivity characteristics, important contributors to productivity improvement. Most improvement is associated with increasingly productive new vintages of mines, plausibly reflecting new technology introductions; much more analysis is needed, however, before the fixed-effects indices can be clearly interpreted. Separating the price effects out of the undifferentiated time effects by the auxiliary regression has almost eliminated any residual time effect, and shows that the price of output relative to the wage rate is an important determinant of labor productivity. The residual time effect reveals a remarkable period of technical regress coinciding with a period when regulatory requirements and increased enforcement were imposed on the industry. Unfortunately, we lack a good indicator of regulatory requirements that would help identify this source of productivity change that has affected surface mining with particular severity.

6. CONCLUDING REMARKS

This paper depicts the rich interplay of factors underlying the dramatic changes in labor productivity within coal mines over the last 25 years in the United States. While our analysis is decidedly statistical in nature, we have accounted for differing production technologies and segregated the impacts of scale, price, and enduring mine-specific features from more common elements of productivity change.

Within the last several decades, important developments have taken place in modeling, measuring, and interpreting productivity growth. Our paper has focused on one element in this evolving literature: the research opportunities created when large microdata sets having a long time series domain are made publicly available. Company-level data sets have been available for firms in certain regulated industries for quite some time, and large-sample time series data for firms in various manufacturing industries are now also available for research. The extraordinary data set analyzed here—up to a quarter century of recent annual data encompassing the entire industry, consisting of thousands of mines—opens many opportunities for new developments in productivity research.

Our initial analysis of this data set has yielded a number of insights that would not have been possible using data on a more aggregate scale. Most notably, levels and growth rates of labor productivity vary dramatically by both region and mining technology. With productivity so diverse across micro-units and various constituent components, aggregate industry productivity trends reflect the impacts of changing shares of various coal sources.

Several insights from our analysis are particularly intriguing. First, a surprisingly strong finding is that scale economies are ubiquitous and substantial, even after mine-specific fixed effects (reflecting, for example, geological conditions) are taken into account. In other work we have done at the industry level of aggregation, economies of scale are insignificant (*ref*. Berndt *et al*., 1997), raising an interesting interpretive issue. Unlike the "new growth theory," in which returns to scale are constant at the micro-level but spillovers induce increases in industry- or economy-wide returns,[20] we appear here to have robust increasing returns at the micro-level of analysis but apparently constant returns to scale at the aggregate industry level. In coal mining, aggregate productivity trends depend on the size distribution of firms (mines) and its changes over time. How these findings link to the new growth theory merits further research.

A second insight offered by the micro-level data concerns responsiveness to price changes. The micro-level data on coal mining show quite clearly that as coal prices increased more rapidly than wages in the mid- to late 1970s, labor productivity declined as companies opened mines that were not only smaller, but also apparently less favorable geologically. Not surprisingly, many of these mines closed within several years as relative coal prices fell, bringing about an increase in industry-level labor productivity. Although this explanation is exactly what one might expect based on economic theory, the micro-level data now available uniquely permit analysts to empirically assess and confirm this prediction from theory.

[20] For a review, see the references in Romer [1994].

BIBLIOGRAPHY

Baker, Joe G. (1981), "Sources of Deep Coal Mine Productivity Change, 1962-1975," The Energy Journal, Vol. 2, No. 2, April, pp. 95-106.

Barnett, Harold and Chandler Morse (1963), Scarcity and Growth, Baltimore: Johns Hopkins Press for Resources for the Future.

Berndt, Ernst R. and A. Denny Ellerman (1996), "Investment, Productivity and Capacity in U.S. Coal Mining: Macro vs. Micro Perspectives." Unpublished Working Draft.

Berndt, Ernst R., Charles Kolstad and Jong-Kun Lee (1993), "Measuring the Energy Efficiency and Productivity Impacts of Embodied Technical Progress," Energy Journal, Vol. 14, No. 1, March, pp. 33-55.

Boyd, Gale A. (1987), "Factor Intensity and Site Geology as Determinants of Returns to Scale in Coal Mining," Review of Economics and Statistics, Vol. 69, No. 1, February, pp. 18-23.

Byrnes, P., Rolf Fare and S. Grosskopf (1984), "Measuring Productive Efficiency: An Application to Illinois Strip Mines," Management Science, Vol. 30, No. 6, June, pp. 671-681.

Christensen, Laurits R. and Dale W. Jorgenson (1973), "Measuring Economic Performance in the Private Sector," in Milton Moss, ed., The Measurement of Economic and Social Performance, Studies in Income and Wealth, Vol. 37, New York: Columbia University Press, pp. 233-251. Reprinted in Dale W. Jorgenson, Productivity, Vol. 1: Postwar U.S. Economic Growth, Cambridge, MA: MIT Press, 1995, pp. 175-272.

Coal Age, "U.S. Longwall Census", annual feature in this and predecessor publications, Intertec Publishing Corporation, Chicago.

Coal Markets, (various issues), Fieldston Publications, Washington, D.C.

Dunne, Timothy, Mark J. Roberts and Larry Samuelson (1988), "Patterns of Firm Entry and Exit in U.S. Manufacturing Industries," Rand Journal of Economics, Vol. 19, No. 4, Winter, pp. 495-515.

Ellerman, A. Denny (1995), "The World Price of Coal," Energy Policy, Vol. 23, No. 6, December, pp. 499-506.

Ellerman, A. Denny (1996), "Price, Productivity and Capacity Utilization in the U.S. Coal Industry, 1947-91." Unpublished Working Draft.

Ellerman, A. Denny and Ernst R. Berndt (1996),"An Initial Analysis of Productivity Trends in the American Coal Industry." Unpublished Report submitted to the Office of Coal, Uranium and Renewable Energy Analysis, Energy Information Administration, U. S. Department of Energy.

Greene, William H. (1997), *Econometric Analysis*, 3rd Edition, Prentice Hall.

Hotelling, Harold (1931), "The Economics of Exhaustible Resources," Journal of Political Economy, Vol. 39, No. 1, pp. 137-175.

Jensen, J. Bradford, Robert H. McGuckin and Kevin J. Stiroh (1998), "The Impact of Vintage and Age on Productivity: Evidence from Cohorts of U.S. Manufacturing Plants." Unpublished second draft dated January 1998.

Jorgenson, Dale W. (1990), "Productivity and Economic Growth." *Fifty Years of Economic Measurement: The Jubilee of the Conference on Research in Income and Wealth*, Washington, D.C., May 12-14, 1988 (vol. 54, NBER Studies in Income and Wealth). Eds. Ernst R. Berndt and Jack E. Triplett, Chicago and London:

University of Chicago Press. pp. 19-118. Also reprinted in Jorgenson, Dale W., *Productivity: International Comparisons of Economic Growth (vol. 2)*. Cambridge and London: The MIT Press, 1995. pp. 1-98.

Jorgenson, Dale W. and Barbara M. Fraumeni (1981), "Relative Prices and Technical Change," in Ernst R. Berndt and Barry C. Field, eds., Modeling and Measuring Natural Resource Substitution, Cambridge and London: The MIT Press, pp. 17-47.

Jorgenson, Dale W., Frank M. Gallop and Barbara M. Fraumeni (1987), *Productivity and U.S. Economic Growth*, Cambridge: Harvard University Press.

Keystone Coal Industry Manual (1996), Intertec Publishing Company, Chicago, IL

Kruvant, William J., Carlisle E. Moody, Jr., and Patrick L. Valentine (1982), "Sources of Productivity Decline in U.S. Coal Mining, 1972-1977," The Energy Journal, Vol. 3, No. 3, July, pp. 53-70.

Lakhani, Hyder (1980), "Economics of Technical Change in U.S. Coal Mines, 1951-1975," Energy, Vol. 5, No. 1, pp. 217-230.

Maddala, G. S. (1965), "Productivity and Technological Change in the Bituminous Coal Industry, 1919-1954," Journal of Political Economy, Vol. 73, No. 3, August, pp. 352-365.

McDermott, David (1997), "Coal mining in the U.S. West: price and employment trends." *Monthly Labor Review*, August 1997, pp. 18-23.

Morrison, Catherine J. (1993), *A Microeconomic Approach to the Measurement of Economic Performance: Productivity Growth, Capacity Utilization, and Related Performance Indicators*. New York: Springer-Verlag.

Romer, Paul (1994), "New Goods, Old Theory, and the Welfare Costs of Trade Restrictions," Journal of Development Economics, Vol. 43, No. 1, pp. 5-38.

Spencer, Vivian Eberle (1963), Raw Materials in the United States Economy: 1900-1961, U. S. Department of Commerce, Bureau of the Census, Working Paper No. 6, Washington, DC.

Temin, Peter, Stan Finkelstein and Bart Clarysse (1996), "Economies of Scale in the Pharmaceutical Industry," Cambridge, MA: MIT Program on the Pharmaceutical Industry, Working Paper No. WP#26-96, February.

U.S. Department of Energy, Energy Information Administration, *Coal Industry Annual,* (Various Years 1993-1995), Washington, D.C.

U. S. Department of Energy, Energy Information Administration, *Coal Production,* (Various Years to 1993), Washington, D.C.

U.S. Department of Energy, Energy Information Administration, *Longwall Mining* (DOE/EIA-TR-0588), March 1995.

U. S. Department of Interior, Bureau of Mines, *Minerals Yearbook,* (various years up to 1976), Washington, D.C.

U. S. Department of Labor, Bureau of Labor Statistics, *Employment, Hours and Earnings, United States (1994, 1996),* Washington, D.C.

U.S. Department of Labor, Mine Safety and Health Administration (1984), Summary of Selected Injury Experience and Worktime for the Mining Industry in the United States, 1931-77, , Informational Report IR 1132, Washington, D.C.

U. S. Department of Labor, Mine Safety and Health Administration, Part 50 Coal Mining Address/Employment and Accident/Injury Files, Division of Mining Information Systems, Denver, CO.

United States Executive Office of the President (1976), A Study of Coal Prices, Washington D.C.: Council on Wage and Price Stability, March.

Wellenius, Kevin (1996), "Technological Progress and Environmental Regulation as Drivers of Productivity Growth: Evidence from the U.S. Coal Industry, 1972-1994," unpublished S.M. thesis, Cambridge, MA: Massachusetts Institute of Technology, Department of Civil and Environmental Engineering, June.

