TECHNICAL AND SOCIAL DETERMINANTS OF PRODUCTIVITY GROWTH IN BITUMINOUS COAL MINING, 1955-1980

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The 1970s productivity slowdown in coal mining was far more severe than in the economy as a whole: productivity fell absolutely in 7 years out of 10 in the 1970s, and did not recover its 1969 level until 1983 (see figure 1). Observers have suggested that the Federal Coal Mine Health and Safety Act (CMHSA) of 1969, while highly successful in reducing coal fatalities, unduly hampered coal-operator efforts to enhance productivity and represented excessive government intervention [Lewis-Beck and Alford, 1980; Denison, 1983; Freeman and Medoff, 1984]. Notwithstanding reduced fatality rates, some have declared that a sufficient productivity decline from the safety protocols would force more workers underground, and could even lead to an increased aggregate number of fatalities [Braithwaite, 1985].

This paper shows that the role attributed to the CMHSA has been overstated: a variety of other political, technical and social factors also contributed to the decline in production-worker coal productivity growth in the 1970s.[1] This assessment of social determinants draws on previous empirical work on the role of conflict-ridden labor relations in undermining productivity pioneered by David Gordon [1981].[2]

FIGURE 1
Bituminous Coal Production-Worker Productivity Growth, 1950-1983

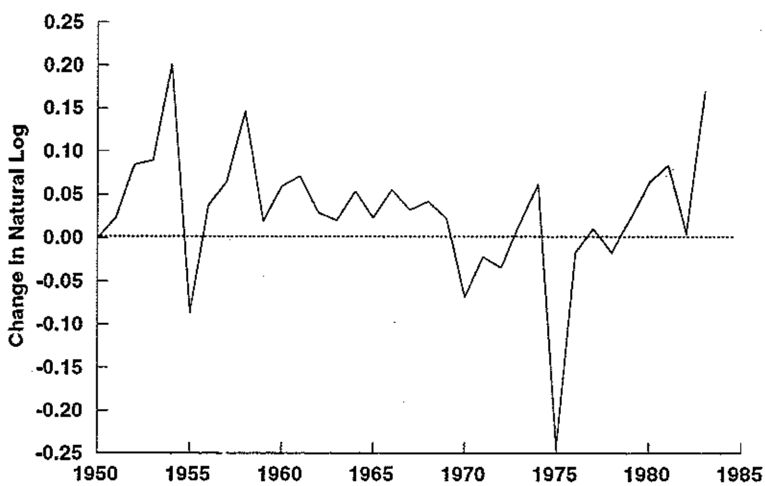

TABLE 1
Bituminous Coal Production-Worker Productivity Growth and Its Determinants over Two Sub-Periods: 1955-1969 vs 1970-1980

	1 Production-Worker Productivity Growth	2 Growth of Capital Labor Ratio	3 Expansion of Continuous Miner Technology	4 Change in Share of Employment, Surface Mines	5 Share of Mines which are New	Percent Change in the Price of Oil[a]
1955-1969	5.4%	6.1%	13.7%	.003 %	2.2%	-1.9%
1970-1980	-2.0%	5.2%	3.7%	.006 %	4.4%	6.6%
Percentage Change in Measure	-137.0%	-14.8%	-73.0%	100.0%	102.0%	--[b]

	Social Variables				
	6 Strike Frequency	7 Number of Strikes Over Working Conditions	8 Federal Spending on MHS[c] per Miner	9 Coal Accident Rate	10 Coal Fatality Rate
1955-1969	195	96	178	44.5	1.06
1970-1980	775	598	634	40.2	0.48
Percentage Change in Measure	297.4%	522.9%	256.2%	-9.7%	-54.7%

Notes:a. Lagged one year. b. Undefined. c.Mine health and safety.

Table 1 provides data on each of the technical and social factors to be explored here over two sub-periods: 1955-1969, and 1970-1980. Among the technical variables, the changes are particularly large for the spread of continuous-mining technology, the shift to surface mines, and oil-price changes which promoted regional production shifts. Yet most of these are swamped by the magnitude of the changes in various dimensions of strike activity and of federal spending on safety-and-health enforcement. In combination, these data provide *prima facie* evidence for the claim that a richer story lies behind the 1970s productivity slowdown in coal than "government interference." In particular, increasingly conflict-ridden labor relations translated into tension and mistrust at the coal face, and consequently slower productivity growth. Broader social and political factors — pollution regulation, the formation of OPEC and the subsequent oil-price jump — also contributed to structural shifts in coal and average productivity decay.

The paper begins with an overview of social and technical determinants of coal productivity behavior in the postwar period, and summarizes the hypotheses to be investigated. It then uses multiple-regression analysis to explore the empirical evidence. Due to multicollinearity and limited degrees of freedom, principal-components analysis of relevant underlying regressors is performed. A technical-determinants factor and a social-determinants factor are shown to enhance the explanatory power of the standard model of productive efficiency based on capital-intensity and technology significantly. A conclusion explores the implications of these findings for how productivity should be conceptualized, even at the level of undergraduate microeconomics.

TECHNICAL DETERMINANTS OF COAL PRODUCTIVITY GROWTH

The salient technical determinants of coal productivity growth are mining technology and the capital-intensity of production. Providing miners with more equipment improves their productivity; the shift to continuous-mining equipment from the conventional mining technology through the 1950s and 1960s was particularly productivity-enhancing. In addition, changes in the industry's environment spurred coal's rush for energy market-share and reduced the focus on productivity, or led to industry shifts which impaired aggregate coal productivity.

Technology and Capital

In the early 1950s, conventional mining dominated coal production. Machines cut 95 percent of all underground coal in 1952, and machines loaded 76 percent [United States Department of Labor, Bureau of Labor Statistics, 1979B, 4]. The innovative continuous miner combined these two operations and eliminated the need for blasting, reducing the size of a work team at the face by about 20 percent. Its share of underground production rose from less than 1 percent in 1950 to more than 31 percent by 1960.

The continuous miner increased coal-dust levels significantly, requiring more extensive ventilation. It also led to more refuse being mined with the coal. Mechanical crushing and cleaning of coal above ground also spread: the percent of coal mechanically cleaned rose from 30 percent in 1948 to 66 pecent in 1959. Expanded haulage systems were also required to carry the increased tonnage; the total length of conveyors leaped 45 percent between 1955 and 1959.

All of these changes contributed to rapid growth in the capital-labor ratio in the period. The spread of continuous miners to more and more mines proceeded rapidly at first, slowing in the late 1960s-1970s.

Surface Mining

The shifting industrial and regional composition of demand made surface mining of lower-quality coal profitable in the 1950s. Because coal was heavy to transport — more than one-third of the price of delivered coal was transportation cost — the railroads had required top-grade lump coal, but were now switching to diesel fuel. Increasing utility demand in the West made western sub-bituminous mines more attractive; new electric utilities were less concerned about weight and more about the delivered price per BTU.

The share of industry output from surface mines rose from 9 to 29 percent between 1940 and 1959. Because productivity for surface-mined coal was two to three greater than that for underground coal, average productivity rose. In surface mining, production workers operated huge pieces of earth-moving equipment, and work groups had less autonomy than in underground mines. Because western strip-mined seams were quite thick, averaging 35 feet (compared to under 10 feet in underground mines [Library of Congress, Congressional Research Service, 1978, 28]), stripminers also faced less rapid changes in natural conditions than miners underground, and had to make fewer independent judgements.

The increase in high-productivity surface mines alone accounted for one-third of the productivity increase from 1954 to 1959 [United States Department of Energy, Energy Information Administration, 1986, 165, 175]. The further increase in surface mining's share in the early 1960s was spurred by the 20 percent decline in the number of underground mines between 1958 and 1965 [United States Department of Labor, Mine Safety and Health Administation, 1984, 38]. The 1967 Clean Air Act and 1970 amendments gave further impetus to the growth of western strip-mined low-sulphur coal [Zimmerman, 1977]. The number of bituminous strip mines jumped 54 percent between 1967 and 1971, while the number of underground mines fell by 49 percent [Mine Safety and Health Administation, 1984, 38].

The entry of so many new surface mines first depressed average productivity because for two years on average, workers had to remove the ground above the coal seam (the overburden) and produce no coal [Bureau of Labor Statistics, 1979B, 10]. In addition the higher prices of clean-burning coal in the aftermath of the Clean Air Act warranted the mining of lower-productivity seams.

Through the early 1970s, state laws regulating the reclamation of strip-mined land were passed, amended, or became more strictly enforced. When surface mines were required to internalize these externalities, covering vacated seams and planting them, their productivity advantage was reduced if not eliminated [Walton and Kaufman, 1977, II-19], and average productivity fell. In light of these other legislative impacts on productivity in coal, the literature's focus on the CMHSA as reducing coal productivity seems myopic.

Oil Prices

In the 1950s, petroleum prices relative to other fuels were significantly lower than in earlier periods, and real oil prices continued to fall through the mid-1960s. This spurred residential replacement of household coal furnaces with oil, and of coal-burning engines with diesel. Retail deliveries of bituminous coal fell 58 percent between 1944 and 1954, and railroad consumption fell 87 percent. Aggregate coal consumption fell by one-fourth from 1950 to 1959, putting intense pressure on operators to cut costs.

The OPEC oil-price increases of 1973 and 1979, however, spurred demand for such energy substitutes as coal. The price of coal jumped accordingly, almost doubling from 1973 to 1974. Operators rushed to increase coal shipments without facing intense cost constraints, or productivity concerns, even mining low-productivity seams [Ellerman, Stoker and Berndt, 1998; Sider, 1983]. In this context, coal sustained windfall profits during the 1973-75 recession despite the substantial decline in average productivity.