APPENDIX 1A: ANNUAL PRODUCTION BY SUB-AGGREGATE, REGION AND TECHNIQUE (SHORT TONS)

	Continuous Mining			Longwall Mining			Surface Mining					National
Year	App-CM	Int-CM	Wst-CM	App-LW	Int-LW	Wst-LW	App-s	Int-s	Wst-s	Lig	PRB	Total
1972	197,680,666	50,508,108	7,434,505	30,118,885	0	1,109,066	106,221,379	95,266,140	20,174,961	10,481,403	9,974,553	528,969,666
1973	190,178,351	56,044,383	7,952,216	29,597,460	0	1,235,613	120,200,545	92,280,171	27,545,899	14,152,565	14,572,911	553,760,114
1974	171,320,989	54,081,508	8,073,739	27,783,345	0	1,797,073	139,251,650	87,491,934	35,687,047	15,085,619	19,805,492	560,378,396
1975	178,760,765	57,127,672	9,354,843	29,931,824	0	1,879,243	146,519,862	93,803,870	36,697,398	19,865,743	26,953,618	600,894,838
1976	177,354,016	54,511,474	9,748,789	34,487,678	1,822,894	2,483,047	160,071,087	91,569,679	46,512,123	25,549,641	34,190,470	638,300,898
1977	154,912,489	51,407,634	12,226,508	33,382,912	1,746,072	2,861,596	181,283,428	92,641,741	53,785,445	29,378,715	47,455,420	661,081,960
1978	140,435,959	40,995,010	12,735,611	30,303,466	2,203,959	1,774,678	168,660,769	77,457,469	54,945,414	34,451,652	58,794,694	622,758,681
1979	179,740,150	47,839,992	14,052,886	49,166,136	4,940,426	4,185,047	165,382,145	88,365,768	60,239,654	42,649,791	76,678,508	733,240,503
1980	194,465,714	48,965,300	13,946,361	50,733,962	6,097,738	6,353,774	170,515,784	87,702,727	66,333,968	46,793,396	96,955,530	788,864,254
1981	183,844,889	41,801,143	15,229,072	45,749,212	5,179,325	7,091,856	175,752,876	82,429,698	61,252,667	49,406,408	110,006,864	777,744,010
1982	188,696,287	47,781,476	16,817,562	60,382,548	5,910,009	8,856,169	159,321,484	87,682,893	59,537,695	51,957,211	121,636,808	808,580,142
1983	156,645,216	42,863,550	12,204,155	66,651,962	5,864,413	5,986,375	140,683,621	83,589,351	56,845,284	57,927,314	125,834,695	755,095,936
1984	188,982,804	48,023,626	11,329,587	75,077,750	9,829,683	9,275,580	163,051,476	96,259,029	59,767,556	63,056,431	151,831,417	876,484,939
1985	186,592,723	48,579,483	10,379,010	76,741,152	9,572,009	10,695,832	144,573,271	81,889,550	56,294,749	72,124,559	157,867,872	855,310,210
1986	188,358,382	53,136,443	8,862,103	79,807,080	10,799,460	11,808,121	144,302,688	79,535,724	55,227,671	76,993,165	160,601,030	869,431,867
1987	184,232,400	53,328,773	8,611,125	91,404,413	13,231,111	13,661,372	152,440,992	80,165,806	51,075,319	78,499,490	169,167,530	895,818,331
1988	188,184,439	51,602,391	10,049,625	95,892,634	15,057,387	16,191,616	154,726,034	69,962,708	58,606,147	84,079,429	192,433,717	936,786,127
1989	191,368,445	50,679,203	9,404,570	100,004,329	14,655,810	21,091,345	160,456,891	74,530,055	58,597,027	86,511,700	199,241,300	966,540,675
1990	203,636,431	53,008,695	9,798,014	112,905,220	16,198,133	23,919,313	165,730,162	77,161,757	57,659,220	87,134,279	208,466,548	1,015,617,772
1991	186,392,882	50,347,189	9,196,046	114,459,673	19,326,816	24,099,760	150,242,612	68,513,009	55,710,499	86,475,607	218,718,233	983,482,326
1992	179,741,210	51,610,671	8,058,911	117,580,137	20,589,522	25,712,089	151,271,593	63,322,962	59,765,302	88,886,673	217,370,786	983,909,856
1993	161,188,836	41,215,403	7,969,868	93,708,125	14,717,175	29,137,820	147,277,092	53,042,486	62,103,911	90,322,658	236,825,325	937,508,699
1994	162,253,764	48,339,958	7,071,655	118,732,801	20,643,151	37,599,595	155,094,458	55,132,621	62,930,883	87,962,692	264,935,074	1,020,696,652
1995	163,201,522	43,492,908	6,567,923	120,270,029	24,457,853	37,573,153	147,555,126	42,885,236	59,827,578	85,825,798	294,280,752	1,025,937,878

BY MINING TECHNIQUE

	Continuous	Longwall	Underground	Surface	Total
1972	255,623,279	31,227,951	286,851,230	242,118,436	528,969,666
1973	254,174,950	30,833,073	285,008,023	268,752,091	553,760,114
1974	233,476,236	29,580,418	263,056,654	297,321,742	560,378,396
1975	245,243,280	31,811,067	277,054,347	323,840,491	600,894,838
1976	241,614,279	38,793,619	280,407,898	357,893,000	638,300,898
1977	218,546,631	37,990,580	256,537,211	404,544,749	661,081,960
1978	194,166,580	34,282,103	228,448,683	394,309,998	622,758,681
1979	241,633,028	58,291,609	299,924,637	433,315,866	733,240,503
1980	257,377,375	63,185,474	320,562,849	468,301,405	788,864,254
1981	240,875,104	58,020,393	298,895,497	478,848,513	777,744,010
1982	253,295,325	75,148,726	328,444,051	480,136,091	808,580,142
1983	211,712,921	78,502,750	290,215,671	464,880,265	755,095,936
1984	248,336,017	94,183,013	342,519,030	533,965,909	876,484,939
1985	245,551,216	97,008,993	342,560,209	512,750,001	855,310,210
1986	250,356,928	102,414,661	352,771,589	516,660,278	869,431,867
1987	246,172,298	118,296,896	364,469,194	531,349,137	895,818,331
1988	249,836,455	127,141,637	376,978,092	559,808,035	936,786,127
1989	251,452,218	135,751,484	387,203,702	579,336,973	966,540,675
1990	266,443,140	153,022,666	419,465,806	596,151,966	1,015,617,772
1991	245,936,117	157,886,249	403,822,366	579,659,960	983,482,326
1992	239,410,792	163,881,748	403,292,540	580,617,316	983,909,856
1993	210,374,107	137,563,120	347,937,227	589,571,472	937,508,699
1994	217,665,377	176,975,547	394,640,924	626,055,728	1,020,696,652
1995	213,262,353	182,301,035	395,563,388	630,374,490	1,025,937,878

BY REGION

Appalachia	Interior	Western	Total
334,020,930	145,774,248	49,174,488	528,969,666
339,976,356	148,324,554	65,459,204	553,760,114
338,355,984	141,573,442	80,448,970	560,378,396
355,212,451	150,931,542	94,750,845	600,894,838
371,912,781	147,904,047	118,484,070	638,300,898
369,578,829	145,795,447	145,707,684	661,081,960
339,400,194	120,656,438	162,702,049	622,758,681
394,288,431	141,146,186	197,805,886	733,240,503
415,715,460	142,765,765	230,383,029	788,864,254
405,346,977	129,410,166	242,986,867	777,744,010
408,400,319	141,374,378	258,805,445	808,580,142
363,980,799	132,317,314	258,797,823	755,095,936
427,112,030	154,112,338	295,260,571	876,484,939
407,907,146	140,041,042	307,362,022	855,310,210
412,468,150	143,471,627	313,492,090	869,431,867
428,077,805	146,725,690	321,014,836	895,818,331
438,803,107	136,622,486	361,360,534	936,786,127
451,829,665	139,865,068	374,845,942	966,540,675
482,271,813	146,368,585	386,977,374	1,015,617,772
451,095,167	138,187,014	394,200,145	983,482,326
448,592,940	135,523,155	399,793,761	983,909,856
402,174,053	108,975,064	426,359,582	937,508,699
436,081,023	124,115,730	460,499,899	1,020,696,652
431,026,677	110,835,997	484,075,204	1,025,937,878

APPENDIX 1B: ANNUAL EMPLOYEE HOURS BY SUB-AGGREGATE, REGION AND TECHNIQUE

	Continuous Mining			Longwall Mining			Surface Mining					National
Year	**App-CM**	**Int-CM**	**Wst-CM**	**App-LW**	**Int-LW**	**Wst-LW**	**App-s**	**Int-s**	**Wst-s**	**Lig**	**PRB**	**Total**
1972	143,535,689	23,850,455	4,779,586	24,188,864	0	871,707	33,096,450	21,571,946	2,659,144	1,113,831	615,936	256,283,608
1973	140,129,029	25,638,328	5,620,802	25,064,829	0	994,885	35,947,570	22,477,048	3,582,065	1,244,124	973,379	261,672,059
1974	138,176,787	27,671,476	4,715,103	25,680,563	0	2,032,444	46,314,747	23,901,296	4,597,662	1,466,479	1,404,481	275,961,038
1975	166,122,611	32,304,985	5,909,599	30,775,236	0	2,239,102	61,394,878	28,327,738	5,506,852	2,283,429	1,874,697	336,739,127
1976	168,678,354	34,054,953	7,004,749	35,565,044	1,040,507	2,719,276	65,051,908	30,101,509	6,681,706	2,633,157	2,586,168	356,117,331
1977	154,626,948	34,655,235	8,724,917	36,025,204	1,004,575	2,474,785	74,165,945	32,673,260	8,810,454	3,709,608	3,629,223	360,500,154
1978	143,553,604	30,800,879	8,769,988	35,287,287	1,950,316	2,194,687	78,056,408	34,210,817	10,539,263	4,798,985	4,816,432	354,978,666
1979	162,078,538	35,577,577	9,649,168	49,052,684	4,643,393	3,949,724	77,620,707	38,251,481	11,969,957	5,833,735	6,128,343	404,755,307
1980	156,283,914	33,589,362	9,482,255	46,859,559	5,286,923	5,088,529	76,047,900	36,874,430	13,519,394	7,300,633	8,147,457	398,480,356
1981	142,019,548	28,851,737	9,255,138	41,172,079	3,881,644	5,131,908	73,645,875	33,774,167	12,391,816	8,048,740	8,682,090	366,854,742
1982	136,179,023	30,684,514	8,796,971	46,387,483	3,983,677	5,447,105	70,581,413	36,024,780	11,494,295	8,146,547	9,223,353	366,949,161
1983	98,357,845	25,445,354	5,984,768	44,021,257	3,148,248	2,765,216	58,473,694	33,106,543	10,726,427	9,317,782	9,856,784	301,203,918
1984	108,979,690	26,816,779	5,134,686	46,756,195	4,644,295	3,666,182	64,386,955	35,774,932	10,932,049	9,738,415	10,169,586	326,999,764
1985	103,981,430	26,151,515	4,688,176	44,716,160	4,626,618	4,659,861	57,352,150	31,614,273	11,309,389	10,101,285	10,621,889	309,822,746
1986	97,682,393	25,918,464	3,637,719	40,897,282	4,424,157	4,218,840	54,674,604	26,939,023	11,199,282	10,231,065	9,850,518	289,673,347
1987	87,167,408	23,562,878	2,896,726	40,002,986	5,157,980	3,878,225	52,297,331	24,994,410	10,339,737	10,333,188	9,395,532	270,026,401
1988	81,245,260	21,635,501	3,608,491	39,860,358	5,491,912	4,173,590	51,340,152	21,088,197	9,985,566	9,997,604	9,320,307	257,746,938
1989	78,214,631	19,665,425	3,102,898	39,779,003	6,409,593	5,139,939	51,407,171	20,069,692	10,132,711	9,829,446	9,376,498	253,127,007
1990	76,841,037	18,823,989	3,002,537	44,574,623	6,178,638	5,421,673	50,791,092	20,260,872	9,910,902	9,905,959	9,137,327	254,848,649
1991	68,659,352	17,120,237	2,590,776	41,934,544	6,712,765	4,735,176	43,226,813	18,119,040	9,701,501	9,891,142	9,674,826	232,366,172
1992	63,688,966	16,578,030	2,088,792	39,486,879	6,551,431	4,974,439	42,039,280	16,077,902	9,938,251	9,904,810	9,708,666	221,037,446
1993	55,631,332	12,967,288	2,162,842	31,082,699	4,796,559	5,017,901	39,340,256	12,437,477	10,112,177	8,773,274	9,211,841	191,533,646
1994	53,797,567	13,686,895	1,697,747	35,332,673	6,808,591	5,899,395	40,037,687	12,777,190	10,176,051	8,236,293	9,801,160	198,251,249
1995	51,424,942	11,474,217	1,885,358	33,700,667	6,319,183	5,393,301	36,184,445	9,733,987	9,770,691	8,207,159	9,759,336	183,853,286