New Technology

Aside from surface mining, few new production techniques were implemented in coal in the 1970s. Some firms experimented with longwall mining, a common underground method in Europe. The longwall machine combines roof support with continuous mining and loading; under continuous mining, roof-support work is done while the main mining equipment sits idle. The longwall method produces less coal dust, since only one coal face is mined in an area. However, the equipment is awkward to move between areas, requiring 30 work-shifts for the task [Congressional Research Service, 1978, 26]. It also requires the largest initial investment of any technique — the equipment is expensive, and mine shafts need to be organized differently from those for continuous miners. Even by the late seventies only 2 percent of all coal was mined by this method [Bureau of Labor Statistics, 1981B, 13].

Industry analysts have attributed the slowness of the switch to longwall (or the related shortwall technique) to exceptional U.S. geological conditions [Congressional Research Service, 1978]. However, it is noteworthy that the longwall method is safer than conventional or continuous mining, in large part because roof falls, which cause half of all fatalities, are reduced. West German, UK and French coal fatalities per employee-hour were one-third to two-thirds those in the United States from 1950-1977 [National Research Council, 1982, 43]. A lack of consensus among coal operators that they should internalize the cost of mine safety and health may have contributed to the unattractiveness of the longwall method.

Summary

This discussion suggests the following hypotheses with respect to technical determinants of bituminous-coal production-worker productivity growth (*CPROD*):

(1) $CPROD = f(CK/L, CCONTMIN, CHSHNSURF, SHNEWMIN, CPOIL82L) + g,$
$f_1, f_2 > 0, f_3, f_4, f_5 < 0,$

where *CK/L* = the rate of change of the capital-labor ratio, controlling for capacity utilization,[3]
CCONTMIN = the rate of change of continuous-mining equipment/worker, controlling for capacity utilization,
CHSHNSURF = change in the share of employment in surface mines,
SHNEWMIN = share of all mines which are new mines,
CPOIL82L = percent change in the relative price of oil, 1982 base year, lagged one year,
g = functional effects of social determinants, as yet unspecified.

The hypothesized sign of *CHSHNSURF* reflects the likely initial negative impact on productivity of surface workers removing the overburden before they can mine the underlying coal.

SOCIAL DETERMINANTS OF COAL PRODUCTIVITY GROWTH

Beyond these technical determinants, coal productivity's pattern reflects changing social relations in mining. In particular, developments in the institutions which shape work relations and workplace conflict (Gordon's [1978] social structure of accumulation) first diminished then accelerated productivity-impairing strike activity. Before specifying quantitative measures of social determinants of productivity, a history of coal labor relations and safety and health, including relevant federal legislation, will be outlined (for a more detailed survey, see Naples [1996]).

The Unraveling of the Truce in Coal Mining

I have elsewhere analyzed the emergence of the postwar accomodation between organized labor and management best understood as a truce [Naples, 1986; 1996].[4] This suspension of hostilities did not eliminate workplace conflict, but established institutional channels for the legitimate resolution of disagreements (negotiation of multi-year contracts, grievance procedures) and narrowed the range of issues deemed legitimate to discuss (wages, fringes, productivity bargain).

In coal mining, the truce came a few years later than in other industries whose unions had already accepted the appropriateness of consolidating their power rather than continuing to expand to unorganized sectors. In coal, new sources of cheap oil and natural gas [Bureau of Labor Statistics, 1961] and the consequent collapsing demand for coal made ongoing worksite conflict a threat to coal's market share and therefore to employment security. Coal's deteriorating economic conditions forced the Mineworkers' union to join in a truce.

In 1952 the United Mine Workers of America (UMWA) signed a historic agreement to permit technical change that reduced employment in exchange for higher wages and fringe benefits. Subsequently, union leaders sought to assure industrial peace; they disciplined wildcat-strike[5] leaders and created an autocratic governance structure. After the 1952 watershed contract, strikes fell precipitously. There was no new coal contract for 10 years, only amendments signed by the union leadership and

management. Fearful for their jobs, miners accepted continuous-mining technology, despite its deleterious impact on working conditions. The continuous miner increased noise and coal dust levels dramatically (the dust produced was too dense to see through), and by the early 1960s there was a significant increase in the number of respiratory complaints lodged with the UMWA Welfare and Retirement Fund [United States Congress, Office of Technology Assessment, 1979, 13]. Mechanization did appear to help reduce accidents (lost work-day accidents fell by one-third from 1947 to 1959), but not the fatality rate, which remained high [Mine Safety and Health Administration].

The Federal Mine Safety Act, also passed in 1952, raised hopes of improved safety in this dangerous industry with novel enforcement provisions . However, the UMWA's defensive posture, and concern with keeping coal operators in business to preserve jobs, meant the union provided little pressure to encourage the Act's enforcement. Federal expenditures on mine safety were relatively low per worker, and the Act had no significant effect on coal fatalities [Lewis-Beck and Alford, 1980].

Economic insecurity, falling accident rates and industrial peace all contributed to the rapid productivity growth of the 1950s. However, when the long macro expansion of the 1960s brought economic relief, coal miners began to demand that both operators and the union address the increased incidence of black lung and coal wages which had slipped behind those of other major unions. The UMWA continued its economic conservatism, cutting back on benefits, eligibility, and closing union hospitals when operators failed to contribute to the Welfare and Retirement Fund in the early 1960s. This only spurred rank-and-file activism. Strike activity accelerated, then tripled between 1966 and 1970; 95 percent of all strikes between 1960 and 1980 were wildcats, which were especially disruptive to production.

The nonresponsiveness of the union in this environment of intense activism gave birth in 1968 to the Black Lung Association, which lobbied for state and federal legislation to reduce coal dust levels, and to "Jock" Yablonski's candidacy for union president. Given these pressures, in the aftermath of a major mine disaster in 1968, union president Tony Boyle did press for passage of the CMHSA in November 1969. When Boyle claimed victory in the union election, Yablonski challenged the results and was murdered on New Year's Eve. Boyle was found guilty of his murder, and the Miners For Democracy candidate, Arnold Miller, ousted Boyle's regime in 1972. The new leadership organized a major rewriting of the union constitution to codify greater democracy and responsiveness of the UMWA to miners.

The successful rank-and-file campaign reinforced continued activism, including wildcats: strike frequency doubled between 1970 and 1973. Increased union attention to mine safety helped enforce the new legislation on site. The coal accident rate declined, and the fatality rate fell dramatically. The 1977 amendments to the CMHSA codified miners' involvement even in non-union mines, requiring that miners' representatives accompany inspectors and be permitted to counter operators' challenges to any findings [National Research Council, 1982, 57-8]. Still, in the late 1970s union mines were significantly less fatality-prone than non-union [Braithwaite, 1985, 9].

While 1974 contract negotiations were quite successful after a four-week strike, the 1977-78 negotiations were less so. The workers in the new mines opened after the Clean Air Act and during the energy crisis had been hard to organize because those miners were not from coal families with a union heritage and because surface mines were safer than those underground (overhead cave-ins and ventilation of gases and coal dust were less of a problem). The UMWA's share of coal output fell from 74 percent to 44 percent from 1968 to 1980 [Navarro, 1983, 228]. The longest walkout in UMWA history (110 days) struck a productivity bargain — a substantial wage increase in exchange for productivity incentives and employer prerogatives to fire wildcat leaders. Subsequent strike activity abated somewhat, but did not decline to the low levels of the postwar truce. Nevertheless productivity started to grow again.

SPECIFYING REGRESSORS

The discussion of a changing climate for labor relations in coal suggests several measures of social determinants of productivity growth.

Strikes

All Strikes. Strikes, especially wildcats strikes, which take place during the term of the contract, disrupt production. Bureau of Labor Statistics wildcat data, available only after 1960, indicate that the vast majority of coal strikes in this period were wildcat strikes. Strike frequency (*STRIKE*) is a decision variable, reflecting the choice to walk out. Strikes are the most vehement expression of workplace discontent, and of frustration with going through the usual channels to settle grievances. As such they are an indication of low morale and disincentives to work hard and perform well.

Strikes over Working Conditions. Strikes over working conditions (*SWC*) may be particularly harmful for productivity growth. They indicate worker militance with respect to issues that the postwar truce had defined as one of management's prerogatives, namely, the organization of work. While such strikes were about half of all strikes from 1958 to 1969, they comprised three-fourths of all strikes from 1970 to 1980. As the strongest expression of criticism of work organization, such strikes may well be a more direct measure than strikes in the aggregate of the hostility and noncooperation at the mine face that would most constrain productivity growth.

Safety and Health

The Mine Health and Safety Act. To control for the implementation of CMHSA, a dummy variable (*D1970*) is set to equal 1 after 1970 (the 1969 Act was passed in November). By being proactive in seeking safer and healthier coal mines, the Act should help improve miner morale and thereby productivity. However, because the Act instituted new inspection and enforcement procedures which took time to learn, it might initially hinder productivity growth. It has also been argued to hamper management flexibility, thereby depressing productivity.

The greater problem in interpreting this dummy variable is that 1970 was also a turning point for pollution legislation which spurred new low-sulphur mines, and for labor relations, in light of Yablonski's murder and the formation of Miners for Democracy. Both of these factors would tend to impair productivity. Mobilization of rank-and-file unionists to fight Boyle and his cozy relationship with operators would be associated with low morale and thereby both low work intensity and performance. A federal act on behalf of workers' safety and health might legitimate and reinforce union members' search for social justice more than it improved workplace morale. To disentangle the Act's impact, it was necessary to explore more direct measures of the Act's consequences.