BY MINING TECHNIQUE

	Continuous	Longwall	Underground	Surface	Total
1972	172,165,730	25,060,571	197,226,301	59,057,307	256,283,608
1973	171,388,159	26,059,714	197,447,873	64,224,186	261,672,059
1974	170,563,366	27,713,007	198,276,373	77,684,665	275,961,038
1975	204,337,195	33,014,338	237,351,533	99,387,594	336,739,127
1976	209,738,056	39,324,827	249,062,883	107,054,448	356,117,331
1977	198,007,100	39,504,564	237,511,664	122,988,490	360,500,154
1978	183,124,471	39,432,290	222,556,761	132,421,905	354,978,666
1979	207,305,283	57,645,801	264,951,084	139,804,223	404,755,307
1980	199,355,531	57,235,011	256,590,542	141,889,814	398,480,356
1981	180,126,423	50,185,631	230,312,054	136,542,688	366,854,742
1982	175,660,508	55,818,265	231,478,773	135,470,388	366,949,161
1983	129,787,967	49,934,721	179,722,688	121,481,230	301,203,918
1984	140,931,155	55,066,672	195,997,827	131,001,937	326,999,764
1985	134,821,121	54,002,639	188,823,760	120,998,986	309,822,746
1986	127,238,576	49,540,279	176,778,855	112,894,492	289,673,347
1987	113,627,012	49,039,191	162,666,203	107,360,198	270,026,401
1988	106,489,252	49,525,860	156,015,112	101,731,826	257,746,938
1989	100,982,954	51,328,535	152,311,489	100,815,518	253,127,007
1990	98,667,563	56,174,934	154,842,497	100,006,152	254,848,649
1991	88,370,365	53,382,485	141,752,850	90,613,322	232,366,172
1992	82,355,788	51,012,749	133,368,537	87,668,909	221,037,446
1993	70,761,462	40,897,159	111,658,621	79,875,025	191,533,646
1994	69,182,209	48,040,659	117,222,868	81,028,381	198,251,249
1995	64,784,517	45,413,151	110,197,668	73,655,618	183,853,286

BY REGION

Appalachia	Interior	Western	Total
200,821,003	45,422,401	10,040,204	256,283,608
201,141,428	48,115,376	12,415,255	261,672,059
210,172,097	51,572,772	14,216,169	275,961,038
258,292,725	60,632,723	17,813,679	336,739,127
269,295,306	65,196,969	21,625,056	356,117,331
264,818,097	68,333,070	27,348,987	360,500,154
256,897,299	66,962,012	31,119,355	354,978,666
288,751,929	78,472,451	37,530,927	404,755,307
279,191,373	75,750,715	43,538,268	398,480,356
256,837,502	66,507,548	43,509,692	366,854,742
253,147,919	70,692,971	43,108,271	366,949,161
200,852,796	61,700,145	38,650,977	301,203,918
220,122,840	67,236,006	39,640,918	326,999,764
206,049,740	62,392,406	41,380,600	309,822,746
193,254,279	57,281,644	39,137,424	289,673,347
179,467,725	53,715,268	36,843,408	270,026,401
172,445,770	48,215,610	37,085,558	257,746,938
169,400,805	46,144,710	37,581,492	253,127,007
172,206,752	45,263,499	37,378,398	254,848,649
153,820,709	41,952,042	36,593,421	232,366,172
145,215,125	39,207,363	36,614,958	221,037,446
126,054,287	30,201,324	35,278,035	191,533,646
129,167,927	33,272,676	35,810,646	198,251,249
121,310,054	27,527,387	35,015,845	183,853,286

APPENDIX 1C: LABOR PRODUCTIVITY BY SUB-AGGREGATE, REGION AND TECHNIQUE (TONS/HOUR)

	Continuous Mining			Longwall Mining			Surface Mining					National
Year	App-CM	Int-CM	Wst-CM	App-LW	Int-LW	Wst-LW	App-s	Int-s	Wst-s	Lig	PRB	Total
1972	1.377	2.118	1.555	1.245		1.272	3.209	4.416	7.587	9.410	16.194	2.064
1973	1.357	2.186	1.415	1.181		1.242	3.344	4.106	7.690	11.376	14.971	2.116
1974	1.240	1.954	1.712	1.082		0.884	3.007	3.661	7.762	10.287	14.102	2.031
1975	1.076	1.768	1.583	0.973		0.839	2.387	3.311	6.664	8.700	14.378	1.784
1976	1.051	1.601	1.392	0.970	1.752	0.913	2.461	3.042	6.961	9.703	13.221	1.792
1977	1.002	1.483	1.401	0.927	1.738	1.156	2.444	2.835	6.105	7.920	13.076	1.834
1978	0.978	1.331	1.452	0.859	1.130	0.809	2.161	2.264	5.213	7.179	12.207	1.754
1979	1.109	1.345	1.456	1.002	1.064	1.060	2.131	2.310	5.033	7.311	12.512	1.812
1980	1.244	1.458	1.471	1.083	1.153	1.249	2.242	2.378	4.907	6.409	11.900	1.980
1981	1.295	1.449	1.645	1.111	1.334	1.382	2.386	2.441	4.943	6.138	12.671	2.120
1982	1.386	1.557	1.912	1.302	1.484	1.626	2.257	2.434	5.180	6.378	13.188	2.204
1983	1.593	1.685	2.039	1.514	1.863	2.165	2.406	2.525	5.300	6.217	12.766	2.507
1984	1.734	1.791	2.206	1.606	2.117	2.530	2.532	2.691	5.467	6.475	14.930	2.680
1985	1.794	1.858	2.214	1.716	2.069	2.295	2.521	2.590	4.978	7.140	14.863	2.761
1986	1.928	2.050	2.436	1.951	2.441	2.799	2.639	2.952	4.931	7.525	16.304	3.001
1987	2.114	2.263	2.973	2.285	2.565	3.523	2.915	3.207	4.940	7.597	18.005	3.318
1988	2.316	2.385	2.785	2.406	2.742	3.880	3.014	3.318	5.869	8.410	20.647	3.635
1989	2.447	2.577	3.031	2.514	2.287	4.103	3.121	3.714	5.783	8.801	21.249	3.818
1990	2.650	2.816	3.263	2.533	2.622	4.412	3.263	3.808	5.818	8.796	22.815	3.985
1991	2.715	2.941	3.550	2.729	2.879	5.090	3.476	3.781	5.742	8.743	22.607	4.232
1992	2.822	3.113	3.858	2.978	3.143	5.169	3.598	3.939	6.014	8.974	22.389	4.451
1993	2.897	3.178	3.685	3.015	3.068	5.807	3.744	4.265	6.141	10.295	25.709	4.895
1994	3.016	3.532	4.165	3.360	3.032	6.373	3.874	4.315	6.184	10.680	27.031	5.149
1995	3.174	3.790	3.484	3.569	3.870	6.967	4.078	4.406	6.123	10.457	30.154	5.580

BY MINING TECHNIQUE

	Continuous	Longwall	Underground	Surface	Total
1972	1.485	1.246	1.454	4.100	2.064
1973	1.483	1.183	1.443	4.185	2.116
1974	1.369	1.067	1.327	3.827	2.031
1975	1.200	0.964	1.167	3.258	1.784
1976	1.152	0.986	1.126	3.343	1.792
1977	1.104	0.962	1.080	3.289	1.834
1978	1.060	0.869	1.026	2.978	1.754
1979	1.166	1.011	1.132	3.099	1.812
1980	1.291	1.104	1.249	3.300	1.980
1981	1.337	1.156	1.298	3.507	2.120
1982	1.442	1.346	1.419	3.544	2.204
1983	1.631	1.572	1.615	3.827	2.507
1984	1.762	1.710	1.748	4.076	2.680
1985	1.821	1.796	1.814	4.238	2.761
1986	1.968	2.067	1.996	4.576	3.001
1987	2.166	2.412	2.241	4.949	3.318
1988	2.346	2.567	2.416	5.503	3.635
1989	2.490	2.645	2.542	5.747	3.818
1990	2.700	2.724	2.709	5.961	3.985
1991	2.783	2.958	2.849	6.397	4.232
1992	2.907	3.213	3.024	6.623	4.451
1993	2.973	3.364	3.116	7.381	4.895
1994	3.146	3.684	3.367	7.726	5.149
1995	3.292	4.014	3.590	8.558	5.580

BY REGION

Appalachia	Interior	Western	Total
1.663	3.209	4.898	2.064
1.690	3.083	5.272	2.116
1.610	2.745	5.659	2.031
1.375	2.489	5.319	1.784
1.381	2.269	5.479	1.792
1.396	2.134	5.328	1.834
1.321	1.802	5.228	1.754
1.365	1.799	5.270	1.812
1.489	1.885	5.292	1.980
1.578	1.946	5.585	2.120
1.613	2.000	6.004	2.204
1.812	2.145	6.696	2.507
1.940	2.292	7.448	2.680
1.980	2.245	7.428	2.761
2.134	2.505	8.010	3.001
2.385	2.732	8.713	3.318
2.545	2.834	9.744	3.635
2.667	3.031	9.974	3.818
2.801	3.234	10.353	3.985
2.933	3.294	10.772	4.232
3.089	3.457	10.919	4.451
3.190	3.608	12.086	4.895
3.376	3.730	12.859	5.149
3.553	4.026	13.824	5.580

APPENDIX 1D: NUMBER OF MINES BY SUB-AGGREGATE, REGION AND TECHNIQUE

	Continuous Mining			Longwall Mining			Surface Mining					National
Year	App-CM	Int-CM	Wst-CM	App-LW	Int-LW	Wst-LW	App-s	Int-s	Wst-s	Lig	PRB	Total
1972	1,382	58	44	32	0	2	1,180	146	20	14	5	2,883
1973	1,217	55	42	34	0	3	1,022	135	25	15	6	2,554
1974	1,252	53	35	38	0	5	1,245	166	24	13	7	2,838
1975	1,477	54	35	41	0	5	1,693	263	32	13	7	3,620
1976	1,731	56	46	46	1	6	2,041	281	36	14	8	4,266
1977	1,866	62	54	48	1	5	2,368	342	42	16	10	4,814
1978	2,137	65	54	52	2	5	2,438	382	43	18	13	5,209
1979	1,992	65	56	58	4	6	2,101	328	46	20	16	4,692
1980	2,024	62	58	54	5	8	1,916	287	47	21	18	4,500
1981	2,063	61	52	53	4	10	1,922	296	45	21	18	4,545
1982	2,072	60	51	58	4	12	1,930	303	42	23	23	4,578
1983	1,780	58	43	62	4	9	1,748	264	41	24	23	4,056
1984	1,858	56	41	64	5	11	1,770	252	40	24	25	4,146
1985	1,741	55	39	60	5	12	1,649	223	35	26	25	3,870
1986	1,746	59	30	55	5	13	1,597	203	34	25	26	3,793
1987	1,695	52	28	54	6	12	1,522	188	32	25	25	3,639
1988	1,615	47	33	53	6	9	1,429	181	30	24	25	3,452
1989	1,514	52	32	52	7	11	1,348	173	27	25	23	3,264
1990	1,509	48	28	55	7	12	1,298	161	26	24	25	3,193
1991	1,326	49	24	54	9	12	1,161	158	25	26	24	2,868
1992	1,204	46	23	54	8	13	1,068	139	25	26	24	2,630
1993	1,057	44	21	52	7	13	963	139	24	24	25	2,369
1994	992	42	18	46	8	15	900	121	21	22	25	2,210
1995	870	36	16	41	8	15	864	93	29	23	24	2,019

BY MINING TECHNIQUE

	Continuous	Longwall	Underground	Surface	Total
1972	1,484	34	1,518	1,365	2,883
1973	1,314	37	1,351	1,203	2,554
1974	1,340	43	1,383	1,455	2,838
1975	1,566	46	1,612	2,008	3,620
1976	1,833	53	1,886	2,380	4,266
1977	1,982	54	2,036	2,778	4,814
1978	2,256	59	2,315	2,894	5,209
1979	2,113	68	2,181	2,511	4,692
1980	2,144	67	2,211	2,289	4,500
1981	2,176	67	2,243	2,302	4,545
1982	2,183	74	2,257	2,321	4,578
1983	1,881	75	1,956	2,100	4,056
1984	1,955	80	2,035	2,111	4,146
1985	1,835	77	1,912	1,958	3,870
1986	1,835	73	1,908	1,885	3,793
1987	1,775	72	1,847	1,792	3,639
1988	1,695	68	1,763	1,689	3,452
1989	1,598	70	1,668	1,596	3,264
1990	1,585	74	1,659	1,534	3,193
1991	1,399	75	1,474	1,394	2,868
1992	1,273	75	1,348	1,282	2,630
1993	1,122	72	1,194	1,175	2,369
1994	1,052	69	1,121	1,089	2,210
1995	922	64	986	1,033	2,019

BY REGION

Appalachia	Interior	Western	Total
2,594	204	85	2,883
2,273	190	91	2,554
2,535	219	84	2,838
3,211	317	92	3,620
3,818	338	110	4,266
4,282	405	127	4,814
4,627	449	133	5,209
4,151	397	144	4,692
3,994	354	152	4,500
4,038	361	146	4,545
4,060	367	151	4,578
3,590	326	140	4,056
3,692	313	141	4,146
3,450	283	137	3,870
3,398	267	128	3,793
3,271	246	122	3,639
3,097	234	121	3,452
2,914	232	118	3,264
2,862	216	115	3,193
2,541	216	111	2,868
2,326	193	111	2,630
2,072	190	107	2,369
1,938	171	101	2,210
1,775	137	107	2,019

Appendix 2A: Appalachian Underground - Continuous

		Fixed-effects (within) regression	
sd(u_id) =	0.6132129	Number of obs =	38100
sd(e_id_t) =	0.4035632	n =	8339
sd(e_id_t + u_id) =	0.7340936	T-bar =	4.56889
corr(u_id, Xb) =	-0.1436	R-sq within =	0.3346
		between =	0.3471
		overall =	0.2656
		F(26, 29735) =	575.13
		Prob > F =	0

lpro	Coef.	Std. Err.	t	P>|t|	[95% Conf.Interval]	
yr73	0.0263523	0.0174932	1.506	0.132	-0.0079351	0.0606398
yr74	-0.0307400	0.0181375	-1.695	0.090	-0.0662902	0.0048102
yr75	-0.1545002	0.0180297	-8.569	0.000	-0.1898392	-0.1191613
yr76	-0.1341293	0.0178100	-7.531	0.000	-0.1690376	-0.0992209
yr77	-0.1477683	0.0178027	-8.300	0.000	-0.1826625	-0.1128742
yr78	-0.1850203	0.0177233	-10.439	0.000	-0.2197588	-0.1502818
yr79	-0.1531406	0.0178526	-8.578	0.000	-0.1881325	-0.1181487
yr80	-0.1052425	0.0179212	-5.873	0.000	-0.1403690	-0.0701161
yr81	-0.0616248	0.0180314	-3.418	0.001	-0.0969671	-0.0262825
yr82	-0.0459776	0.0180458	-2.548	0.011	-0.0813481	-0.0106070
yr83	0.0219613	0.0185893	1.181	0.237	-0.0144744	0.0583971
yr84	0.0250962	0.0185944	1.350	0.177	-0.0113497	0.0615421
yr85	0.0237831	0.0188523	1.262	0.207	-0.0131683	0.0607345
yr86	0.0567506	0.0189419	2.996	0.003	0.0196237	0.0938774
yr87	0.0901966	0.0191852	4.701	0.000	0.0525928	0.1278004
yr88	0.1420543	0.0194356	7.309	0.000	0.1039598	0.1801489
yr89	0.1295800	0.0197282	6.568	0.000	0.0909118	0.1682483
yr90	0.1902852	0.0199067	9.559	0.000	0.1512672	0.2293032
yr91	0.1935045	0.0205063	9.436	0.000	0.1533112	0.2336977
yr92	0.1568353	0.0210348	7.456	0.000	0.1156061	0.1980644
yr93	0.1724541	0.0218219	7.903	0.000	0.1296822	0.2152260
yr94	0.1795084	0.0224807	7.985	0.000	0.1354452	0.2235717
yr95	0.1889685	0.0237657	7.951	0.000	0.1423867	0.2355504
lton	1.7843080	0.0496362	35.948	0.000	1.6870190	1.8815980
slto	-0.1580390	0.0055077	-28.694	0.000	-0.1688344	-0.1472437
clto	0.0051910	0.0001997	25.991	0.000	0.0047995	0.0055825
_cons	-6.8544570	0.1487466	-46.081	0.000	-7.1460060	-6.5629070
id		F(8338,29735) =	7.323	0.000	(8339 categories)	

Appendix 2B: Appalachian Underground - Longwall

		Fixed-effects (within) regression	
sd(u_id) =	0.3138451	Number of obs =	1216
sd(e_id_t) =	0.1853778	n =	111
sd(e_id_t + u_id) =	0.3645047	T-bar =	10.955
corr(u_id, Xb) =	-0.1277	R-sq within =	0.7754
		between =	0.7008
		overall =	0.7428
		F(26, 1079) =	143.31
		Prob > F =	0

lpro	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
yr73	-0.0283679	0.0457477	-0.620	0.535	-0.1181324	0.0613966
yr74	-0.0402993	0.0449160	-0.897	0.370	-0.1284319	0.0478332
yr75	-0.1830404	0.0443310	-4.129	0.000	-0.2700252	-0.0960557
yr76	-0.2437599	0.0434962	-5.604	0.000	-0.3291066	-0.1584132
yr77	-0.2177740	0.0438262	-4.969	0.000	-0.3037682	-0.1317798
yr78	-0.1965967	0.0440425	-4.464	0.000	-0.2830155	-0.1101780
yr79	-0.1987345	0.0423025	-4.698	0.000	-0.2817390	-0.1157301
yr80	-0.0914245	0.0429681	-2.128	0.034	-0.1757349	-0.0071140
yr81	-0.0577512	0.0433862	-1.331	0.183	-0.1428821	0.0273796
yr82	-0.0365054	0.0428582	-0.852	0.395	-0.1206003	0.0475896
yr83	0.1343658	0.0427492	3.143	0.002	0.0504849	0.2182467
yr84	0.1383418	0.0424852	3.256	0.001	0.0549789	0.2217048
yr85	0.1804803	0.0431287	4.185	0.000	0.0958547	0.2651060
yr86	0.2366630	0.0440356	5.374	0.000	0.1502578	0.3230681
yr87	0.3434134	0.0444564	7.725	0.000	0.2561827	0.4306441
yr88	0.3849491	0.0446882	8.614	0.000	0.2972636	0.4726347
yr89	0.3884825	0.0450184	8.629	0.000	0.3001489	0.4768161
yr90	0.3770312	0.0452851	8.326	0.000	0.2881743	0.4658881
yr91	0.4541046	0.0454959	9.981	0.000	0.3648341	0.5433750
yr92	0.4922763	0.0457786	10.753	0.000	0.4024511	0.5821016
yr93	0.5077272	0.0454452	11.172	0.000	0.4185562	0.5968982
yr94	0.5006814	0.0483066	10.365	0.000	0.4058959	0.5954670
yr95	0.5813528	0.0502501	11.569	0.000	0.4827538	0.6799518
lton	0.2647975	1.2389280	0.214	0.831	-2.1661830	2.6957780
slto	0.0310022	0.0991657	0.313	0.755	-0.1635773	0.2255817
clto	-0.0011741	0.0026204	-0.448	0.654	-0.0063158	0.0039676
_cons	-6.2057090	5.1004660	-1.217	0.224	-16.2136600	3.8022470
id		F(110,1079) =	20.929	0.000	(111 categories)	

Appendix 2C: Interior Underground - continuous

Fixed-effects (within) regression

sd(u_id) =	0.6026587	Number of obs =	1295
sd(e_id_t) =	0.2601318	n =	173
sd(e_id_t + u_id) =	0.6564039	T-bar =	7.48555
corr(u_id, Xb) =	-0.4192	R-sq within =	0.6335
		between =	0.5918
		overall =	0.4394
		F(26, 1096) =	72.85
		Prob > F =	0.0000

lpro	Coef.	Std. Err.	t	P>|t|	[95% Conf.Interval]	
yr73	-0.0196848	0.0513018	-0.384	0.701	-0.1203457	0.0809760
yr74	-0.0564364	0.0525908	-1.073	0.283	-0.1596264	0.0467536
yr75	-0.1746172	0.0528772	-3.302	0.001	-0.2783692	-0.0708652
yr76	-0.2759244	0.0524991	-5.256	0.000	-0.3789345	-0.1729143
yr77	-0.3163727	0.0516265	-6.128	0.000	-0.4176707	-0.2150747
yr78	-0.2954249	0.0517575	-5.708	0.000	-0.3969798	-0.1938700
yr79	-0.3974270	0.0521030	-7.628	0.000	-0.4996599	-0.2951942
yr80	-0.3179301	0.0527637	-6.026	0.000	-0.4214595	-0.2144007
yr81	-0.2241661	0.0532998	-4.206	0.000	-0.3287474	-0.1195849
yr82	-0.2262387	0.0534595	-4.232	0.000	-0.3311332	-0.1213443
yr83	-0.1345711	0.0544993	-2.469	0.014	-0.2415059	-0.0276363
yr84	-0.1681926	0.0553073	-3.041	0.002	-0.2767127	-0.0596725
yr85	-0.1337302	0.0549293	-2.435	0.015	-0.2415086	-0.0259518
yr86	-0.0351306	0.0544886	-0.645	0.519	-0.1420443	0.0717830
yr87	-0.0359265	0.0562095	-0.639	0.523	-0.1462168	0.0743638
yr88	0.0223978	0.0573786	0.390	0.696	-0.0901864	0.1349821
yr89	0.0726960	0.0565725	1.285	0.199	-0.0383066	0.1836986
yr90	0.0669440	0.0576039	1.162	0.245	-0.0460825	0.1799705
yr91	0.0630596	0.0575383	1.096	0.273	-0.0498380	0.1759573
yr92	0.0981134	0.0590508	1.662	0.097	-0.0177520	0.2139788
yr93	0.1773398	0.0601451	2.949	0.003	0.0593273	0.2953523
yr94	0.1328189	0.0633863	2.095	0.036	0.0084467	0.2571911
yr95	0.1747884	0.0663950	2.633	0.009	0.0445128	0.3050640
lton	5.2229630	0.4633923	11.271	0.000	4.3137270	6.1322000
slto	-0.4107455	0.0411061	-9.992	0.000	-0.4914010	-0.3300901
clto	0.0113086	0.0012030	9.400	0.000	0.0089481	0.0136690
_cons	-22.6397900	1.7288470	-13.095	0.000	-26.0320200	-19.2475700
id		F(172,1096) =	15.994	0.000	(173 categories)	