Federal Expenditures on Mine Health and Safety. The CMHSA greatly expanded the federal budget dedicated to inspecting mines and enforcing compliance with safety-and-health mandates beyond the allocations under the 1952 Federal Mine Safety Act. Ongoing pressure from mineworkers and the UMWA contributed to a growing budget per miner in the 1970s (*FEDSP/CAP*). Since these data are more quantitative and less lumpy than the dummy variable, they may provide a better indication of the role of government intervention in reducing accidents and fatalities and thereby improving productivity, or impairing productivity by constraining operators and/or empowering the rank-and-file movement.

Accidents. The coal accident rate (*ACCID*) is a salient measure of unsafe working conditions, since it captures only injuries severe enough to cause miners to take at least one day off from work. Increased accidents would be expected to lead to increased concern about mine safety, which can impair morale, intensity, and performance. However, a faster pace of work can be associated with more accidents, which would give a positive coefficient. Whether morale or speed-up dominate the effect of this variable is an empirical question.

Fatalities. The coal fatality rate (*FATAL*) measures the worst-case dimension of unsafe conditions, lives lost to cave-ins, fires, gas explosions, etc. Like accidents, increased fatalities will intensify concerns about mine safety, which can lead to anxiety and wariness at the coal face and impair productivity. Similarly, pressures to mine quickly and improve productivity can lead to mistakes and missed signals of unsafe conditions, which contribute to fatalities. The coefficient of this variable will depend on which effect dominates.

Summary

This discussion suggests the following hypotheses with respect to social determinants of productivity growth for production workers at bituminous coal mines, expanding on the technical model described above:

$$CPROD = g(STRIKE, SWC, D1970, FEDSP/CAP, ACCID, FATAL) + f(CK/L, CCONTMIN, CHSHNSURF, SHNEWMIN, CPOIL82L), \quad (2)$$

$$g_1, g_2, g_3 < 0, g_4, g_5, g_6 \gtrless 0$$

where *D1970* = dummy variable, D1970=1 for 1970 forward,
STRIKE = number of strikes, bituminous coal,
SWC = number of strikes over working conditions, bituminous coal,
FEDSP/CAP = real federal spending on mine safety and health per miner,
ACCID = coal accident rate,
FATAL = coal fatality rate.

The last three variables are more direct measures of the impact of the CMHSA than the dummy variable, and therefore less ambiguous to interpret. The relationships are assumed to be linear.

ECONOMETRIC RESULTS

The empirical estimation of the productivity relations are provided in Table 2. As equation (1) shows, the fundamental technological determinants of coal productivity growth — capital intensity and the continuous-miner technology — together account for 63 percent of the variation in bituminous coal productivity growth for 1955-1980, ignoring other determinants.[6] Each of the other regressors, whether technical or social, is individually significant at the 1-6 percent level when added by itself to these core variables, and earns the hypothesized sign (see Table 2). However, when more than one other regressor is added, given likely collinearity, the relatively small sample size, and few degrees of freedom, typically neither regressor remains significant.

It was necessary to remedy the collinearity problem while differentiating the effects of technical from social factors. It was also desirable to confirm that a significant 1970 dummy may reflect other underlying lines of causation between social determinants and productivity growth besides passage of the CMHSA. Therefore two principal-components analyses were performed. The first constructed a factor which was the principal component of additional technical determinants of productivity growth in coal beyond capital intensity and technology, *FTECH*. Its factor loads are provided in Table 3. The second analysis did the same for social determinants, constructing the factor *FSOC*;[7] its factor loads are also given in Table 3. The similarly high factor loads for several of these measures, especially on the *FSOC* factor, reflect their mutual correlation and account for the collinearity encountered in multiple-regression analysis. In particular, the dummy variable representing both the CMHSA and the breakdown in labor relations in coal, *D1970*, was fairly highly correlated with the strike dimensions (0.76 – 0.77). Its factor score of 0.95 is higher than for any of the other measure of safety and health or strikes, and closer to the factor loads for the two strike measures. This confirms the interpretation of *D1970* as marking the breakdown in the postwar labor-management truce and productivity bargain as well as the advent of new federal regulations.