Appendix 2D: InteriorUnderground - Longwall

		Fixed-effects (within) regression	
sd(u_id) =	0.1538153	Number of obs =	106
sd(e_id_t) =	0.0988326	n =	14
sd(e_id_t + u_id) =	0.1828306	T-bar =	7.57143
corr(u_id, Xb) =	-0.3117	R-sq within =	0.9304
		between =	0.8575
		overall =	0.8703
		F(22, 70) =	42.56
		Prob > F =	0.0000

lpro	Coef.	Std. Err.	t	P>|t|	[95% Conf.Interval]	
yr73	(dropped)					
yr74	(dropped)					
yr75	(dropped)					
yr76	(dropped)					
yr77	0.0132405	0.1398045	0.095	0.925	-0.2655907	0.2920717
yr78	-0.1080703	0.1300397	-0.831	0.409	-0.3674262	0.1512856
yr79	-0.2877483	0.1210739	-2.377	0.020	-0.5292226	-0.0462741
yr80	-0.2154295	0.1190537	-1.810	0.075	-0.4528746	0.0220156
yr81	-0.1060743	0.1216591	-0.872	0.386	-0.3487157	0.1365671
yr82	-0.0707935	0.1192271	-0.594	0.555	-0.3085844	0.1669974
yr83	0.0782082	0.1193826	0.655	0.515	-0.1598929	0.3163093
yr84	0.1439989	0.1117369	1.289	0.202	-0.0788534	0.3668511
yr85	0.1221235	0.1122870	1.088	0.281	-0.1018258	0.3460728
yr86	0.2285861	0.1116137	2.048	0.044	0.0059795	0.4511927
yr87	0.3208267	0.1100890	2.914	0.005	0.1012612	0.5403922
yr88	0.3257754	0.1098739	2.965	0.004	0.1066388	0.5449121
yr89	0.2285870	0.1096312	2.085	0.041	0.0099345	0.4472396
yr90	0.3267667	0.1090162	2.997	0.004	0.1093408	0.5441926
yr91	0.4851273	0.1081955	4.484	0.000	0.2693381	0.7009165
yr92	0.5293591	0.1089320	4.860	0.000	0.3121009	0.7466172
yr93	0.6230074	0.1128266	5.522	0.000	0.3979818	0.8480330
yr94	0.5610184	0.1094937	5.124	0.000	0.3426400	0.7793967
yr95	0.7206157	0.1124516	6.408	0.000	0.4963380	0.9448934
lton	-44.9797900	20.2161300	-2.225	0.029	-85.2995900	-4.6599890
slto	3.2452560	1.4680630	2.211	0.030	0.3172980	6.1732150
clto	-0.0771514	0.0354134	-2.179	0.033	-0.1477812	-0.0065216
_cons	205.6630000	92.4315100	2.225	0.029	21.3142100	390.0119000
id		F(13,70) =	10.603	0.000	(14 categories)	

Appendix 2E: Western Underground - Continuous

sd(u_id) =	0.6492001		Fixed-effects (within) regression	
			Number of obs =	902
sd(e_id_t) =	0.4257077		n =	128
sd(e_id_t + u_id) =	0.7763297		T-bar =	7.04688
corr(u_id, Xb) =	-0.0231		R-sq within =	0.5559
			between =	0.7018
			overall =	0.6091
			F(26, 748) =	36.01
			Prob > F =	0.0000

lpro	Coef.	Std. Err.	t	P>|t|	[95% Conf.Interval]	
yr73	-0.1989728	0.0971992	-2.047	0.041	-0.3897884	-0.0081571
yr74	-0.1339716	0.1023605	-1.309	0.191	-0.3349196	0.0669764
yr75	-0.3940834	0.1045670	-3.769	0.000	-0.5993631	-0.1888037
yr76	-0.6624306	0.0993096	-6.670	0.000	-0.8573893	-0.4674720
yr77	-0.5042840	0.0967049	-5.215	0.000	-0.6941292	-0.3144387
yr78	-0.5104269	0.0963281	-5.299	0.000	-0.6995324	-0.3213213
yr79	-0.7184482	0.0975671	-7.364	0.000	-0.9099860	-0.5269103
yr80	-0.6454650	0.0968167	-6.667	0.000	-0.8355299	-0.4554001
yr81	-0.6410914	0.0991059	-6.469	0.000	-0.8356502	-0.4465326
yr82	-0.5963467	0.0992203	-6.010	0.000	-0.7911301	-0.4015634
yr83	-0.4587980	0.1035274	-4.432	0.000	-0.6620369	-0.2555592
yr84	-0.2950149	0.1059451	-2.785	0.005	-0.5030000	-0.0870297
yr85	-0.2351987	0.1067238	-2.204	0.028	-0.4447126	-0.0256848
yr86	-0.2998365	0.1149161	-2.609	0.009	-0.5254330	-0.0742401
yr87	-0.1381503	0.1178455	-1.172	0.241	-0.3694976	0.0931970
yr88	-0.2879984	0.1143111	-2.519	0.012	-0.5124071	-0.0635898
yr89	-0.2078084	0.1154421	-1.800	0.072	-0.4344375	0.0188206
yr90	-0.2429684	0.1205672	-2.015	0.044	-0.4796586	-0.0062781
yr91	-0.0968996	0.1258643	-0.770	0.442	-0.3439889	0.1501896
yr92	-0.0587900	0.1276038	-0.461	0.645	-0.3092942	0.1917143
yr93	-0.2239503	0.1309275	-1.710	0.088	-0.4809794	0.0330787
yr94	0.0176201	0.1363313	0.129	0.897	-0.2500174	0.2852576
yr95	-0.1759400	0.1483912	-1.186	0.236	-0.4672527	0.1153727
lton	2.1927730	0.3194432	6.864	0.000	1.5656610	2.8198850
slto	-0.1650408	0.0343152	-4.810	0.000	-0.2324065	-0.0976752
clto	0.0046724	0.0011839	3.947	0.000	0.0023482	0.0069967
_cons	-9.6897020	0.9572968	-10.122	0.000	-11.5690100	-7.8103940
id		F(127,748) =	10.019	0.000	(128 categories)	

Appendix 2F: Western Underground - Longwall

		Fixed-effects (within) regression	
sd(u_id) =	0.4114457	Number of obs =	224
sd(e_id_t) =	0.3429353	n =	29
sd(e_id_t + u_id) =	0.5356232	T-bar =	7.72414
corr(u_id, Xb) =	0.4841	R-sq within =	0.5737
		between =	0.8529
		overall =	0.7972
		F(26, 169) =	8.75
		Prob > F =	0.0000

lpro	Coef.	Std. Err.	t	P>|t|	[95% Conf.Interval]	
yr73	-0.0580775	0.3200127	-0.181	0.856	-0.6898148	0.5736597
yr74	-0.1058964	0.2938121	-0.360	0.719	-0.6859109	0.4741182
yr75	-0.1104566	0.2935032	-0.376	0.707	-0.6898614	0.4689481
yr76	-0.1628935	0.2869612	-0.568	0.571	-0.7293838	0.4035968
yr77	0.0906238	0.2927880	0.310	0.757	-0.4873691	0.6686167
yr78	-0.2322330	0.2929880	-0.793	0.429	-0.8106208	0.3461548
yr79	-0.2113821	0.2962575	-0.714	0.477	-0.7962241	0.3734599
yr80	-0.1305081	0.2837557	-0.460	0.646	-0.6906703	0.4296541
yr81	0.0343598	0.2789699	0.123	0.902	-0.5163548	0.5850744
yr82	0.1472200	0.2720440	0.541	0.589	-0.3898221	0.6842621
yr83	0.5342566	0.2776342	1.924	0.056	-0.0138211	1.0823340
yr84	0.6259507	0.2734239	2.289	0.023	0.0861845	1.1657170
yr85	0.2988630	0.2733275	1.093	0.276	-0.2407130	0.8384390
yr86	0.4697724	0.2729875	1.721	0.087	-0.0691322	1.0086770
yr87	0.6190192	0.2738542	2.260	0.025	0.0784034	1.1596350
yr88	0.4860759	0.2862816	1.698	0.091	-0.0790727	1.0512250
yr89	0.4632198	0.2836002	1.633	0.104	-0.0966355	1.0230750
yr90	0.5551683	0.2829022	1.962	0.051	-0.0033090	1.1136460
yr91	0.5043891	0.2841700	1.775	0.078	-0.0565909	1.0653690
yr92	0.5265197	0.2825447	1.863	0.064	-0.0312519	1.0842910
yr93	0.6343205	0.2838120	2.235	0.027	0.0740472	1.1945940
yr94	0.6373745	0.2867462	2.223	0.028	0.0713088	1.2034400
yr95	0.6481570	0.2867565	2.260	0.025	0.0820708	1.2142430
lton	9.2127290	3.1013710	2.971	0.003	3.0903110	15.3351500
slto	-0.7308651	0.2552846	-2.863	0.005	-1.2348230	-0.2269076
clto	0.0198822	0.0069447	2.863	0.005	0.0061728	0.0335917
_cons	-39.7185400	12.4466100	-3.191	0.002	-64.2893900	-15.1476900
id		F(28,169) =	5.236	0.000	(29 categories)	

Appendix 2G: Appalachian Surface

		Fixed-effects (within) regression	
sd(u_id) =	0.7483126	Number of obs =	37161
sd(e_id_t) =	0.4845688	n =	9019
sd(e_id_t + u_id) =	0.8915036	T-bar =	4.1203
corr(u_id, Xb) =	-0.3004	R-sq within =	0.3024
		between =	0.1324
		overall =	0.1773
		F(26, 28116) =	468.74
		Prob > F =	0.0000

lpro	Coef.	Std. Err.	t	P>|t|	[95% Conf.Interval]	
yr73	-0.0059650	0.0237274	-0.251	0.802	-0.0524718	0.0405419
yr74	-0.0751355	0.0240054	-3.130	0.002	-0.1221873	-0.0280837
yr75	-0.3006296	0.0235378	-12.772	0.000	-0.3467649	-0.2544942
yr76	-0.2727556	0.0230642	-11.826	0.000	-0.3179625	-0.2275487
yr77	-0.2814363	0.0228786	-12.301	0.000	-0.3262795	-0.2365931
yr78	-0.3687277	0.0229863	-16.041	0.000	-0.4137819	-0.3236734
yr79	-0.4247661	0.0233506	-18.191	0.000	-0.4705344	-0.3789978
yr80	-0.3777336	0.0236558	-15.968	0.000	-0.4241001	-0.3313671
yr81	-0.3571794	0.0237023	-15.069	0.000	-0.4036371	-0.3107216
yr82	-0.4278305	0.0238577	-17.933	0.000	-0.4745928	-0.3810681
yr83	-0.3343260	0.0242105	-13.809	0.000	-0.3817798	-0.2868723
yr84	-0.3870477	0.0243249	-15.912	0.000	-0.4347258	-0.3393697
yr85	-0.3827615	0.0246404	-15.534	0.000	-0.4310579	-0.3344650
yr86	-0.3643138	0.0247562	-14.716	0.000	-0.4128372	-0.3157904
yr87	-0.3632825	0.0250844	-14.482	0.000	-0.4124492	-0.3141158
yr88	-0.3903301	0.0253752	-15.382	0.000	-0.4400667	-0.3405934
yr89	-0.3895438	0.0256883	-15.164	0.000	-0.4398942	-0.3391934
yr90	-0.4144666	0.0259700	-15.959	0.000	-0.4653690	-0.3635642
yr91	-0.3893181	0.0266077	-14.632	0.000	-0.4414704	-0.3371657
yr92	-0.3800885	0.0270199	-14.067	0.000	-0.4330487	-0.3271282
yr93	-0.3789908	0.0276944	-13.685	0.000	-0.4332732	-0.3247085
yr94	-0.4259672	0.0284219	-14.987	0.000	-0.4816755	-0.3702588
yr95	-0.4134832	0.0294069	-14.061	0.000	-0.4711222	-0.3558443
lton	1.6859570	0.0685671	24.588	0.000	1.5515620	1.8203520
slto	-0.1281229	0.0074373	-17.227	0.000	-0.1427003	-0.1135455
clto	0.0036987	0.0002639	14.013	0.000	0.0031813	0.0042160
_cons	-6.5849230	0.2084149	-31.595	0.000	-6.9934260	-6.1764200
id		F(9018,28116) =	5.490	0.000	(9019 categories)	

Appendix 2H: Interior Surface

sd(u_id) =	0.7574923	Fixed-effects (within) regression	
		Number of obs =	5219
sd(e_id_t) =	0.4040758	n =	1260
sd(e_id_t + u_id) =	0.8585288	T-bar =	4.14206
corr(u_id, Xb) =	-0.4753	R-sq within =	0.3912
		between =	0.1430
		overall =	0.1796
		F(26, 3933) =	97.20
		Prob > F =	0.0000

lpro	Coef.	Std. Err.	t	P>|t|	[95% Conf.Interval]	
yr73	-0.1197283	0.0524109	-2.284	0.022	-0.2224834	-0.0169731
yr74	-0.1493789	0.0525760	-2.841	0.005	-0.2524576	-0.0463002
yr75	-0.3104462	0.0508642	-6.103	0.000	-0.4101689	-0.2107235
yr76	-0.2456503	0.0503648	-4.877	0.000	-0.3443939	-0.1469068
yr77	-0.3110763	0.0494763	-6.287	0.000	-0.4080780	-0.2140747
yr78	-0.5285835	0.0492858	-10.725	0.000	-0.6252117	-0.4319553
yr79	-0.5385967	0.0499008	-10.793	0.000	-0.6364305	-0.4407629
yr80	-0.5062602	0.0508806	-9.950	0.000	-0.6060150	-0.4065054
yr81	-0.5441195	0.0508198	-10.707	0.000	-0.6437553	-0.4444838
yr82	-0.6067668	0.0508337	-11.936	0.000	-0.7064297	-0.5071039
yr83	-0.5304232	0.0518203	-10.236	0.000	-0.6320204	-0.4288260
yr84	-0.5571016	0.0522402	-10.664	0.000	-0.6595220	-0.4546812
yr85	-0.5895142	0.0532401	-11.073	0.000	-0.6938950	-0.4851334
yr86	-0.4792165	0.0540874	-8.860	0.000	-0.5852584	-0.3731745
yr87	-0.4628845	0.0547275	-8.458	0.000	-0.5701815	-0.3555875
yr88	-0.4263859	0.0555243	-7.679	0.000	-0.5352451	-0.3175267
yr89	-0.4023328	0.0560569	-7.177	0.000	-0.5122361	-0.2924295
yr90	-0.4697721	0.0569484	-8.249	0.000	-0.5814232	-0.3581210
yr91	-0.4326818	0.0574078	-7.537	0.000	-0.5452337	-0.3201298
yr92	-0.4156898	0.0593043	-7.009	0.000	-0.5319599	-0.2994196
yr93	-0.3768329	0.0606064	-6.218	0.000	-0.4956559	-0.2580100
yr94	-0.4128114	0.0629061	-6.562	0.000	-0.5361431	-0.2894797
yr95	-0.4141029	0.0667955	-6.200	0.000	-0.5450599	-0.2831459
lton	1.5019610	0.1894081	7.930	0.000	1.1306140	1.8733080
slto	-0.1141249	0.0186418	-6.122	0.000	-0.1506733	-0.0775765
clto	0.0034839	0.0006005	5.802	0.000	0.0023066	0.0046613
_cons	-6.0862110	0.6349970	-9.585	0.000	-7.3311650	-4.8412570
id	F(1259,3933) =		7.874	0.000	(1260 categories)	

Appendix 2I: Western Surface (Except Lignite & PRB)

sd(u_id) =	1.007285	Fixed-effects (within) regression	
		Number of obs =	789
sd(e_id_t) =	0.4094241	n =	87
sd(e_id_t + u_id) =	1.087314	T-bar =	9.06897
corr(u_id, Xb) =	-0.6977	R-sq within =	0.6739
		between =	0.5729
		overall =	0.6190
		F(26, 676) =	53.72
		Prob > F =	0.0000

lpro	Coef.	Std. Err.	t	P>|t|	[95% Conf.Interval]	
yr73	0.1142837	0.1266663	0.902	0.367	-0.1344230	0.3629904
yr74	-0.1010702	0.1275639	-0.792	0.428	-0.3515393	0.1493988
yr75	-0.1938583	0.1221641	-1.587	0.113	-0.4337251	0.0460084
yr76	-0.4001005	0.1201676	-3.330	0.001	-0.6360471	-0.1641538
yr77	-0.5666876	0.1186497	-4.776	0.000	-0.7996539	-0.3337214
yr78	-0.5973972	0.1183910	-5.046	0.000	-0.8298554	-0.3649389
yr79	-0.6224586	0.1182021	-5.266	0.000	-0.8545461	-0.3903711
yr80	-0.7529965	0.1181723	-6.372	0.000	-0.9850253	-0.5209676
yr81	-0.6591496	0.1175844	-5.606	0.000	-0.8900241	-0.4282750
yr82	-0.6793089	0.1186523	-5.725	0.000	-0.9122802	-0.4463377
yr83	-0.5845813	0.1187392	-4.923	0.000	-0.8177232	-0.3514393
yr84	-0.5842395	0.1198208	-4.876	0.000	-0.8195052	-0.3489737
yr85	-0.6440039	0.1224519	-5.259	0.000	-0.8844358	-0.4035720
yr86	-0.5753709	0.1231107	-4.674	0.000	-0.8170962	-0.3336456
yr87	-0.5935624	0.1248288	-4.755	0.000	-0.8386612	-0.3484637
yr88	-0.4035814	0.1248825	-3.232	0.001	-0.6487857	-0.1583771
yr89	-0.4601151	0.1269541	-3.624	0.000	-0.7093869	-0.2108433
yr90	-0.4863086	0.1312044	-3.706	0.000	-0.7439258	-0.2286915
yr91	-0.4697076	0.1312011	-3.580	0.000	-0.7273182	-0.2120969
yr92	-0.5442774	0.1319953	-4.123	0.000	-0.8034475	-0.2851073
yr93	-0.4656649	0.1322346	-3.522	0.000	-0.7253048	-0.2060250
yr94	-0.5090617	0.1355667	-3.755	0.000	-0.7752442	-0.2428793
yr95	-0.4667681	0.1335789	-3.494	0.001	-0.7290475	-0.2044887
lton	1.4577710	0.2470238	5.901	0.000	0.9727453	1.9427980
slto	-0.0572095	0.0244473	-2.340	0.020	-0.1052113	-0.0092077
clto	0.0008322	0.0007806	1.066	0.287	-0.0007005	0.0023650
_cons	-9.0202350	0.8201103	-10.999	0.000	-10.6305000	-7.4099660
id		F(86,676) =	12.589	0.000	(87 categories)	

Appendix 2J: Lignite

		Fixed-effects (within) regression	
sd(u_id) =	1.543535	Number of obs =	506
sd(e_id_t) =	0.2801424	n =	40
sd(e_id_t + u_id) =	1.568751	T-bar =	12.65
corr(u_id, Xb) =	-0.8138	R-sq within =	0.7667
		between =	0.4839
		overall =	0.5310
		F(26, 440) =	55.61
		Prob > F =	0.0000

lpro	Coef.	Std. Err.	t	P>|t|	[95% Conf.Interval]	
yr73	0.1277630	0.1047356	1.220	0.223	-0.0780812	0.3336072
yr74	0.1145870	0.1091984	1.049	0.295	-0.1000282	0.3292022
yr75	-0.0850982	0.1099604	-0.774	0.439	-0.3012111	0.1310147
yr76	-0.1490996	0.1102594	-1.352	0.177	-0.3658000	0.0676008
yr77	-0.2375030	0.1063843	-2.232	0.026	-0.4465875	-0.0284184
yr78	-0.2264371	0.1027606	-2.204	0.028	-0.4283996	-0.0244745
yr79	-0.3713283	0.1023138	-3.629	0.000	-0.5724128	-0.1702438
yr80	-0.3857333	0.1003860	-3.842	0.000	-0.5830290	-0.1884376
yr81	-0.4300583	0.1015973	-4.233	0.000	-0.6297346	-0.2303821
yr82	-0.3786516	0.0995763	-3.803	0.000	-0.5743559	-0.1829472
yr83	-0.4275932	0.0981668	-4.356	0.000	-0.6205274	-0.2346591
yr84	-0.4676844	0.0982707	-4.759	0.000	-0.6608226	-0.2745461
yr85	-0.3500249	0.0971248	-3.604	0.000	-0.5409111	-0.1591387
yr86	-0.3061226	0.0981539	-3.119	0.002	-0.4990314	-0.1132139
yr87	-0.2892370	0.0989408	-2.923	0.004	-0.4836922	-0.0947818
yr88	-0.2538868	0.0999286	-2.541	0.011	-0.4502835	-0.0574902
yr89	-0.2309153	0.0996461	-2.317	0.021	-0.4267567	-0.0350740
yr90	-0.1837796	0.0998253	-1.841	0.066	-0.3799733	0.0124141
yr91	-0.1438161	0.0986964	-1.457	0.146	-0.3377910	0.0501589
yr92	-0.1397027	0.0987446	-1.415	0.158	-0.3337723	0.0543669
yr93	-0.1150483	0.1003770	-1.146	0.252	-0.3123262	0.0822297
yr94	-0.1089243	0.1024214	-1.063	0.288	-0.3102203	0.0923717
yr95	-0.0781603	0.1011720	-0.773	0.440	-0.2770007	0.1206802
lton	0.9657626	0.3151631	3.064	0.002	0.3463505	1.5851750
slto	-0.0008312	0.0307170	-0.027	0.978	-0.0612015	0.0595392
clto	-0.0006587	0.0009410	-0.700	0.484	-0.0025081	0.0011907
_cons	-9.2346170	1.0242220	-9.016	0.000	-11.2475900	-7.2216420
id	F(39,440) =		37.268	0.000	(40 categories)	

Appendix 2K: Powder River Basin (PRB)

		Fixed-effects (within) regression	
sd(u_id) =	0.6756505	Number of obs =	450
sd(e_id_t) =	0.2856467	n =	30
sd(e_id_t + u_id) =	0.7335514	T-bar =	15
corr(u_id, Xb) =	-0.459	R-sq within =	0.8284
		between =	0.4278
		overall =	0.6070
		F(26, 394) =	73.16
		Prob > F =	0.0000

lpro	Coef.	Std. Err.	t	P>|t|	[95% Conf.Interval]	
yr73	-0.0494382	0.1855495	-0.266	0.790	-0.4142290	0.3153526
yr74	-0.0655399	0.1803749	-0.363	0.717	-0.4201576	0.2890777
yr75	-0.1807119	0.1802930	-1.002	0.317	-0.5351686	0.1737447
yr76	-0.4268190	0.1767759	-2.414	0.016	-0.7743610	-0.0792770
yr77	-0.5930694	0.1709507	-3.469	0.001	-0.9291589	-0.2569798
yr78	-0.6088940	0.1659377	-3.669	0.000	-0.9351280	-0.2826599
yr79	-0.5567778	0.1627320	-3.421	0.001	-0.8767095	-0.2368461
yr80	-0.7004616	0.1611979	-4.345	0.000	-1.0173770	-0.3835461
yr81	-0.6090365	0.1615268	-3.770	0.000	-0.9265986	-0.2914743
yr82	-0.5571156	0.1586958	-3.511	0.000	-0.8691120	-0.2451192
yr83	-0.6311535	0.1591243	-3.966	0.000	-0.9439924	-0.3183147
yr84	-0.5423789	0.1584853	-3.422	0.001	-0.8539616	-0.2307962
yr85	-0.4961688	0.1591171	-3.118	0.002	-0.8089934	-0.1833441
yr86	-0.4602015	0.1586336	-2.901	0.004	-0.7720757	-0.1483274
yr87	-0.3911272	0.1595588	-2.451	0.015	-0.7048204	-0.0774341
yr88	-0.3141845	0.1597397	-1.967	0.050	-0.6282332	-0.0001359
yr89	-0.3121812	0.1608904	-1.940	0.053	-0.6284923	0.0041298
yr90	-0.2451154	0.1604380	-1.528	0.127	-0.5605371	0.0703062
yr91	-0.2621353	0.1610557	-1.628	0.104	-0.5787713	0.0545007
yr92	-0.2705858	0.1609648	-1.681	0.094	-0.5870431	0.0458715
yr93	-0.1946998	0.1610913	-1.209	0.228	-0.5114059	0.1220063
yr94	-0.2359980	0.1620984	-1.456	0.146	-0.5546839	0.0826880
yr95	-0.2137448	0.1639410	-1.304	0.193	-0.5360534	0.1085638
lton	1.2735130	0.5523149	2.306	0.022	0.1876600	2.3593660
slto	0.0000852	0.0459078	0.002	0.999	-0.0901697	0.0903400
clto	-0.0012169	0.0012408	-0.981	0.327	-0.0036564	0.0012225
_cons	-11.8987700	2.1702580	-5.483	0.000	-16.1655000	-7.6320340
id		F(29,394) =	33.632	0.000	(30 categories)	