TABLE 2

Technical and Social Determinants of Coal-Mining Productivity Growth, 1955-1980

	Technical Variables					Social Variables									
Equation	1 Growth K/L	2 Growth Continuous Miners/L	3 Change Percent of Employment Surface	4 %Change Price of oil at t-1	5 Share New Mines	6 Number of Strikes (100's)	7 Strikes over Working Conditions (100's)	8 D1970	9 Federal Spending, Mine Safety and Health[a]	10 Accident Rate	11 Fatality Rate	R^2	$\bar{R}^2$	F	DW
1	0.57 (5.27)[b]	0.39 (3.73)[b]										0.66	0.63	22.22[b]	1.96
2	0.45 (4.28)[b]	0.30 (3.22)[b]	-2.85 (2.84)[b]									0.75	0.72	22.03[b]	1.42
3	0.45 (3.93)[b]	0.33 (3.36)[b]		-0.18 (2.30)[c]								0.72	0.69	19.33[b]	1.80
4	0.42 (3.55)[b]	0.33 (3.87)[b]			-0.43 (2.27)[c]							0.70	0.66	17.20[b]	1.99
5	0.5 (4.85)[b]	0.28 (2.62)[b]				-0.0051 (2.28)[c]						0.72	0.69	19.26[b]	2.35
6	0.49 (4.74)[b]	0.2 (2.24)[b]					-0.0071 (2.72)[b]					0.72	0.69	19.24[b]	2.36
7	0.56 (5.99)[b]	0.19 (1.72)[b]						-0.051 (2.94)[b]				0.76	0.72	23.64[b]	2.17
8	0.55 (5.27)[b]	0.27 (2.30)[c]							-0.057 (1.73)[c]			0.70	0.66	17.09[b]	2.16
9	0.53 (4.82)[b]	0.25 (2.69)[b]								0.0032 (1.71)[d]		0.67	0.63	15.18[b]	2.06
10	0.56 (5.43)[b]	0.22 (2.48)[c]									0.058 (2.38)[c]	0.71	0.67	17.67[b]	2.31

a. /1000. b. Significant at the 1 percent level. c. Significant at the 5 percent level. d. Significant at the 6 percent level.
t-statistics appear in parentheses. Constant term is estimated but not reported.

TABLE 3
Principle Component Analysis of Underlying Determinants of Coal Productivity

A. The Principle Component of Additional Technical Factors: The Opening of New Mines and the Energy Crisis

	Change in Percent of Employment at Surface Mines	Percent Change in Price of Oil in Previous Year	Percent of All Mines which are New
Correlations:	1.00		
	0.73	1.00	
	0.37	0.47	1.00
Factor Loads [69 Percent of variance explained]	0.87	0.90	0.70

B. The Principle Component of Social Factors: Labor Relations and Coal Mine Safety and Health

	All Strikes	Strikes Over Working Conditions	D1970	Federal Spending on Mine Safety and Health	Accident Rate	Fatality Rate
Correlations:	1.00					
	1.00	1.00				
	0.76	0.77	1.00			
	0.80	0.81	0.83	1.00		
	-0.61	-0.63	-0.48	-0.35	1.00	
	-0.69	-0.70	-0.87	-0.67	0.58	1.00
Factor Loads [76 Percent of variance explained]	0.91	0.94	0.95	0.86	-0.68	-0.86

The anticipated signs of these factors in the productivity regression derive from the underlying hypotheses about their components. For *FTECH*, as observed above, the oil-price increases accelerated the shift to surface mining and consequent opening of new mines. This shift to surface mining (requiring the removal of the overburden), the increased number of new mines and oil-price jumps should contribute to lower productivity. Hence the anticipated sign of *FTECH* is unambiguously negative.

For *FSOC*, the positive loads for the 3 strike indices and negative loads for the unsafe indicators are consistent in implying a negative impact of *FSOC* on productivity growth. The hypothesized signs of federal spending on safety and health and the CMHSA were ambiguous: (1) increased federal attention to coal-mine safety and health could initially empower miners vis-à-vis operators, who opposed the legislation, and therefore spur workplace activism and impair productivity; or (2) spending and legislation that successfully reduced fatalities and accidents could thereby reduce safety-and-health activism, raise miner morale and therefore productivity. The positive factor loads for both federal spending and *D1970* on *FSOC*, despite the negative factor loads for the accident and fatality rates, support the first argument — in the case of coal, federal intervention to improve safety and health stimulated rather than dissipating activism and consequently productivity was impaired. Therefore, *FSOC* is expected to earn a negative sign.

The econometric results for these factors and the core technical variables are provided in Table 4. When either factor is added to the core technical variables, there is some evidence of serial correlation; the Durbin method was used to correct for the problem. In both equations (11') and (12'), the technical or social factor is significant and negative. When both factors are included in equation (13), both have a statistically significant negative impact on productivity growth. Although the addition of neither factor significantly improves the explanatory power of the equation, there is no longer evidence of serial correlation. This supports the view that both equations (11') and 12') are underspecified, and equation (13) the preferred model.

To interpret these results, table 5 provides information on the contribution of all regressors, including the various underlying components of the two factors ranked by their factor loads, to the productivity slowdown of 1970-1980. Row 1 gives the actual change in productivity growth, a decline of 0.074 or 7.4 percentage points in the average rate of growth. For the remaining four rows, the last column shows how changes in these regressors caused productivity growth to decline, based on the results of equation (13). The slowing spread of new technology as continuous mining became the norm accounts for about one-fourth of the slowdown. The start-up of new mines spurred by changing pollution regulation and the energy crisis, and the oil-price change together account for another one-fifth of the slowdown. But a substantial 44 percent of the decline in growth is explained by the changing climate of labor relations and safety-and-health regulation and experience combined in the measure *FSOC*.