APPENDIX 3A: Scale Effect Indices												
Year	**App-LW**	**Int-LW**	**Wst-LW**	**App-CM**	**Int-CM**	**Wst-CM**	**App-s**	**Int-s**	**Wst-s**	**Lig**	**PRB**	**National**
1972	1.0000		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1973	0.9664		0.9151	1.0205	1.0552	1.0290	1.0568	1.0150	1.0315	1.1423	1.1028	1.0307
1974	0.8946		0.8810	0.9900	1.0558	1.0817	1.0459	0.9351	1.1430	1.2835	1.1864	1.0101
1975	0.8940		0.8919	0.9635	1.0693	1.1231	0.9919	0.8316	1.0459	1.4930	1.3644	0.9740
1976	0.9046	1.0000	0.9164	0.9297	1.0386	1.0587	0.9719	0.8101	1.0898	1.6421	1.4271	0.9581
1977	0.8748	0.9791	1.0100	0.8903	0.9839	1.0765	0.9670	0.7685	1.0865	1.6475	1.4911	0.9353
1978	0.8079	0.7725	0.8779	0.8500	0.9026	1.0878	0.9468	0.7091	1.0857	1.6841	1.4616	0.8984
1979	0.9552	0.8199	1.0781	0.9055	0.9468	1.1051	0.9726	0.7673	1.0949	1.7824	1.4972	0.9470
1980	0.9992	0.8144	1.1287	0.9173	0.9684	1.0931	0.9976	0.7953	1.1231	1.8237	1.5699	0.9716
1981	0.9628	0.7481	1.0843	0.9032	0.9258	1.1499	1.0033	0.7745	1.1094	1.8757	1.6496	0.9665
1982	1.0448	0.8012	1.0995	0.9072	0.9710	1.1860	0.9822	0.7830	1.1247	1.8367	1.5584	0.9673
1983	1.0594	0.8963	1.0609	0.9009	0.9480	1.1406	0.9771	0.8034	1.1163	1.9006	1.5797	0.9695
1984	1.0999	1.0369	1.1539	0.9283	0.9949	1.1328	1.0048	0.8485	1.1449	1.9850	1.6456	1.0061
1985	1.1412	1.0239	1.1783	0.9386	1.0048	1.1219	0.9946	0.8388	1.1734	2.0405	1.6704	1.0149
1986	1.2037	1.0827	1.1869	0.9399	1.0113	1.1525	1.0008	0.8549	1.1772	2.1506	1.6563	1.0273
1987	1.2835	1.0928	1.3009	0.9414	1.0576	1.1646	1.0223	0.8768	1.1704	2.1715	1.7145	1.0519
1988	1.3192	1.1545	1.6192	0.9556	1.0836	1.1616	1.0389	0.8515	1.2507	2.2926	1.7972	1.0817
1989	1.3526	1.0676	1.6760	0.9727	1.0390	1.1510	1.0594	0.8795	1.2938	2.2787	1.8734	1.1025
1990	1.3889	1.1160	1.7124	0.9870	1.0859	1.2046	1.0749	0.9082	1.3028	2.3331	1.8488	1.1194
1991	1.4071	1.0799	1.7197	0.9961	1.0583	1.2339	1.0779	0.8812	1.3048	2.2345	1.9062	1.1233
1992	1.4224	1.1662	1.7050	1.0098	1.0921	1.2050	1.0983	0.8944	1.3342	2.2651	1.9022	1.1381
1993	1.3170	1.0696	1.8321	1.0147	1.0249	1.2307	1.1160	0.8483	1.3678	2.3744	1.9312	1.1334
1994	1.5224	1.1674	1.9611	1.0314	1.1023	1.2421	1.1441	0.8944	1.4314	2.4453	2.0034	1.1902
1995	1.6008	1.2416	1.9602	1.0656	1.1222	1.2568	1.1420	0.8977	1.2730	2.3646	2.0968	1.2100

APPENDIX 3B: Fixed Effects Indices												
Year	**App-LW**	**Int-LW**	**Wst-LW**	**App-CM**	**Int-CM**	**Wst-CM**	**App-s**	**Int-s**	**WSX**	**Lig**	**PRB**	**National**
1972	1.0000		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1973	1.0078		0.9714	0.9810	0.9867	1.1695	0.9811	0.9430	1.0520	1.1657	0.9222	0.9831
1974	1.0067		0.7702	0.9982	0.9483	1.2078	0.9819	1.0768	0.8715	0.8621	0.8416	0.9890
1975	1.0266		0.7702	1.0299	0.9815	1.1944	1.0182	1.2441	1.1648	0.6558	0.8416	1.0470
1976	1.0338	1.0000	0.7700	1.0779	0.9693	1.1170	1.0534	1.2601	1.1899	0.7162	0.8727	1.0763
1977	1.0201	1.0000	0.7436	1.1181	1.0163	1.1682	1.0745	1.3425	1.0438	0.5885	0.8911	1.0922
1978	1.0242	0.9307	0.7436	1.2268	1.0186	1.1932	1.0913	1.4245	1.0987	0.6614	0.9150	1.1428
1979	1.0231	0.9913	0.7361	1.2014	1.0617	1.1558	1.1195	1.2711	1.0490	0.6865	0.9068	1.1278
1980	0.9776	1.0064	0.6636	1.2262	1.1028	1.2498	1.1439	1.3697	1.2060	0.6714	0.9186	1.1629
1981	0.9754	1.0080	0.7333	1.2742	1.0697	1.2839	1.1550	1.4348	0.9739	0.7098	0.9387	1.1687
1982	1.0023	1.0080	0.7535	1.2710	1.0272	1.3638	1.2021	1.5088	0.9221	0.9120	1.0219	1.2060
1983	1.0165	0.9913	0.7387	1.3021	1.1249	1.4110	1.2467	1.4903	0.9285	0.6808	1.0219	1.2142
1984	1.0327	1.0187	0.7599	1.3095	1.1677	1.3878	1.2910	1.4820	0.9409	0.6811	1.0215	1.2298
1985	1.0673	1.0187	0.8476	1.3103	1.1228	1.2181	1.3143	1.4755	0.8554	0.6564	1.0611	1.2316
1986	1.0801	1.0187	0.9644	1.3089	1.1685	1.2984	1.3103	1.5055	0.8753	0.5887	1.0827	1.2388
1987	1.0581	0.9744	0.9105	1.3117	1.0966	1.3796	1.3431	1.5593	0.7949	0.6490	1.1029	1.2438
1988	1.0469	0.9744	1.0193	1.2841	1.1709	1.4662	1.3495	1.4910	0.7940	0.6274	1.1029	1.2383
1989	1.0017	0.9724	1.0154	1.2753	1.2180	1.5629	1.3613	1.5048	0.7374	0.6051	1.0867	1.2252
1990	0.9982	0.9724	0.9909	1.2861	1.1696	1.6303	1.3862	1.4639	0.8707	0.5501	1.2447	1.2598
1991	0.9972	0.9747	1.0515	1.2819	1.1594	1.7180	1.4293	1.5234	0.7779	0.4985	1.1210	1.2334
1992	1.0218	0.9563	1.0608	1.2848	1.2723	1.6692	1.4317	1.5409	0.8189	0.4985	1.1210	1.2487
1993	1.0334	0.9197	1.0608	1.2789	1.2733	1.7107	1.4716	1.6824	0.8110	0.4594	1.2447	1.2813
1994	1.0223	0.8715	1.1799	1.2958	1.3589	1.6864	1.5085	1.6808	0.6943	0.4593	1.2447	1.2833
1995	0.9662	0.8894	1.2422	1.3304	1.2990	1.6510	1.5501	1.6525	0.9579	0.4578	1.1210	1.2783

APPENDIX 3C: Undifferentiated Time Effects Indices												
Year	**App-LW**	**Int-LW**	**Wst-LW**	**App-CM**	**Int-CM**	**Wst-CM**	**App-s**	**Int-s**	**Wst-s**	**Lig**	**PRB**	**National**
1972	1.0000		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1973	0.9720		0.9436	1.0267	0.9805	0.8196	0.9941	0.8872	1.1211	1.1363	0.9518	0.9878
1974	0.9605		0.8995	0.9697	0.9451	0.8746	0.9276	0.8612	0.9039	1.1214	0.9366	0.9338
1975	0.8327		0.8954	0.8568	0.8398	0.6743	0.7404	0.7331	0.8238	0.9184	0.8347	0.7979
1976	0.7837	1.0000	0.8497	0.8745	0.7589	0.5156	0.7613	0.7822	0.6703	0.8615	0.6526	0.7842
1977	0.8043	1.0133	1.0949	0.8626	0.7288	0.6039	0.7547	0.7327	0.5674	0.7886	0.5526	0.7567
1978	0.8215	0.8976	0.7928	0.8311	0.7442	0.6002	0.6916	0.5894	0.5502	0.7974	0.5440	0.7087
1979	0.8198	0.7500	0.8095	0.8580	0.6720	0.4875	0.6539	0.5836	0.5366	0.6898	0.5731	0.6927
1980	0.9126	0.8062	0.8776	0.9001	0.7277	0.5244	0.6854	0.6027	0.4710	0.6800	0.4964	0.7061
1981	0.9439	0.8994	1.0350	0.9402	0.7992	0.5267	0.6996	0.5804	0.5173	0.6505	0.5439	0.7333
1982	0.9642	0.9317	1.1586	0.9551	0.7975	0.5508	0.6519	0.5451	0.5070	0.6848	0.5729	0.7270
1983	1.1438	1.0813	1.7062	1.0222	0.8741	0.6320	0.7158	0.5884	0.5573	0.6521	0.5320	0.7786
1984	1.1484	1.1549	1.8700	1.0254	0.8452	0.7445	0.6791	0.5729	0.5575	0.6265	0.5814	0.7785
1985	1.1978	1.1299	1.3483	1.0241	0.8748	0.7904	0.6820	0.5546	0.5252	0.7047	0.6089	0.7852
1986	1.2670	1.2568	1.5996	1.0584	0.9655	0.7409	0.6947	0.6193	0.5625	0.7363	0.6312	0.8246
1987	1.4098	1.3783	1.8571	1.0944	0.9647	0.8710	0.6954	0.6295	0.5524	0.7488	0.6763	0.8558
1988	1.4695	1.3851	1.6259	1.1526	1.0227	0.7498	0.6768	0.6529	0.6679	0.7758	0.7304	0.8906
1989	1.4747	1.2568	1.5892	1.1384	1.0754	0.8124	0.6774	0.6688	0.6312	0.7938	0.7318	0.8902
1990	1.4579	1.3865	1.7422	1.2096	1.0692	0.7843	0.6607	0.6251	0.6149	0.8321	0.7826	0.9064
1991	1.5748	1.6244	1.6560	1.2135	1.0651	0.9076	0.6775	0.6488	0.6252	0.8660	0.7694	0.9255
1992	1.6360	1.6978	1.6930	1.1698	1.1031	0.9429	0.6838	0.6599	0.5803	0.8696	0.7629	0.9239
1993	1.6615	1.8645	1.8857	1.1882	1.1940	0.7994	0.6846	0.6860	0.6277	0.8913	0.8231	0.9587
1994	1.6498	1.7525	1.8915	1.1966	1.1420	1.0178	0.6531	0.6618	0.6011	0.8968	0.7898	0.9375
1995	1.7885	2.0557	1.9120	1.2080	1.1910	0.8387	0.6613	0.6609	0.6270	0.9248	0.8076	0.9647