The figures in parentheses in column 2, row 4 provide the percent change in the variables which comprise *FSOC*. Of these, strikes over working conditions showed the greatest proportionate change over the two sub-periods. When unionized workers took disruptive steps to express emphatic concern about the mining process and its management, productivity growth was impaired.

Analysts who have focused on the CMHSA as the source of coal's productivity slowdown have told an incomplete story. This econometric research has illustrated the difficulty of separating safety and health from labor-relations issues in this period for coal. Any future effort to disentangle the two will have to model the influence of various dimensions of strike activity explicitly for the CMHSA results to be reliable. The quality of union-management relations, and in particular miners' willingness to strike, during the term of the contract, and/or over working conditions, clearly matter for coal productivity. Further steps to measure those aspects of increasing federal regulation which had an impact on productivity (federal spending, the number of inspectors or inspections, etc.) might be fruitful in confirming that the results reflect policy implementation rather than underlying conflict-ridden labor relations. In light of the collinearity and sample limitations in this aggregate time-series study, mine-

Table 4
The Components of Technical and Social Determinants of Coal-Mining Productivity Growth, 1955-1980

Eq.	Growth K/L	Growth Continuous Miners/L	FTECH	FSOC	Lagged Productivity Growth	$\bar{R}^2$	R^2	F	DW
11	0.33	0.26	-0.03			0.77	0.73	24.09	1.47[c]
	(3.01)	(3.45)	(3.57)						
11'	0.36	0.11	-0.031		0.41	0.80	0.77	28.24[a]	1.87
	(3.69)[a]	(1.27)	(4.50)[a]		(2.23)[b]				
12	0.51	0.17		-0.026		0.74	0.70	20.85	2.38[c]
	(5.22)	(1.88)		(3.03)					
12'	0.49	0.16		-0.026	-0.23	0.79	0.75	25.58[a]	1.97
	(4.95)[a]	(1.68)		(3.59)[a]	(1.20)				
13	0.35	0.18	-0.023	-0.018		0.81	0.78	22.80[a]	1.80
	(3.46)[a]	(2.24)[b]	(2.86)[a]	(2.28)[b]					

t-statistics are in parentheses.
The constant term is estimated but not reported.
a. significant at 1 percent level.
b. significant at 5 percent level.
c. lies between lower and upper bound of Durbin-Watson statistics at 5 percent level, insignificant at 1 percent level.

level research might prove a more powerful avenue for such research [Connerton, Freeman and Medoff, 1979; Ellerman, Stoker and Berndt, 1998].

CONCLUSION: CONCEPTUALIZING PRODUCTIVITY

The empirical findings presented here underline the social and distributive character of labor productivity, reaffirming a wide-ranging body of empirical research (see footnote 2, Katz, Kochan, and Keefe [1987] and Levine and Tyson [1990]). Microeconomic theory as currently taught to undergraduates ignores the multiple social aspects of production, taking a mechanical approach where the capital-labor ratio and human capital combined determine labor productivity. Recent innovations in productivity theory from a variety of perspectives have recognized that eliciting effort and performance are crucial management functions since firms cannot effectively secure labor-services on the labor market.[8] A microeconomic approach based on Strategic Competition[9] can be outlined which may serve as a common framework across different intellectual traditions.

In this Strategic-Competition approach, firms have some market power in setting wages. They do not have perfect information about what will enhance productivity in a world of uncertainty, but learn from experience. Firms hire people based on their potential. Workers' choices are constrained by local job opportunities, and most trade-off work against poverty rather than leisure. Workers sell not services *per se*, but hours of employment. Actual miner effort and the quality of miner performance are

TABLE 5
The Contributions of Explanatory Variables to the Drop in Coal Productivity Growth after 1970

Variable Name	1 Estimated Coefficient, Eq. 13	2 Average Change in Variable 1955-69 to 1970-80	3 Predicted Change in Productivity Growth	4 % of Actual Change in Productivity Growth
1 Productivity Growth		-0.07370		
2 Growth K/L	0.350	-0.00932	-0.00326	4.4
3 Growth Continuous Miners/L	0.180	-0.09981	-0.01797	24.4
4 FTECH - Additional Tech. Factors [a]	-0.023	0.67010	-0.01541	20.9
Lagged % Change in Oil Prices		b		
Change in share of Employment, Surface Mines		(100%)		
Share of Mines which are New		(102%)		
5 FSOC - Social Factors [a]	-0.018	1.80596	-0.03251	44.1
D1970 (CMSHA; Yablonski murder)		c		
Strikes over Working Conditions		(523%)		
All Strikes		(297%)		
Federal Spending, Mine Safety and Health		(256%)		
Fatality Rate		(-55%)		
Accident Rate		(-10%)		
Total Estimated Change in Productivity Growth			-0.06915	93.8

a. Rank ordered by factor loads, high to low
b. Average lagged change in prices was -1.9%, 1955-1969, and 6.6%, 1970-1980
c. D1970 changes from 0, 1955-1969, to 1, 1970-1980.

variables determined inside the coal mine, not by contract. Economic agents inside the company (managers, miners) actively pursue their own self-interest rather than passively implementing an employment contract. Productivity reflects the effectiveness of the work group at the coal face rather than being characteristic of an individual. Conflict-ridden labor relations will not only disrupt production but impair effort and performance. Unsafe, unhealthy work conditions can contribute to workplace conflict. Labor productivity is the product of three factors: labor efficiency, labor performance, and labor intensity;[10] the traditional model equates productivity with the first, labor efficiency.