APPENDIX 3D: Price Effects Indices												
Year	**App-LW**	**Int-LW**	**Wst-LW**	**App-CM**	**Int-CM**	**Wst-CM**	**App-s**	**Int-s**	**Wst-s**	**Lig**	**PRB**	**National**
1972	1.0000		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1973	0.9586		1.0059	0.9800	0.9889	1.0077	1.0023	0.9914	1.0047	1.0249	0.9339	0.9875
1974	0.5729		0.8423	0.7661	0.8216	0.7981	1.0302	0.8595	0.8701	1.0343	0.8373	0.8424
1975	0.5500		0.6561	0.7514	0.7332	0.5747	1.0324	0.7873	0.7104	0.9043	0.7876	0.7987
1976	0.5787	1.0000	0.6822	0.7699	0.7166	0.6050	1.0296	0.7736	0.7333	0.8578	0.8108	0.8050
1977	0.6013	0.9288	0.7547	0.7841	0.6942	0.6908	1.0275	0.7549	0.7959	0.8502	0.7454	0.8088
1978	0.6268	0.8476	0.7894	0.7998	0.6674	0.7329	1.0253	0.7323	0.8255	0.7506	0.7357	0.8080
1979	0.6181	0.8421	0.7622	0.7945	0.6655	0.6998	1.0260	0.7307	0.8023	0.7268	0.7126	0.8000
1980	0.6291	0.8033	0.7284	0.8012	0.6522	0.6594	1.0251	0.7194	0.7733	0.6787	0.7036	0.7935
1981	0.6083	0.7087	0.6644	0.7884	0.6179	0.5843	1.0269	0.6901	0.7177	0.6284	0.6705	0.7688
1982	0.6688	0.7905	0.6768	0.8250	0.6477	0.5987	1.0217	0.7156	0.7286	0.6383	0.6857	0.7922
1983	0.7379	0.8917	0.7463	0.8647	0.6821	0.6807	1.0164	0.7447	0.7887	0.6600	0.7127	0.8272
1984	0.8022	1.0010	0.7811	0.9000	0.7169	0.7227	1.0118	0.7738	0.8184	0.6711	0.7645	0.8605
1985	0.8276	1.0008	0.7456	0.9135	0.7168	0.6799	1.0102	0.7738	0.7881	0.6765	0.7935	0.8677
1986	0.8896	1.0653	0.7616	0.9456	0.7364	0.6991	1.0063	0.7900	0.8017	0.6900	0.8144	0.8907
1987	0.9287	1.1379	0.7894	0.9652	0.7576	0.7329	1.0040	0.8074	0.8254	0.6928	0.8642	0.9142
1988	0.9537	1.2152	0.8392	0.9776	0.7793	0.7942	1.0025	0.8252	0.8674	0.7380	0.9188	0.9409
1989	0.9684	1.2987	0.8418	0.9848	0.8019	0.7974	1.0017	0.8436	0.8696	0.7553	0.9464	0.9545
1990	0.9872	1.3459	0.9190	0.9939	0.8143	0.8950	1.0007	0.8536	0.9338	0.7530	0.9791	0.9734
1991	1.0095	1.3750	0.8684	1.0045	0.8218	0.8308	0.9995	0.8597	0.8919	0.7307	0.9939	0.9760
1992	1.0368	1.4085	0.9034	1.0174	0.8304	0.8750	0.9981	0.8666	0.9209	0.7351	0.9987	0.9880
1993	1.0221	1.5576	0.9135	1.0105	0.8671	0.8879	0.9988	0.8960	0.9292	0.7245	1.0428	0.9999
1994	1.0882	1.6811	0.9543	1.0412	0.8961	0.9404	0.9955	0.9189	0.9628	0.7546	1.0946	1.0351
1995	1.1193	1.8961	0.9857	1.0554	0.9437	0.9813	0.9940	0.9563	0.9884	0.7699	1.1491	1.0653

APPENDIX 3E: Residual Time Effects Indices

Year	App-LW	Int-LW	Wst-LW	App-CM	Int-CM	Wst-CM	App-s	Int-s	Wst-s	Lig	PRB	National
1972	1.0000		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1973	1.0140		0.9381	1.0477	0.9916	0.8133	0.9918	0.8948	1.1158	1.1087	1.0191	1.0003
1974	1.6767		1.0679	1.2658	1.1503	1.0958	0.9004	1.0020	1.0388	1.0842	1.1186	1.1085
1975	1.5140		1.3648	1.1404	1.1454	1.1733	0.7171	0.9312	1.1596	1.0157	1.0597	0.9989
1976	1.3541	1.0000	1.2455	1.1359	1.0590	0.8523	0.7394	1.0111	0.9140	1.0043	0.8048	0.9741
1977	1.3376	1.0910	1.4508	1.1002	1.0498	0.8743	0.7345	0.9706	0.7129	0.9275	0.7413	0.9356
1978	1.3107	1.0589	1.0042	1.0391	1.1151	0.8190	0.6746	0.8049	0.6666	1.0623	0.7393	0.8771
1979	1.3263	0.8906	1.0620	1.0800	1.0098	0.6966	0.6373	0.7986	0.6689	0.9491	0.8042	0.8658
1980	1.4507	1.0036	1.2049	1.1235	1.1158	0.7953	0.6687	0.8379	0.6090	1.0019	0.7055	0.8898
1981	1.5516	1.2690	1.5576	1.1925	1.2933	0.9014	0.6813	0.8409	0.7207	1.0351	0.8112	0.9539
1982	1.4416	1.1786	1.7118	1.1576	1.2314	0.9200	0.6381	0.7618	0.6958	1.0728	0.8354	0.9178
1983	1.5500	1.2127	2.2861	1.1821	1.2814	0.9285	0.7043	0.7900	0.7067	0.9880	0.7465	0.9412
1984	1.4314	1.1538	2.3941	1.1394	1.1789	1.0301	0.6711	0.7403	0.6813	0.9335	0.7604	0.9048
1985	1.4474	1.1290	1.8084	1.1211	1.2204	1.1626	0.6751	0.7168	0.6664	1.0416	0.7673	0.9049
1986	1.4242	1.1798	2.1005	1.1193	1.3111	1.0599	0.6903	0.7839	0.7016	1.0672	0.7750	0.9257
1987	1.5180	1.2113	2.3525	1.1338	1.2734	1.1884	0.6926	0.7796	0.6692	1.0809	0.7826	0.9360
1988	1.5409	1.1399	1.9376	1.1791	1.3123	0.9441	0.6751	0.7912	0.7700	1.0512	0.7949	0.9466
1989	1.5228	0.9677	1.8879	1.1559	1.3411	1.0187	0.6762	0.7928	0.7259	1.0510	0.7733	0.9326
1990	1.4769	1.0301	1.8957	1.2171	1.3131	0.8763	0.6602	0.7323	0.6585	1.1051	0.7993	0.9312
1991	1.5600	1.1813	1.9069	1.2080	1.2960	1.0925	0.6779	0.7546	0.7010	1.1852	0.7741	0.9483
1992	1.5780	1.2054	1.8741	1.1498	1.3284	1.0776	0.6851	0.7615	0.6301	1.1830	0.7640	0.9351
1993	1.6256	1.1970	2.0643	1.1759	1.3770	0.9003	0.6854	0.7657	0.6755	1.2302	0.7893	0.9588
1994	1.5161	1.0424	1.9820	1.1492	1.2745	1.0822	0.6561	0.7202	0.6243	1.1884	0.7215	0.9056
1995	1.5978	1.0842	1.9397	1.1446	1.2621	0.8547	0.6653	0.6911	0.6344	1.2012	0.7028	0.9055

APPENDIX 3F: INDICES OF AGGREGATE
NATIONAL COAL LABOR PRODUCTIVITY

Year	Tons	Btus	3 Region	11 Groups	Product of 4 Effects	Scale Eff	Fixed Eff	Price Eff	ResTimeEf	UndifTime
1972	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1973	1.0253	1.0197	1.0058	0.9916	1.0009	1.0307	0.9831	0.9875	1.0003	0.9878
1974	0.9838	0.9750	0.9548	0.9055	0.9329	1.0101	0.9890	0.8424	1.1085	0.9338
1975	0.8646	0.8525	0.8359	0.7812	0.8136	0.9740	1.0470	0.7987	0.9989	0.7979
1976	0.8684	0.8516	0.8230	0.7656	0.8086	0.9581	1.0763	0.8050	0.9741	0.7842
1977	0.8885	0.8649	0.8132	0.7301	0.7730	0.9353	1.0922	0.8088	0.9356	0.7567
1978	0.8500	0.8193	0.7558	0.6571	0.7276	0.8984	1.1428	0.8080	0.8771	0.7087
1979	0.8777	0.8432	0.7707	0.6852	0.7398	0.9470	1.1278	0.8000	0.8658	0.6927
1980	0.9591	0.9169	0.8181	0.7187	0.7978	0.9716	1.1629	0.7935	0.8898	0.7061
1981	1.0271	0.9767	0.8611	0.7477	0.8283	0.9665	1.1687	0.7688	0.9539	0.7333
1982	1.0676	1.0119	0.8926	0.7747	0.8481	0.9673	1.2060	0.7922	0.9178	0.7270
1983	1.2146	1.1391	0.9882	0.8326	0.9165	0.9695	1.2142	0.8272	0.9412	0.7786
1984	1.2986	1.2197	1.0689	0.8992	0.9633	1.0061	1.2298	0.8605	0.9048	0.7785
1985	1.3375	1.2464	1.0731	0.9070	0.9814	1.0149	1.2316	0.8677	0.9049	0.7852
1986	1.4542	1.3526	1.1622	0.9827	1.0493	1.0273	1.2388	0.8907	0.9257	0.8246
1987	1.6073	1.4954	1.2825	1.0795	1.1197	1.0519	1.2438	0.9142	0.9360	0.8558
1988	1.7609	1.6299	1.3838	1.1688	1.1930	1.0817	1.2383	0.9409	0.9466	0.8906
1989	1.8500	1.7126	1.4448	1.2202	1.2024	1.1025	1.2252	0.9545	0.9326	0.8902
1990	1.9308	1.7921	1.5158	1.2841	1.2783	1.1194	1.2598	0.9734	0.9312	0.9064
1991	2.0506	1.8924	1.5772	1.3253	1.2822	1.1233	1.2334	0.9760	0.9483	0.9255
1992	2.1566	1.9880	1.6395	1.3755	1.3131	1.1381	1.2487	0.9880	0.9351	0.9239
1993	2.3715	2.1614	1.7404	1.4604	1.3924	1.1334	1.2813	0.9999	0.9588	0.9587
1994	2.4944	2.2801	1.8447	1.5361	1.4318	1.1902	1.2833	1.0351	0.9056	0.9375
1995	2.7036	2.4589	1.9631	1.6342	1.4921	1.2100	1.2783	1.0653	0.9055	0.9647