Nationwide, ongoing workplace experimentation with quality circles and other forms of worker participation indicate that firms have become attuned to the social aspects of productivity [Appelbaum and Batt, 1994; Levine and Tyson, 1990].[11] It is time that microeconomics education incorporate a perspective such as Strategic Competition that can make sense of these trends in transforming work relations to improve productivity, an approach in which productivity depends not only on the capital-labor ratio and workers' potential but on the quality of relations at work.

NOTES

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1. In a dynamic industry, operators will only remain profitable if they constantly seek ways to improve productivity; hence the appropriate dependent variable is productivity growth, rather than the productivity level. Production workers are the focus of operator efforts to increase productivity, and the most likely to unionize. Hence the paper focuses on production-worker productivity growth.
2. See also Boddy and Crotty, 1975; Bowles, Gordon, Weisskopf, 1990; Buchele and Christiansen, 1992; Christiansen, 1982; Connerton, Freeman and Medoff, 1979; Fairris, 1997; Flaherty, 1987; Green and Weisskopf, 1990; Grunberg, 1983; Naples, 1981, 1986, 1988; Norsworthy and Zabala, 1985; Weisskopf, 1987; Weisskopf, Bowles and Gordon, 1983.
3. Because the capital-labor ratio combines stocks and flows, it is necessary to convert the numerator to a flow of capital services (capacity utilization times the capital stock); otherwise layoffs will register as an increase in the capital-labor ratio. Continuous-mining equipment per worker will be similarly adjusted.
4. Gordon [1978], Gordon, Edwards and Reich [1983] and Bowles, Gordon, Weisskopf [1990] view the labor-relations *accord* as a dimension of the postwar social structure of accumulation.
5. Wildcat strikes take place during the term of the contract, and are particularly disruptive for production.
6. Data sources for Table 2, by column: (1) U.S. Department of Commerce, BEA for capital stock; Bureau of Mines for employment; Bureau of Labor Statistics for average weekly hours; Wharton School for coal capacity utilization, used to correct for capital utilization; (2) continuous miner machines underground from Bureau of Mines, courtesy of Larry Marsh; (3, 4) Bureau of Labor Statistics; (6) U.S. Government Budget; (7, 8) Mine Enforcement and Safety Administration; (9) U.S. Department of Energy, Energy Information Agency, prices for crude oil; (10) Bureau of Mines data on number of anthracite and bituminous (underground and surface) mines in use. Coal productivity is the Bureau of Mines series (output per miner) divided by Bureau of Labor Statistics data on average weekly hours in mining.
7. At first, FSOC was differentiated into a safety factor and a labor-relations factor. While each was individually significant in an equation with the core technology variables, when both of these were included in the same equation, neither was individually significant. This suggested that the connection between deteriorating health and safety and increasingly conflict-ridden labor relations were too closely intertwined for their effects on productivity to be distinguished by regression analysis, hence the single social-relations factor.
8. Radical economists have focused on conflict-ridden labor relations as leading to lower effort and therefore productivity (for examples, see footnote 2). Agency theorists have interpreted the shortfall of work effort below potential as reflecting moral hazard. They have emphasized that costly monitoring, and setting wages above market to ensure an excess supply of labor to the plant, will help raise effort ratios. Human-resource and industrial-relations specialists have analyzed the promotion, hiring, compensation structures and managerial initiatives that best elicit high-level performance, including total quality management, quality circles and team work [Kaufman, 1994].
9. For more on Strategic Competition, see Naples and Aslanbeigui [1998], Dean [1951]. David Gordon considered competition among capitalist firms as fundamental a conflict as labor-management relations. His work with Richard Edward and Michael Reich [1982] on the changing character of that conflict in this century took for granted a world of strategic competition dominated by large firms.
10. Efficiency is output per labor-service, q/LS, performance is labor-service per labor-effort, LS/LE, and intensity is labor-effort per labor-hour, LE/LH. Therefore productivity (AP_L) is $AP_L = q/LH = q/LS \times LS/LE \times LE/LH$ [Christiansen and Naples, 1986].

11. Taking their lead from the business community, the premier accrediting agency for schools of business, the American Assembly of Collegiate Schools of Business (now AACSB: the International Association for Management Education) decided in 1991 to begin to require candidate schools to demonstrate active workplace democracy and accountability to stakeholders as vehicles to promote continuous improvement in student performance. Half of all economics departments in the United States are situated in business schools [Aslanbeigui and Naples, 1996].

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